Fall 2015

An Approach for the Development of Complex Systems Archetypes

Walter Lee Akers
Old Dominion University

AN APPROACH FOR THE DEVELOPMENT OF COMPLEX SYSTEMS ARCHETYPES

By

Walt Akers
B.S.C.S., May 2007, Park University
M.P.M., December 2010, Western Carolina University

A Dissertation Presented to the Academic Faculty
in Partial Fulfillment Of the Requirements for the Degree of

DOCTOR OF PHILOSOPHY
SYSTEMS ENGINEERING
OLD DOMINION UNIVERSITY

December 2015

Approved by:

Charles B. Keating (Director)

Adrian Gheorghe (Member)

Andres Sousa-Poza (Member)

Andrew Hutton (Member)

Abstract

AN APPROACH FOR THE DEVELOPMENT OF COMPLEX SYSTEMS ARCHETYPES

Walt Akers
Old Dominion University, 2015
Director: Dr. Charles B. Keating

The purpose of this research is to explore the principles and concepts of systems theory in pursuit of a collection of complex systems archetypes that can be used for system exploration and diagnostics. The study begins with an examination of the archetypes and classification systems that already exist in the domain of systems theory. This review includes a critique of their purpose, structure, and general applicability. The research then develops and employs a new approach to grounded theory, using a visual coding model to explore the origins, relationships, and meanings of the principles of systems theory. The goal of the visual grounded theory approach is to identity underlying, recurrent imagery in the systems literature that will form the basis for the archetypes.

Using coding models derived from the literature, the study then examines the interrelationships between system principles. These relationships are used to clearly define the environment where the archetypes are found in terms of energy, entropy and time. A collection of complex system archetypes is then derived which are firmly rooted in the literature, as well as being demonstrably manifested in the real world. The definitions of the emerging complex systems archetypes are consistent with the environmental definition and are governed by the system's behavior related to energy collection, entropy displacement, and the pursuit of viability.

Once the archetypes have been identified, this study examines the similarities and differences that distinguish them. The individual system principles that either define or differentiate each of the archetypes are described, and real-world manifestations of the archetypes are discussed. The collection of archetypes is then examined as a continuum, where they are related to one another in terms of energy use, entropy accumulation, self-modification and external-modification.

To illustrate the applicability of these archetypes, a case study is undertaken which examines a medium-sized organization with multiple departments in an industrial setting. The individual departments are discussed in detail, and their archetypical forms are identified and described. Finally, the study examines future applications for the archetypes and other research that might enhance their utility for complex systems governance.

For my wife, Evelyn, and my children, Madelaine and Daniel.

Acknowledgments

First, I wish to extend my thanks to my committee members for the time, effort, and diligence that they have shown in helping me to prepare this manuscript, and in ensuring that this research product reflected credit on the university and on our discipline. Many, many thanks are owed to my advisor, Professor Chuck Keating, who has spent long hours reviewing and guiding my work as it transformed from a loose confederation of ideas to a cohesive, final product. I also want to express my appreciation to the Complex Systems Governance study group at Old Dominion University where a multitude of new ideas have emerged, developed and grown to contribute to this research. Further, I wish to express my gratitude to my employer, Thomas Jefferson National Accelerator Facility, which has supported my pursuit of this degree and has provided me with the opportunity to apply what I have learned in a tangible way.

Beyond the academic front, there are a number of individuals whose support and care have made this effort possible. To my grandparents, Walter and Mattie Akers, who took me in as a child; to Father James Healy who taught me the importance of caring for my fellow man; and to Superintendent Dan Smith who provided me with never ending opportunities to serve my community – I am truly grateful.

Finally, none of this could have been accomplished without the seemingly endless patience of my wife, Evelyn, who has been instrumental in helping me to make the time for this endeavor.

Glossary

Adaptation	Modification of an organism or its parts that makes it more fit for existence under the conditions of its environment. (Merriam-Webster, 2015)
Algedonodes	A system or component that receives information and then rapidly passes it forward or wholly suppresses it, depending on its importance. (Beer, 1981)
Allomorphosis	The activities and effects that a system achieves by making modifications to things outside of itself. (Akers, 2015)
Allopoiesis	The process of producing material entities other than those required for maintaining the system itself. (Krippendorff, 1981)
Allostasis	The process of maintaining system stability by actively adapt to predicted changes in their environment. (Wingfield, 2005)
Attractors	A set of points or states within some volume of state-space to which a system's trajectory will converge over time. (Kauffman S. , 1993)
Autonomy	The ability of an entity to independently perform the purpose, goal or function for which it was created. (Hester & Adams, 2014)
Automorphosis	The activities and effects that a system achieves by making modifications to itself or its own configuration. (Akers, 2015)
Autopoiesis	A system that is capable of producing or regenerating the functional elements within its system boundaries. (Luhmann, 1990)
Bandwidth	The channel capacity that limits the volume of information that can be sent or received over a communications channel. (Shannon, 1948)

Basins of Attraction	An arrangement of attractors within a volume of space, creating regional basins to which systems will be attracted over time. (Kauffman S. , 1993)
Basins of Stability	Regions of stability within a volume of space that are physically bounded by regions of instability. (Clemson, 1984)
Black Box	Entities whose internal functions and mechanisms are encapsulated and cannot be observed during operation. (Ashby, 1956)
Boundary Location	The process by which the organizational or systemic boundaries are drawn to distinguish between different socio-technical systems. (Cherns, 1976)
Canalization	The process by which systems "flow" along a path or basin of attraction. (Waddington, 1942)
Channel Coding	The process of correcting errors or reducing noise in a communication channel. (Anderson & Mohan, 1991)
Circular Causality	The presence of causal loops that perpetually create emergence within a system through there simultaneous top-down and bottom-up interactions. (Witherington, 2011)
Communications	The process by which information is exchanged between individuals through a common system of symbols, signs, or behavior. (Merriam-Webster, 2015)
Complementarity	Viewing a system from different perspectives will reveal information that is neither entirely independent nor entirely compatible. (Bohr, 1928)
Conant-Ashby Theorem	Every good regulator of a system must be a model of a system. (Conant & Ashby, 1970)
Control	The mechanisms that are used to move a system between two equilibrium states or into a non-equilibrium state. (Benson, 2002)

Dissectibility	The capacity of a hierarchy to be dissected into its constituent branches along the channels of communications and control. (Koestler, 1967)
Downward Causation	All processes at the lower levels of a hierarchy are restrained by and act in conformity to the laws of the higher levels. (Campbell, 1974)
Dynamic Equilibrium	Maintenance of stability in complex systems is achieved through adjustments to internally or externally generated disturbances that impact system performance. (Skyttner, 2005)
Emergence	Qualities or characteristics that arise in the higher levels of a system which are dependent upon, but not present in, the lower levels. (Alexander, 1922)
Engineering Redundancy	The use or inclusion of multiple elements capable of performing the same function in order to improve safety or integrity of the system. (Downer, 2009)
Entropy	The degradation of the matter and energy in the universe to an ultimate state of inert uniformity. (Merriam-Webster, 2015)
Equifinality	The ability of an open system to reach the same final state from different initial conditions and in different ways. (Von Bertalanffy, 1968)
Evolution	The capacity of a system to adapt or evolve, usually toward greater levels of complexity, in order to remain viable. (Fromm, 2004)
Feedback	A control mechanism that detects the system state using a receptor and then transmits signals to an effector to facilitate changes based on the new conditions. (Von Bertalanffy, 1968)
Filtering	A process of attenuation by which transmissions are selectively filtered along a communication channel. (Zadeh, 1953)
Free Energy	A manifestation of negative entropy that can be consumed by a

	system to decrease local entropy. (Rapoport, 1968)
Gaia Theory	The proposal that organisms interact with one another and their inorganic surroundings to form a self-regulating system that maintains the conditions for life on Earth. (Lovelock, 1972)
Generic Design	A collection of concepts describing the fundamental principles that are inherent in the generic system design process. (Warfield, 1990)
Governors	A part of a machine by which the velocity of the machine is kept nearly uniform, notwithstanding variations in the driving-power or resistance. (Maxwell, 1868)
Hemibel Thinking	The use of a coarse unit of measure to gauge the difference between an actual outcome and the computed, theoretical outcome to determine if significant improvement is possible. (Morse & Kimball, 1951)
Heterostasis	The principle that stability can only be maintained for one variable at the expense of modification, or heterostasis, of another. (Davis R. , 1958)
Hierarchy	A system that is composed of interrelated subsystems which are, in turn, hierarchic structures continuing downward until a lowest level of elementary subsystem is reached. (Simon H. A., 1962)
Hierarchy of Needs	The principle that a system is motivated by a hierarchy of needs, one of which is dominant until satisfied, after which the next in the hierarchy takes over. (Maslow, 1943)
Holism	An arrangement of parts in a definite structural arrangement with mutual activities that constitute a whole. (Smuts, 1926)
Holons	Subordinate elements (less than the whole) that are present on any level of the whole system's hierarchy. (Koestler, 1967)
Homeokinesis	While attempting to maintain homeostasis and dynamic

	equilibrium, systems are actually in a state of sustained disequilibrium that exists between and upper and lower bound of controllability. (Van Gigch, 1991)
Homeokinetic Plateau	A region in a system's life cycle, existing between an upper and lower boundary, wherein the system uses negative feedback to remain viable. Once the system leaves this plateau, positive feedback propels them to inviability. (Van Gigch, 1991)
Homeorhesis	The principle that a system's basin of attraction does not lie at a specific point, but along an invariant ensemble of trajectories that the system is drawn along. (Waddington, 1968)
Homeostasis	A coordinated system of physiological reactions that maintain the steady-state of key variables within the system. (Cannon, 1929)
Homeostat	An adaptive mechanical system designed to achieve ultra-stability in a continuously changing environment of both positive and negative feedback. (Ashby, 1952)
Indeterminancy	The principle that energy and time or position and momentum of a quantum mechanical system, cannot both be accurately measured simultaneously. (Heisenberg, 1927)
Information Channels	The distinct communication path or medium through which information is transmitted from a source to a destination. (Shannon, 1948)
Information Flow	A socio-technical design principle stating that information should be transmitted first to the place where it will be needed first. (Cherns, 1976)
Information Redundancy	The use of additional, redundant data during a communication transaction in order to overcome noise or information entropy. (Shannon, 1948)
Inherent Conflict	A group working together to solve a complex problem will have

	an inherent conflict concerning the relative significance of the factors involved. (Warfield, 1990)
Instability	The tendency of a system, when disturbed, to continue in the direction of displacement, or increased oscillation, rather than to return to equilibrium. (Hurt, 1965)
Integration	The degree with which a system must sacrifice autonomy in order to function as part of a larger system. (Beer, 1979)
Irreducibility	Systemic properties are irreducible if they are not behaviorally analyzable or if the behavior of the components over which they supervene is irreducible. (Eronen, 2004)
Minimum Critical Specification	The development of a minimum set of core requirements with which an operable unit can produce a satisfactory result without external control of its internal functions. (Herbst, 1974)
Morphogenesis	A deviation-amplifying relationship that exists between the system and the environment resulting in evolutionary system change. (Maruyama, 1963)
Morphostasis	A deviation-counteracting relationship that exists between the system and the environment which impedes evolutionary system change. (Maruyama, 1963)
Motivation Theory	The theory that system needs are organized into a hierarchy of relative prepotency. (Maslow, 1943)
Multifinality	The process by which similar initial conditions, and/or routing by different paths, may lead to dissimilar end-states. (Maruyama, 1963)
Multifunctionality	A characteristic of system design where the same function can be performed in different ways by using different combinations of elements. (Cherns, 1976)
Mutual Causal Systems	A system whose component elements influence each other

	either simultaneously or alternatingly. (Maruyama, 1963)
Near Decomposibility	A property of hierarchies where linkages with a component are stronger than the linkages between different components. (Simon H. A., 1962)
Negative Entropy	The process by which a system absorbs free-energy in order to reduce the accumulation of entropy (or disorder) within the system. (Flear, 1948)
Negative Feedback	A property of deviation-counteracting systems which causes them to respond to a perturbation by attempting to return to their prior state. (Maruyama, 1963)
Noise	The presence of unwanted additions to a communication transmission, including distortions, static or errors in transmission. (Shannon & Weaver, 1949)
Organizational Redundancy	The level of redundancy within an organizational or social structure that is necessary to reasonably assure success. (Streeter, 1992)
Oscillation	The tendency of a disturbed body to move in a cyclic path around a point of equilibrium or attraction over a period of time. (Airy, 1840)
Participative Design	A socio-technical process by which individuals are responsible for designing their own work environments, roles and responsibilities. (Cherns, 1976)
Positive Feedback	A property of deviation-amplifying systems which causes them to respond to a perturbation by continuing in the direction of the change. (Maruyama, 1963)
Power and Authority	Those who need equipment, materials, or other resources to carry out their responsibilities should have access to them and authority to command them. (Cherns, 1987)
Principle of Population	The principle that population should always be kept down to

	the level of the means of subsistence. (Malthus, 1798)
Punctuated Equilibria	The principle that most species exhibit very little evolutionary change over time, however, when significant evolutionary changes do occur they are rapid. (Eldredge & Gould, 1972)
Purposeful Behavior	Actions undertaken by an entity with the objective of achieving an identifiable goal or end state. (Rosenbleuth, Wiener, & Bigelow, 1943)
Rational Choice Theory	The theory that an individual will make decisions in a manner designed to maximize a specific, desired outcome. (Von Neumann & Morgenstern, 1944)
Recursion	The fundamental laws governing the processes at one level are also present at the next higher level. (Adams & Keating, 2012)
Redundancy of Potential Command	Power and control should be vested in the location that has the most information or is best equipped to use it. (McCulloch, 1965)
Regeneration	The capability of a system to maintain itself by regenerating its own internal components. (Varela, 2000)
Regulation Channels	The communication channels connecting higher and lower echelons in the hierarchy which are used to transmit regulatory instructions, one step at a time, up or down. (Koestler, 1967)
Relaxation Time	The time required for a system to return to a steady-state after being perturbed. (Goodwin, 1963)
Reliability	The application of redundancy, and other engineering approaches, to increase the likelihood that a system will function properly and achieve its objective. (Blanchard & Fabrycky, 1981)
Reproduction	The process, distinct from autopoiesis or regeneration, by which an organism ensures its genetic continuity. (Margulis & Sagan, 1986)

Requisite Hierarchy	A lack of regulatory ability within a system can be compensated for, to some extent, by increased hierarchy in its organizational structure. (Aulin-Ahmavaara, 1979)
Requisite Parsimony	The theory that a normal person can successfully manage between 5 and 9 concepts in their short term memory. (Miller G. , 1956)
Requisite Saliency	The factors involved in system design are rarely of equal importance, and there is an underlying logic awaiting discovery that will reveal the relative saliency of each factor. (Warfield, 1995)
Requisite Variety	The variety of a controller must match the variety of the system being controlled and the variety of the environment. (Ashby, 1956)
Resource Redundancy	Maintenance of stability under conditions of disturbance requires redundancy of critical resources. (Clemson, 1984)
Reticular Formation	A control mechanism in the central nervous system of vertebrates that commits the whole animal to adapt a specific mode of behavior from a small number of mutually exclusive modes. (Kilmer, McCulloch, & Blum, 1969)
Satisficing	Rather than optimizing, an organism will general seek the first solution that adequately satisfies all of its needs. (Simon, 1956)
Self-Assertion	The tendency of an element in a hierarchy to preserve and assert its individuality as a quasi-autonomous whole. (Koestler, 1967)
Self-Organization	The process by which a system moves beyond self-regulation, to alter its internal structure to increase its level of adaptability. (Leonard, 1990)
Self-Reference	The process by which a system distinguishes itself from the environment and uses itself as a pattern for regeneration and

autopoiesis. (Luhmann, 1983)

Self-Regulation — The ability of living beings (or systems) to maintain their own stability in the face of the colossal, often adverse, forces which surround them. (Cannon, 1929)

Socio-Technical Design — An approach that advocates the direct participation of the end-users in the system design process. (Cherns, 1976)

Source Coding — The process of compressing or reducing redundancy in information transmitted across a communications channel. (Anderson & Mohan, 1991)

Span of Absolute Judgment — The limitation that governs the accuracy with which we can identify absolutely the magnitude of a unidimensional stimulus variable. (Miller G. , 1956)

Span of Attention — When viewing groups of objects, test subjects can subitize (identify without counting) groups of seven or less, while they estimate the number of larger groups. (Miller G. , 1956)

Span of Immediate Memory — The number of concepts that a test subject can maintain and recall from immediate memory (typically around 7). (Miller G. , 1956)

Spurious Saliency — The assignment of importance to an issue based on the dramatic quality of events, rather than its actual or intrinsic importance. (Underwood, 1969)

Stability — The tendency of a system to return to equilibrium (or for its amplitude of motion to decrease) following a disturbance or perturbation. (Hurt, 1965)

Static Equilibrium — A state of equilibrium where the system is at rest and has zero net force applied to it. (Hurt, 1965)

Steady-State Principle — If a system is in a state of equilibrium, then all sub-systems must be in equilibrium. If all sub-systems are in a state of equilibrium, then the system must be in equilibrium. (Clemson,

	1984)
Sub-Optimization	If each subsystem, regarded separately, is made to operate with maximum efficiency, the system as a whole will not operate with utmost efficiency. (Skyttner, 2005)
Supervenience	A relationship that exists between two entities, A and B, such that any variation in A must, by definition, also exist in B. (Broad, 1925)
Sympoiesis	A systemic behavior, complementary to autopoiesis, where the systems have a collective boundary, collectively produce themselves and are organizationally ajar. (Dempster, 2000)
System Darkness	No system can be known completely. (Clemson, 1984)
Technical Redundancy	The design of system redundancy to explicitly deals with issues such as reserve power and safety factors in the design process. (Landau, 1969)
Teleology	The presence of purpose or purposeful behavior in the application of system feedback. (Rosenbleuth, Wiener, & Bigelow, 1943)
Unpredictability	For emergent characteristics, the inability to foresee the emergence of events or properties using all available knowledge or experience. (Morgan C. L., 1923)
Variance Control	In socio-technical design, problems should be corrected as close to the point of origin as possible. (Cherns, 1976)
Viability	The capacity of an organism to maintain a separate existence, that is, to survive regardless of the changes in its environment. (Perez Rios, 2010)
Viable Systems Model	A system of interlocking Ashbean homeostats that can be used to model any viable system in terms of its operational units, coordinators, and governing metasystem. (Beer, 1984)

Welfare Economics	A perspective of economic study that focuses on the relationship between wealth and human welfare. (Fetter, 1920)
Wholeness	The philosophical principle that asserts that the whole is greater than the sum of its parts. (Aristotle, 350 B.C.E)

Table of Contents

Chapter Page

Chapter Page

List of Figures

Figure Page

1. INTRODUCTION

In introducing this research, it will be helpful if the reader has an understanding of the context, and of the variety of converging research paths, that led to the development of the research question. In early discussions with scholarly colleagues, a recognition emerged that an inability to identify and diagnose system pathologies was a significant obstacle within the domain of system theory. The pathologies under discussion were not merely diseases and malfunctions of the system, but often consisted of a collection of circumstances and conditions in which the performance, and even the *nature*, of a system under study did not match the expectations of those who governed it. Pathologies were manifestations of system problems, and system diagnosis was a necessary first step in addressing them.

Since that time, significant research has been undertaken to develop a framework for governance that, similar to Beer's viable system model, provides a generic approach for exploring and contextually framing a system (Keating, Katina, & Bradley, 2014). Concurrently, emerging research has been conducted that contributed to the body of knowledge regarding pathologies within the system domain and how they might be manifested within a system (Keating & Katina, 2012). Still, the challenge of complex system diagnostics remained elusive.

Here's why.

At the point where the fields of *system governance* and *system pathologies* converge, a number of practical challenges arise. In particular, how does one bridge the gap between the process of framing a system under study and the process of identifying the pathologies that impact it? This question led to a preliminary exploration of system diagnostics and a discussion of what approaches might be employed to address the issue.

In examining the existing diagnostic approaches, I found that they were centered primarily in the fields of medicine, biology, and psychology. This was not unexpected because all of these disciplines have a long history of diagnostics and diagnosticians. The research suggested that the approaches used for model-based diagnosis of complex systems generally fell into two broad categories: consistency-based and abduction-based (Console & Torasso, 1991). In the case of the consistency-based approaches, a model of the system's correct behavior is used for comparison, and deviations that occur in the system under study are identified and categorized. When effective, this leads to a *differential diagnosis* that identifies the principle pathology or pathologies.

For abduction-based diagnostics, the opposite approach is taken. In this case, the signs and symptoms present in the system under study are compared to the model of a *diseased* system. Here the pathology is identified by its similarities to an afflicted model, rather than by its deviations from the norm (Priest, Eshghi, & Bertolino, 1991).

One will note that both of these approaches share a common theme. They require a system reference model. In the case of consistency-based diagnostics, it is a model of the *well-system*; for abduction-based diagnosis, it is a model of the *diseased-system* (or systems).

Fortunately for medical science, there is a rich history of conceptual models that have been developed specifically for the purpose of diagnosis (Overall & Williams, 1961). Further, health models have emerged that provide a *wellness continuum* against which an individual's total wellness can be evaluated (Travis & Ryan, 1981).

Within the realm of system theory, there has also been significant effort to develop explanatory and diagnostic models that seek to catalog and categorize systems based on underlying characteristics. These approaches include the *system dynamics* models advanced by Senge (1990) and Braun (2002), the *skeleton of science* devised by Boulding (1956), the system classifications of Ackoff and Gharajedaghi (1996), and even the *viable systems model* advanced by Stafford Beer (1984). Still, this research shows that these approaches lack key characteristics that might allow them to effectively bridge the gap between system examination and general system diagnostics. To demonstrate this, each of the existing approaches is examined through the prism of six criteria. These criteria, which will be explained in depth later, are as follows:

Structured: Does the existing approach provide a defined framework into which systems are distributed?

Rigorous: Does the existing approach have a rigorously documented mechanism for determining how systems will be distributed within the framework?

Holistic: Does the approach examine and categorize the system as a whole, rather than by its components and assemblies?

Inclusive: Is the approach sufficiently generalized to be applicable to *all systems?*

Transformative: Does the approach categorize systems using parameters which might allow them to adapt or evolve into new or different classifications?

Theory Based: Does the approach have a firm basis in systems theory?

By employing this evaluation process, the study demonstrates why these criteria hold particular significance in developing a model of "*system-ness",* and why such a model is a necessary step in bridging the gap between system examination and system diagnosis.

1.1. Research Purpose

The purpose of this research is to develop a systems-theory based taxonomy of system archetypes using an inductive research design. The resulting taxonomy permits classification of a system based on its characteristics, resulting in the system's assignment to a particular archetype. The number, nature, and characteristics of these archetypes is a direct result of the inductive research design.

As suggested by the criteria discussed earlier, the identification of the archetype associated with a sample system is determined by comparing the system under study to the fundamental characteristics of the archetype. This comparison is targeted at selecting the archetype which is most consistent with the *"condition"* or *"nature"* of the system as a whole. This suggests that while the evaluation process may look below the surface of the system under study and consider its sub-components and parts, the category into which a system is placed must be fully compatible with the nature of the system as a whole.

Further, the archetypes that were developed in this research were, as much as possible, derived from parameters of the system that are subject to either selective or directed change. This is because characterizing a system by its immutable factors, although useful in some cases, does little to identify the areas where the system under study can be transformed from one archetypical state to another.

Finally, the resultant system archetypes and the methodology by which they were derived have been rigorously linked to the principles of system theory. The archetypes themselves not only comply with the axioms, principals, and aphorisms that constitute the canons of system theory, but are directly linked to literature within the field.

1.2. Research Questions

The following research questions follow naturally from the earlier discussion and are designed to specifically address the research purpose. In conjunction with the assumptions, limitations, and boundaries that are described in section 1.3, answering these research questions should address the goal of developing a framework for identifying complex systems archetypes and bridging a gap in the current body of knowledge.

This research answers the following questions:

1.2.1. What taxonomy of systems archetypes emerges from a structured examination of the principles of Systems Theory?

To answer this question, the research endeavored to develop a system-based framework which examines the body of system theory principles that are represented by the literature within this and related disciplines. Here, a system-based framework should be viewed as a theoretical construct as described by Eisenhart (1991) and later reinforced by Lester (2005). Per Eisenhart, a theoretical construct is "a structure that guides research by relying on a formal theory… constructed using an established, coherent explanation of certain phenomena on relationships" (Eisenhart, 1991, p. 205). Accordingly, this study draws from the formal theories within the field of system theory.

At first blush, the number of different perspectives and avenues by which the literature and the nature of systems may be explored seems endless. In the past, systems have been classified in hierarchies of increasing complexity (Boulding, 1956), by internal flows and dynamics (Senge, 1990) (Braun, 2002), or by the functions and objectives of their various system levels (Beer, 1984). Such approaches were undertaken with the objective of making a generic system easier to understand or, at the very least, easier to reference. If it is assumed that all of those techniques and taxonomies, in some regard, are inadequate to satisfy the needs of current and future research, then the great challenge is to find one that is.

In engaging the foundational literature, this research sought to identify and document the major themes and relationships that have emerged in system theory through the application of a grounded theory approach. The various definitions of systems, systemic structure, functions, behavior, and hierarchy are examined and interrelated using a visual coding structure that was developed as part of this research. This collection of visual models allows the vast and complex collection of system concepts to be viewed from an abstract, top-level perspective from which the richness of their relationships can be understood.

During the development of this model, new and meaningful relationships among system principles not previously included in the literature emerged through the exploration of the modeled entities. These new relationships drew connections to other system principles that have not traditionally been included in the catalog of system principles detailed by Adams et al. (2014). As those relationships emerged, the related principles were integrated and explored in the same manner as the documented concepts. This approach was undertaken in hope of developing the most expansive perspective achievable.

After the complete collection of conceptual models was developed, the relationships and concepts were re-examined from the perspective of selective coding and theoretical sampling. The goal of this examination was to ferret out a collection of archetypes that are both prevalent and recurrent within the literature, as well as highly representative of the complex systems that are manifested around us.

While it was not an objective of this research to develop a methodology that can be used to differentiate one archetype from another, some general evaluation criteria emerged during the course of the research. These criteria were noted in the findings and were employed during the sample case application to evaluate its compliance with each of the complex systems archetypes.

1.2.2. What results, when the system archetype taxonomy is used for classification of an existing system?

After the theoretical framework was established, a sample system was evaluated to determine its fit to the expectations of each of the archetypes. The exploration was undertaken using a case study that examines a generic complex system. For the purpose of this study, a facilities management department within a large industrial operation was selected. The department is comprised of several sub-systems (work groups), each of which is tasked to perform a specific subset of the organizational activities. The case study examines each of the work groups and, by exploring their objectives and behavior, identifies which of the system archetypes best represents them. Because of the complexity and diversity of functions within the work groups, in many cases they are associated with more than one archetypical representation.

1.3. Research Assumptions, Limitations, and Delimitations

As with all research, this study is approached with an understanding that certain boundaries must exist which establish what is accepted or known, what knowledge is being sought, and where this search for knowledge will end. These issues are addressed in this discussion of assumptions, limitations, and delimitations.

For the purpose of this research, an assumption is any idea, principle, or concept that the author and reader must agree upon in order for the balance of the study to have a foundation of legitimacy. Using these assumptions, the study establishes a research path which addresses the research questions as defined. This path, however, cannot extend indefinitely and, therefore, limitations are established which identify what is within the bounds of the research and what is beyond it. Likewise, the delimitations provided here describe the scope of the products which are produced as a result of performing the research as described.

With this in mind, the following sections describe the assumptions, limitations, and delimitations of this research.

1.3.1. Assumptions

> *"What do I believe that my readers must also believe (but may not) before they will think that my reasons are relevant to my claims?" (Williams & Colomb, 2006, p. 200).*

- **The Existing Research is Sufficient**

  As stated earlier, this research is almost fully driven by the body of systems research that has been done in the past. Clearly, because research into system theory continues, not all knowledge in the field has been acquired, nor have all avenues been exhausted. For this research to be valid, one must assume that the principles, axioms, and aphorisms within the field of system science, at this time, are sufficiently mature to fuel this research.

- **The Cost of Abstraction is Acceptable**

  When developing a collection of system archetypes that are designed to represent any and all systems, one is faced with two options: resolution or abstraction. In the extreme, to classify all systems with maximum resolution would require a category for every single instance of every single type. This is driven by the reality that there are always differences, even between the most similar entities. To address this, abstraction is used to eliminate those characteristics that are not immediately pertinent from further consideration. This does not mean that they are unimportant in other contexts, merely that they do not contribute directly within this domain.

In order to develop a system of archetypes that is generally applicable, significant abstraction will be required, if only to keep the number of archetypes reasonable. This demands that the resultant system of classification will not address or encompass all characteristics of all systems; it will, however, fully address the ones that fall within its scope.

- **The Purpose Driving the Design is Appropriate**

  As discussed in the introduction, this research emerged from a need to bridge the gap between system examination and diagnostics. Because of this, the exploration of the literature and the pursuant development of the archetypes were geared to produce a structure that, in some way, helps to bridge that gap. It is this underlying purpose that gives the research real value and provides the most promising avenue for it to make a meaningful contribution within the field of system theory.

1.3.2. Limitations

The literature review and examination of existing research spans the domain of systems theory and also extends into other disciplines, where appropriate. However, the record of humanity's efforts to categorize and catalog the natural world extends to earliest history. While, in some cases, literature and methodologies from outside the field of systems theory were considered and integrated, it was impractical for this research to explore all of these variants. Because of this, the exploration of approaches to system classification is largely limited to the ones that exist within the field of system theory.

1.3.3. Delimitations

- **Research Product**

  The product of this research is a structured, inclusive collection of system archetypes possessing documented characteristics which allow a system under study to be categorized. Although this research was borne of a desire to improve system diagnostics and pathology identification, it does not address this directly – nor is it intended to. It was the goal of this work to produce a framework which other researchers may employ or extend in order to achieve those objectives in the future.

The case study generated as part of this research is designed to demonstrate the applicability of the archetypes within a single case environment. While the study system was selected to provide a diverse and challenging application for exploring the applicability of the archetypes, it was not undertaken for the purpose of *proving* that these archetypes are the only ones which can be derived from the system literature. Neither does the case study attempt to prove that no other perspectives can be used to examine or dissect the study system. The case study merely seeks to demonstrate that, using the study system, these archetypes can be used to effectively identify and categorize the behaviors that are observed.

1.4. Significance of the Proposed Study

The significance of this research lies in its potential to bridge the gap between *system examination* and *system diagnosis* or *transformation*. For the purpose of this research, system examination is any process by which the system is explored, viewed, or categorized in terms of function, behavior, purpose, or any other meaningful parameter. System diagnosis, on the other hand, is the recognition or identification of systemic deficiencies or pathologies that prevent the system from achieving its purposeful objective. Finally, system transformation describes the changes that are instigated, either internally or externally, to bring the system closer to achieving those purposeful objectives.

The gap between system examination and diagnosis is addressed by developing a methodology and structure that allows a researcher to classify a system under study according to its systemic characteristics. Such a classification allows that system (within the context of all systems) to be more easily understood. This opens the door for further research linking discernable system characteristics with identifiable pathologies, thus forming a basis for differential diagnosis.

Further, even in a system that is not considered dysfunctional or diseased, it is often desirable to alter its configuration or characteristics with a view to emerging conditions. This archetypal framework allows system developers to better understand where their system is today and what alternatives are available to ensure its success in the future.

1.5. Theoretical, Methodological, and Practical Contribution of the Research

1.5.1. Theoretical Contribution

This research contributes to the theoretical foundations of system science in the following ways:

Foremost, the study examines the elements of system theory as they exist today and links them together to synthesize a new structure that can be used to classify and categorize any system. The theoretical structure which is developed within this research is firmly rooted in the documented principles of system science and provides a rigorously defined platform for future theoretical research.

Secondly, the research begins to bridge the theoretical gap that persists between existing literature on systems exploration, framing, and context and the literature on system pathologies. This bridge forms a basis for continued theoretical research on system assessment, diagnostics and treatment approaches.

Finally, the lines of distinction that are drawn between each of the theoretical constructs are like conduits which simultaneously link and separate the different archetypes. Recognizing these distinctions, and identifying those that are variable versus those that are immutable, is a significant step in determining how systems might be transformed to adapt to emerging conditions.

1.5.2. Methodological Contribution

The methodological contribution of this work is represented by the development of a new approach for performing grounded theory research. Through the introduction of highly documented, '*code-based*' models to traditional grounded theory, this research achieves the following objectives:

1) it provides a visual mechanism for abstracting complex, expansive data so that relationships and interactions can be seen at the highest levels;
2) it leverages these models to identify and document previously unseen relationships that exist within the data; and

3) it uses the expanded model as a basis for performing axial coding and theoretical sampling in pursuit of grounded theory.

When applied properly, such a *visual grounded theory* approach will produce highly documented models that can be exchanged and employed across multiple studies within the discipline.

1.5.3. Practical Contribution

Because this research largely revolves around the concepts of theory and methodology, its immediate practical contribution is challenging to define. To appreciate its practical value, one must examine it outside of the implications that it has for future research in systems theory and consider the value that it provides in an immediate sense.

For those who employ these complex system archetypes, the most important practical benefit is *understanding*; a specific benefit is an understanding of where a system is now, where it stands in relationship to other systems, and where it can be if appropriate changes are applied. Often, this process of rigorous introspection is all that is needed to provide a clearer perspective of the true nature of a system and how it might be transformed. It is this type of introspective examination that can truly benefit the systems with which we interact, as well as those that we inhabit.

2. LITERATURE REVIEW

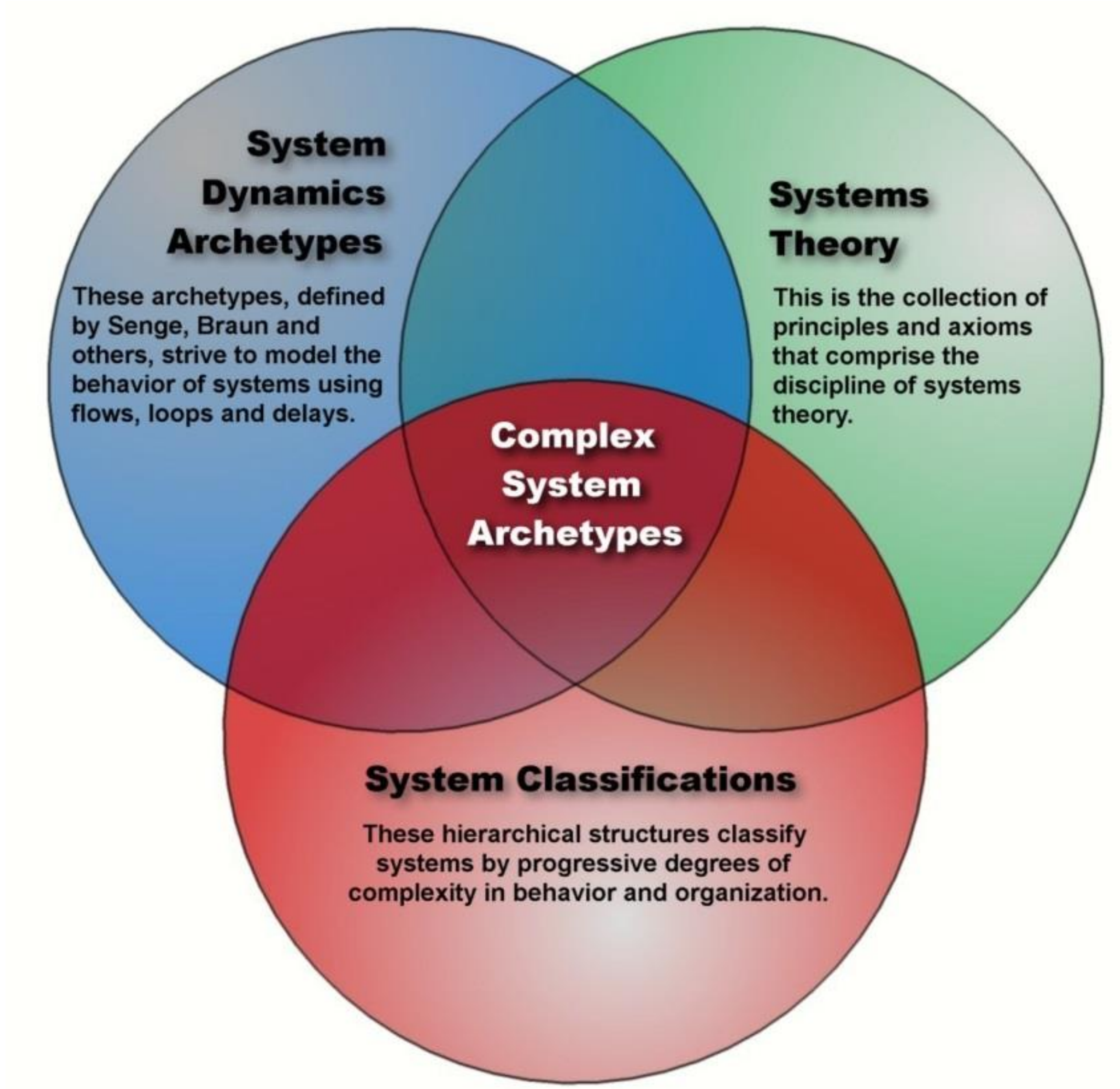

Figure 1. Venn Diagram of Contributing Research Areas

2.1. Introduction

Because of the nature of the subject area, the volume of literature that it represents is understandably vast. The notion of cataloging and categorizing knowledge to enhance our understanding traces its history to the earliest times. As intimated by Bruner (1957, p. 123), "perception involves an act of categorization.... The use of cues in inferring the categorical identity of a perceived object... is as much a feature of perception as the sensory stuff from which percepts are made." To discuss the multitude of techniques that have been developed across all disciplines would require many volumes and would likely produce few insights that would not be found within a smaller subset. Because of this, with an acknowledgement that the world of research is much larger than what is represented here, this research effort focuses on three primary areas in the literature which are most likely to provide insight.

As illustrated in figure 1, this literature review focuses on specific research that has been conducted related to the archetypes of system dynamics, past approaches to system classification, and how these areas interact within the field of system theory as a whole. It should be noted here that the system dynamics archetypes focus solely on system behavior which is a result of the system's structural configuration, as opposed to the classifications of systems theory which are driven by the complexity and nature of the system itself.

During the exploration of each subject area, the major work within the field is discussed and synthesized, followed by a presentation of critiques from within both the subject area and related fields of research. Each of these topic areas closes with an evaluation of the literature using six evaluation criteria. These criteria are discussed in detail in the following section.

Following the presentation and preliminary evaluation of all of the subject areas, the literature review closes with a summary and gap analysis. Here, a composite of the results from the earlier evaluation is presented and the gap in the literature is identified.

2.2. Criteria for Evaluation of the Literature

In evaluating the literature, this research examines it through the prism of six distinct criteria that were developed specifically for the purpose of this study. The criteria are defined in detail in the following sections and were designed to assess the capabilities of the existing taxonomies and structures, with particular attention given to their ability to distinguish between different system types. While these criteria are certainly not the only metrics by which the literature can be measured, they provide a distinct and rigorous collection which should be sufficient to identify where a gap exists in the knowledge and to distinguish the areas in which this research makes a significant original contribution.

2.2.1. Structure

Within the context of this research, structure is the presence of an ordered pattern of categorization that is used to classify a system under study. The notion of exclusivity, where a system exists in one and only one category, is not an absolute requirement, and systems may have characteristics allowing them to span more than one category.

The presence of structure is essential because it provides a framework through which the system under study can be examined and classified. Since the number of vantage points from which a system may be viewed is infinite, the presence of structure ensures that, at some level, all observers are evaluating the system using the same collection of criteria. Structure is the foundation for reproducibility of research and for consistency of results.

Evaluation Criteria:

1) Does a documented catalog of system classifications exist within the research area?
2) Is the meaning of each classification within the catalog sufficiently documented that an observer can draw consistent distinctions between items?

2.2.2. Rigorous

The presence of structure alone is not sufficient to provide a mechanism for evaluating and classifying systems. Another critical ingredient is that of rigor.

The application of rigor is a key element in reliable analysis. Rigor allows the approach to rely less on the perspectives of the observer and more on the principles and standards that are the theoretical underpinnings of the methodology. Further, the presence of rigor helps to ensure consistency in the analytical process, as well as in the manner in which systems are categorized, thus providing a reliable platform from which future exploration and treatment of the system under study can proceed.

In order to be rigorous, the approach must provide documented evaluation criteria that govern how systems will be distributed into categories. This classification method must be both precise and reproducible, such that any observer using these criteria from a similar perspective would obtain the same result. As with structure, this criterion does not dictate that a system cannot exist in multiple categories, only that the classification occurs consistently.

Evaluation Criteria

1) Do documented criteria exist for distributing systems into the classification structure?
2) Are the criteria sufficiently objective, precise, and unbiased to ensure a consistent categorization between observers?

2.2.3. Holistic

The concept of holism dictates that a system is more than the sum of its parts, and that the interaction of the various components within a system result in a synergy that creates new, potentially unpredictable behaviors that are not present in other combinations of the components (Smuts, 1926). It is this concept of holism that demands we look beyond the mere parts comprising a system in order to understand its greater meaning and, perhaps, purpose.

Evaluation Criteria

1) Does the approach classify the system based on its holistic structure, behavior, or characteristics?
2) Is the classification made from an outside perspective, as opposed to the perspective of one or more of its components?

2.2.4. Inclusive

Where the concept of holism is concerned with examination of the system as a whole, inclusiveness examines the approach from a more global perspective. For the purpose of this research, the question of inclusiveness asks if the approach is sufficiently broad or generalized to be applied to any and all systems, or is it restricted to a subset of systems that exist within its domain.

Note that inclusiveness here does not dictate that all system domains are equally detailed or have similar depth. In reality, domains of higher complexity are likely to require more complex categorization than the domains of "clockworks" and "thermostats" (Boulding, 1956).

Evaluation Criteria

1) Can the approach be applied to any system in any domain of systems?
2) Can the approach be applied outside of its originating domain without inferring unjustified/unobserved characteristics on the system under study?

2.2.5. Transformative

The concept of transformation differs from the other criteria in that it infers a type of purposefulness to the approach that goes beyond simple categorization of data. An example of this type of *limited* system is the Linnaean Taxonomy described in Systema Naturae

(Linnaeus, 1735), which provided an early taxonomy for classifying life. Here, biological systems are disseminated into an expansive reference collection in which, once categorized, they are firmly entrenched and cannot change. While hugely beneficial for reference, it is not designed to accommodate the transformation of its included systems.

The goal of transformation here is to position a system under study in such a way that it can be meaningfully compared to other systems at the same level. Here, distinctions can be identified, goals and objectives can be considered and, potentially, a system might adapt or evolve based on the new knowledge, allowing it to move between archetypes.

Evaluation Criteria

1) Does the approach categorize systems in a manner that allows future adaptation *(as opposed to a strict classification of their current state)*?
2) Does the approach position systems for meaningful comparison against one another at a co-equal level?
3) Is the approach based on characteristics that support modification, adaptation, and evolution of the system?

2.2.6. Basis in System Theory

Because this research is being conducted within the field of system theory with the purpose of advancing knowledge within that domain, any approach being studied must have a shared anchor within the discipline. This anchor provides a common frame of reference from which other relationships may be established. To have a basis in system theory, the approach being evaluated must have been developed from the underlying principles of system theory and must be rooted in that discipline. Further, the approach must be compliant with the governing principles that have been developed by researchers within the field.

Evaluation Criteria

1) Does the approach reference the principles, axioms, and aphorisms of system theory to support its conclusions?

Having established the criteria by which the literature will be evaluated, the following sections undertake an examination of representative classifications and archetypes from the field of system theory and system science.

2.3. System Dynamics Archetypes

2.3.1. Synthesis of the Literature

In his book, The Fifth Discipline, Peter Senge (1990) developed a collection of archetypes that were derived from the principles of system dynamics. Each of these models was represented by circles of causality, specifically balancing loops and reinforcing loops as described below.

Balancing loops: The purpose of a balancing loop is to alter the current state to some desired state by means of an action. A balancing loop is characterized by a gap that represents the variation between the current state and the desired state.

Reinforcing loops: A reinforcing loop is a type of feedback in which the action that occurs produces a result, which then influences more of the same action, and eventually has a compounding effect of either growth or decline. The concept of compounding interest and its effect on the principle within a bank account provides a good example of a reinforcing loop.

Delays: These are the periods between when an action or series of actions occurs and the resultant feedback is received.

Senge developed a system of archetypes that could be used (alone or collaboratively) to represent the feedback loops that existed within any system. He posited that if one could understand the archetype to which a system belonged, that would invariably indicate where leverage could be applied to change the dynamics of the system.

The Archetypes which he discussed in the Fifth Discipline are:

- **Limits to Growth**

  Originally introduced by Meadows, Meadows, Randers, and Behrens (1972), this condition is caused when a reinforcing process that contributes to growth eventually encounters a limit that is created by a balancing process. The balancing process will eventually stop the growth, and will likely cause an accelerating collapse as the reinforcing loop unwinds.

  Senge's example: "an animal population that grows rapidly when its natural predators are removed, only to overgraze its range and decline due to starvation" (Senge, 1990, p. 391).

- **Shifting the Burden**

  This occurs when a stop-gap solution is used to address a problem and is determined to be effective. This solution is increasingly used until, eventually, the fundamental solution (the real fix) and its supporting infrastructure atrophy from a lack of use. As this happens, the system becomes increasingly reliant on the stop-gap solution.

  Senge's example: "paying bills by borrowing, instead of going through the discipline of budgeting" (Senge, 1990, p. 392).

- **Eroding Goals**

  This situation occurs where pressure to deliver causes the participants to lower their goals and objectives in order to get past the crisis. In this scenario, the goals will continue to decline because the crisis is often associated with failing to meet the original goals.

  Senge's example: "successful people who lower their own expectations for themselves and gradually become less successful" (Senge, 1990, p. 395).

- **Escalation**

  Escalation occurs when two entities each perceive that each needs to have an advantage over the other. As one gains an advantage, the other must respond by advancing its own position, *ad infinitum*. In the end, each entity is compelled to proceed much further than either would have preferred.

  Senge's example: "the arms race and the war on terror" (Senge, 1990, p. 396).

- **Success to the Successful**

  This is a situation in which two entities are competing for the same resources. The more successful one of the entities becomes, the more it is rewarded with additional resources. This eventually results in the starvation of the less successful entity.

- **Tragedy of the Commons**

  This occurs when individuals share a common, but scarce, resource that is distributed solely based on need. The resource is sufficient, as long as no one attempts to gain an advantage in its use. As one individual does try to gain an advantage, the others are compelled to increase their usage as well, eventually depleting the shared resource.

  Senge's Example: "depletion of a natural resource by competing companies which mine it" (Senge, 1990, p. 398).

- **Fixes That Fail**

  This is where a short term solution is attempted that, while successful in the short term, produces unintended consequences that require additional fixes in the future.

  Senge's Example: "cutting back maintenance schedules to save costs, which eventually leads to more breakdowns and higher costs" (Senge, 1990, p. 399).

- **Growth and Underinvestment**

  This is a situation in which an entity's growth approaches a limit which can be overcome by investing in additional capacity. If the entity fails to make the investment, particularly if the entity is waiting on further growth to justify it, growth is hampered and the expectation is never achieved.

In *The Systems Modeling Workbook,* William Braun (2002) largely reiterated the archetypes presented by Senge (1990), but also expanded the catalog to include two more:

- **Accidental Adversaries**

  An extension of the escalation model, in this case the two parties begin in a cooperative relationship that leverages one another's strengths and minimizes their individual weaknesses. Unintentionally, one party takes an action that is seen as adversarial by the other, and the response is retaliation. The parties then enter into a typical escalation scenario. Braun notes that the final feedback loop differs from traditional escalation because the communications infrastructure remains in place that would allow them to achieve resolution if they wish.

- **Attractiveness Principle**

  Braun describes this situation as a *Limits to Growth* scenario in which there is more than one limit and all of the limits cannot be addressed equally. In this case, the entity must select which of the solutions is most attractive based on perceived costs and benefits.

A graphical representation of the interactions and relationships that exist between all of these archetypes was published by Michael Goodman and Art Kleiner (1993). Their diagram is shown in figure 2.

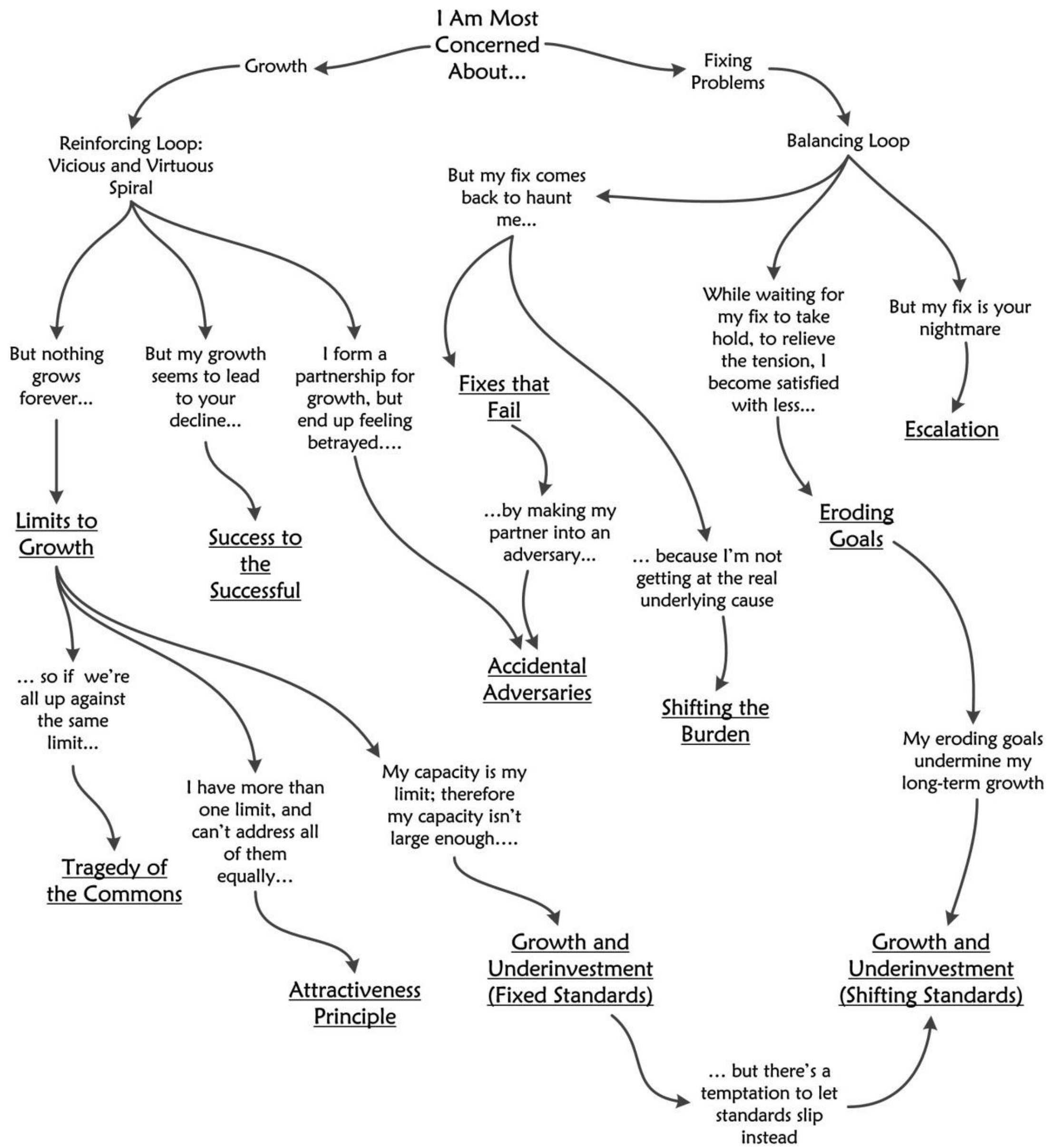

Figure 2. Archetype Relationships - Adapted from Goodman and Kleiner (1993)

The application of archetypes within the realm of systems dynamics was further extended by Marais, Saleh, and Leveson (2006). In their work, Archetypes of Organizational Safety, they identified two collections of archetypes that impacted industrial and institutional safety practices. These are:

- **Challenges of Maintaining Safety**

  These archetypes focused on issues of stagnant safety practices in the face of technological advances, decreasing safety consciousness, eroding safety goals, and general complacency.

- **Side Effects and Symptomatic Responses**

  In these archetypes, the authors dealt with the unintended side-effects of safety fixes and efforts that fixed symptoms rather than the underlying problems.

2.3.2. A Critique of the System Dynamics Archetypes within the Study Domain

Despite popular reception, and perhaps because of it, Senge's archetypes received critical reviews across multiple disciplines. In his book, *Rethinking the Fifth Discipline* (1999), Robert Flood addresses the lack of systemic thinking that permeates Senge's work.

> *"System dynamics explains people's experiences through systems archetypes and the underlying structure in behaviour that they help to locate, which is one useful insight. However, contributions from other systemic thinkers locate many more central insights that systemic thinking can offer and which people might take into account. Senge misses out on these. He therefore stops short of drawing together a wide-ranging and coherent theory of systemic thinking. Senge's readers are continually referred back to the narrower focus of system dynamics for an account of what systemic thinking has to offer" (Flood, 1999, p. 68).*

Flood makes reference to the works of Bertalanffy (1968), Beer (1979; 1981), Ackoff (1971), Checkland (1980) and Churchman (1971; 1963) and discusses how integrating their contributions would strengthen Senge's approach and its basis in systems theory. Raymond Caldwell (2005) takes a stronger stance when discussing the theoretical underpinnings of Senge's work, saying,

> *"the concept is critically flawed because it cannot theorise the organizing practices by which learning to lead and leading to learn are shared or distributed in organizations. It is concluded that Senge's under-theorized focus on distributed leadership consistently neglects issues of practice and issues of power" (Caldwell, 2005, p. 39).*

Finally, George Richardson took exception to the general employment of causal loop diagrams as a mechanism for system diagnostics, saying that *"people wishing to construct* *meaningful dynamic models should either avoid them or use them exceedingly carefully" (Richardson, 1986, p. 169).* His primary concern was that to fully appreciate such representations, the reader would have to be an expert in both the model and the modeled behavior. He concluded that, while these diagrams might have a role in teaching elementary system dynamics, their employment in conceptually modeling systems was best used in expository writing for public consumption. In that role, the use of the causal loops was supported by the modeler's certain knowledge of how the real system behaved.

2.3.3. An Evaluation of System Dynamics Archetypes Using the Research Criteria

In examining the system dynamics archetypes, it is clear that the collection of elements is well structured and that each element within the system of classification is sufficiently documented that an observer can draw consistent distinctions. Regarding rigor, though, the literature is not highly prescriptive regarding how a system under study might be consistently placed into a classification; this concern is alluded to by Richardson (1986).

When considering how this approach might be employed within an organization, it is evident that each archetype is likely to apply only to one relationship within that system. Unless the system consists of only *that* relationship, the approach relies on combinations and interlocking relationships between a variety of archetypes, resulting in the emergence of new and undocumented aggregations. This suggests that, while the approach can be used to represent larger, more complex systems, it is more focused on subsets of the system and is not truly ***holistic***.

Accordingly, the approach's ***inclusiveness*** is largely dependent on the effort applied by the modeler and on the sophistication of the observer. While the methodology can be used to represent virtually any system, the model becomes increasingly unwieldy as its complexity and the number of its relationships increases. This limits its applicability within more exotic systems as suggested by Caldwell (2005). When applied properly in a limited environment, though, it can certainly be ***transformative*** and can provide insights into what Senge (1990) describes as points where leverage may be applied to alter system behavior.

Finally, as Flood (1999) suggests, while the approach has some roots in both management theory and in systems dynamics, it lacks depth in regard to its ***basis in system theory***.

2.4. Classifications within Systems Theory

2.4.1. The Perspective of Kenneth Boulding (Skeleton of Systems)

One of the earliest efforts to classify systems within the domain of system theory appears in *The Skeleton of Science* (Boulding, 1956). Boulding posited that there were two possible approaches for organizing general system theory. The first approach was to examine the empirical universe and to identify phenomena which were found in many different disciplines. One would use these phenomena to construct a general theoretical model that represented the universe. In examining this approach, Boulding referred to examples such as:

- **Aggregates of Individuals**

  These are collections of individuals, regardless of type, into which new members are added or removed. These groups have observable collective behavior, such as migration, and they can be evaluated statistically.

- **Interaction between the Individual and its Environment**

  These empirical elements include individual entities of any type (electron, cell, animal, tribe, and so on) that exhibit behavior, action, and change. These collectives have organizing structures beneath them which explain their reactions with the environment and suggest preferred states to which the collective will seek to return.

- **Growth**

  Boulding asserts that growth theory is a phenomenon of universal significance and an important aspect of behavior.

- **Information and Communication**

  Communications and the exchange of information are universal elements that are found in wide varieties of empirical situations and are unquestionably essential to the development of both biological and social organizations.

The second approach recommended by Boulding was to place the empirical systems into a hierarchy based on their complexity and then develop a level of abstraction appropriate to each one. The following are the classifications of systems that Boulding proposed:

- **Frameworks**

  These are the static structures of the universe. They are specific patterns to which all things of a certain type should, or sometimes must, comply. Examples include the patterns of electrons around a nucleus, the arrangement of atoms in a crystal, and the organization of the astronomical universe. He states that without an accurate description of these static structures, it is impossible to develop a theory of function or of dynamic behavior that is accurate.

- **Clockworks**

  These are simple dynamic systems that exhibit predetermined, necessary motion. This category includes the solar system and the astral bodies which perform in a precise and predictable manner, as well as complex and simple machines. Into this system, Boulding also includes physics and chemistry, which are governed by immutable, natural laws.

- **Thermostats**

  These are control mechanisms or cybernetic systems that work to maintain homeostasis within an environment. They will attempt to maintain equilibrium, within their limits.

- **Cells**

  This is the level at which "open systems", or self-maintaining structures, emerge. One characteristic of these systems is that they have input and output flows that facilitate the exchange of material, energy, or information with the external environment.

- **Plants**

  Boulding refers to this as the "genetic-societal" level. It is here that a "cell-society" emerges which is characterized by the division of labor among highly specialized cells. These cells exist in a mutually dependent relationship. Further, the "plant" level is limited in that it has no specialized sense organs and does not exchange information extensively with other cells.

- **Animals**

  This level is characterized by mobility, self-awareness, and purposeful behavior. Animals have specialized information receptors which allow them to receive and process enormous amounts of information from the external environment. They collect data which is then used to develop evolving, internal representations of the environment. These, in turn, are used to guide goal seeking behavior.

- **Humans**

  While there are many differentiations between man and animal, Boulding selects to differentiate largely on the notion of man's capacity to perceive time and to be aware of his own mortality, or where he stands in the time process at each stage of life and development. Because the human perceives history, his behavior is profoundly impacted by an appreciation of time and his relationship within an emerging reality.

- **Social Organizations**

  On the surface, the relationship between social organizations and humans might appear analogous to the one between the plant and the cell. The differentiating factor, says Boulding, is that social organizations have value systems and the members must be concerned with the content and meaning of their messages. An appreciation of art, music, and poetry occurs within this level, along with the complexities of human emotion and societal interactions.

- **Transcendental Systems**

  Boulding describes these as "inescapable unknowables that also exhibit systematic structure and relationship" (Boulding, 1956, p. 205). These are the systems that are beyond our immediate comprehension; these are those to which we aspire to understand.

2.4.2. The Perspective of Kenneth Boulding *(World as a Total System)*

Later, Boulding would revise and extend his classifications of systems in the book *The World as a Total System* (1985). While the major categories were largely unchanged, several nuances were added over time:

- **Mechanical Systems**

  These systems are essentially equivalent to clockworks. Mechanical systems are governed by constant and relatively simple parameters which function with regularity and predictability within the domain defined by Boulding's frameworks.

- **Cybernetic Systems**

  Consistent with Boulding's thermostats, cybernetic systems operate in a realm where they are governed by negative feedback. Such systems consist of three essential elements: the receptor, which detects when the system is not at equilibrium; the transmitter, which communicates the need make an adjustment; and the effector, which is empowered to change the system.

- **Positive Feedback Systems**

  Boulding differentiates these from negative feedback systems, in that these systems tend to reinforce the condition that is detected by the receptor. The positive feedback system is functionally equivalent to a thermostat that detects that the room is hot and then turns on the furnace. In this scenario, the condition compounds itself until it reaches a breaking point, and a new system emerges.

- **Creodic Systems**

  These are systems that have an embedded functional pattern that governs how they will develop. Although the development cycle may be delayed or interrupted, when it resumes, it will continue on the same course and will have the same result. Boulding equates this process to the gestation of an embryo, the growth of a building from an architect's design, or the maturation of an organization from the founder's concepts.

- **Reproductive Systems**

  Similar to biological systems, these are systems that take *"genetic"* material from their participants and then produce new systems that are organically similar, but are still possessed of distinctions that are derived from the variety that is introduced by all of the previous contributors.

- **Demographic Systems**

  These are a natural outgrowth of the reproductive system. As reproductive systems produce an increasing number of similar types of organisms, these organisms can be categorized as a population. The number of organisms in the population will have variations in size and performance that, while not perfectly predictable, can be measured statistically to determine trends and causal relationships that are inherent to the group.

- **Ecological Systems**

  For Boulding, the ecological system is a population of varied organisms whose number and variety seek an equilibrium that can be supported by their environment. The governing factors may be the availability of food, water, and shelter, or the prevalence of predators who limit the size of the prey's population, while simultaneously being limited by the availability of prey.

- **Evolutionary Systems**

  Evolutionary systems emerge from the changes that occur within an ecological system in terms of climate and mutation. In evaluating the evolutionary system of Earth, Boulding notes that the system displays a flow from simplicity toward complexity, which is likely a result of ecological systems having niches at the higher levels that might be filled by organisms of greater complexity. This complexity emerges through mutations.

- **Human Systems**

  Boulding's discussion of human systems, here, is consistent with his view of the human system from *The Skeleton of Science* (1956). Here, though, he goes beyond a perception of time and mortality to discuss the capacity of man's nervous system to capture images which are used to interpret the world. Further, he points out the criticality of man's ability to communicate, a capacity which allows him to transfer and receive conceptual images representing things that he has never seen nor experienced.

- **Social Systems**

  Social systems, Boulding asserts, "arise out of the interaction of human beings and their artifacts" (Boulding, 1985, p. 28). He contends they are the direct result of the human ability to share complex information to facilitate a collective learning process. Unlike demographic systems, a social system can only partially be described by statistical information regarding the population and its members. Instead, this system is governed by motivations, variations of purpose, and the interpersonal relationships that emerge among its members.

2.4.3. An Evaluation of Boulding's Classifications Using the Research Criteria

While the Boulding's classification systems do provide a ***structured*** linear hierarchy that extends from the basic frameworks of reality to the "inescapable unknowables" and addresses those systems in a ***holistic*** manner, the hierarchy that it creates is not expansive. In developing the structure, Boulding follows a linear path where elements are cataloged into a hierarchy of growing complexity. In discussing Boulding's work, Martinelli (2001, p. 72) supports this assertion when he states that we must "keep in mind that any level incorporates characteristics from all the previous levels - thus, in a corporation, one can find the static structure, the clockwork, etc., up to the seventh level, the `human' level." However, Boulding's selection of this path through the tree does not mean that there are no other branches, that the other branches are unimportant, or that the concepts that are revealed along Boulding's traversal of a system hierarchy will fully explain what might be found along the other paths.

Martinelli further suggests that the Boulding system might be greatly enriched by incorporating the hierarchies derived in Miller's *Living Systems* (Miller, 1978). Along those lines, the hierarchy provided by Boulding does not fully represent aggregate collections where distinct representatives of many levels coexist and have discernable relationships and dependencies that are not represented within any one level. For example, humans and collections of humans are dependent on animals and plants in the ecosystem for their continued existence. None-the-less, it seems unlikely that Boulding would classify them as part of our social organization. As a result, while the Boulding model does provide a degree of ***rigor*** in discriminating between the systems within its scope, it is not fully ***inclusive***.

Regarding its ability to support ***transformation***, since the hierarchy developed by Boulding was structured to illustrate the effect that increasing complexity has on the nature of systems, it does not lend itself to supporting transformation by the entities within each classification. Nor should it. Each of the Boulding systems adequately serves the purpose for which they were designed; they provide a perspective on complexity and the power of communications and shared ideas and how they fuel an increasingly intricate system of relationships.

2.4.4. The Perspectives of Russell Ackoff and Jamshid Gharajedaghi

In their combined work, Ackoff and Gharajedaghi (1996) develop a set of four types that can be used to classify any system. These types are deterministic (or mechanical), ecological, animate, and social. The structure and differentiation that the authors use is as follows:

- **Deterministic**

  Members of this class are mechanisms, and their behavior is determined entirely by their physical state, in concert with the state of their environment. The essential parts of a deterministic system have a function, but they are not possessed of a purpose. This is to say that their actions are not the result of choice, but rather the result of a set of internal and external conditions that align sufficiently to facilitate their behavior. They are governed by causal laws.

- **Ecological**

  The ecological system as defined by Ackoff and Gharajedaghi has characteristics that one sees in both the animate and the deterministic variants. Here, the ecological system is composed of sub-systems that make decisions and exercise choice to influence their environments. The ecological system's response, however, is deterministic in nature and, although it does serve the purpose of the organisms and social systems that it is composed of, it does not *decide* to do so. Notably, these are considered to be living systems in that they are self-organizing and self-maintaining.

- **Animate**

  According to the authors, to be an animate system requires more than merely being a living biological organism. Animate systems must make choices regarding their responses to the world around them. Plants, for instance, do not make conscious choices; rather their behavior is a deterministic reaction to changing conditions in their environment. Ackoff and Gharajedaghi posit that, "reactions are determined; responses involve choice" (Ackoff & Gharajedaghi, 2003, p. 4).

  As examples, Ackoff and Gharajedaghi direct attention to the organs of the human body. Each organ has a function, and the function is necessary for the continuation of human life. However, the organs do not elect whether or not they will perform this function – it is not their choice. Therefore, the organs themselves are not animate systems, although they are components of a system that is animate.

- **Social**

  Social systems are composed of animate systems. They are differentiated from ecological systems in that they display collective choice. This is illustrated in the decisions made by organizations, corporations, governments, and other social systems. Further, social systems are typically members of other social systems that are constituted of still other social systems, in a distributed hierarchy.

In addition to identifying these four categories of systems, the authors also asserted that many of the issues that arise in addressing systemic problems are the result of an inconsistency between the model that is being used to address the problem and the type of system that is being treated. Their work, *Reflections on Systems and Their Models* (1996), took special care in demonstrating the ineffectiveness of such approaches in effecting meaningful change.

2.4.5. An Evaluation of Ackoff - Gharajedaghi Using the Research Criteria

While having a definite ***basis in systems theory*** and a well-defined ***structure***, the categorizations developed by Ackoff and Gharajedaghi were not developed with the intent of discerning systems. On the contrary, these categorizations were developed with the objective of aligning diagnostic solutions with the nature of the system being treated. Further, in his examination of the work, Eriksson (2004) asserts that in addition to meta-modeling *(modeling system models)*, this approach is also useful for modeling and adapting empirical systems. He uses the model to illustrate an "imperative of goal alignment" (p. 75) within organizations. However, because of the nature of the definitions, transformation of a system, particularly between classifications, is impractical in this model. An example can be devised using an entity from the deterministic class. It is impossible for a deterministic system to decide to become animate because, by definition, it is the lack of purposeful decision making capacity that confines it to the deterministic class.

In examining the design of the classification architecture and how systems are allocated to the various classes, it is clear that the distinctions between the classes are ***rigorously*** defined and that the classification applies to the system as a ***whole.*** Unfortunately, it is within the domain of ***inclusiveness*** that the approach falls short. The individual classifications are too limited in scope to provide meaningful distinction between all of the systems to which it might be applied. While the sub-classes do distinguish between purposeful and unpurposeful entities (Eriksson, 2004), they provide little other distinction.

2.4.6. The Perspective of Dante Martinelli

Martinelli (2001) provides a seven-level hierarchy that describes systems that are driven, primarily, by the diversity of their system interactions. These levels are:

- **Non-Systems**

  These are individuals or aggregations that have random, haphazard interactions. Their relationships are either ill-defined or non-existent, and they function without governing principles.

- **Static**

  Martinelli defines these as immobile systems with static relationships which are perfectly defined by fixed, unchanging rules.

- **Simple Dynamic**

  These differ from static systems only in the degree that they support kinematic interactions which introduce movement into the system. Martinelli likens them to automated procedures for payrolls and invoices.

- **Feedback Dynamic**

  These systems possess the same kinematic interactions characterized in the simple dynamic systems, but also have the capacity to receive, and respond to, rigidly defined feedback.

- **Multilevel**

  The multilevel system is endowed with the concept of hierarchy, allowing a higher degree of complexity in both the structure and interactions. Subordination and command emerge at this level, as well as the capacity for roles and positions among the components.

- **Autopoietic**

  At this level, the system gains the capacity for self-reproduction. Martinelli differentiates these as a) systems that are capable of generating an identical system, and b) systems that are capable of generating a similar, but different, system.

- **Adaptive**

  Here, systems gain the capacity to "record the past in order to choose and organize the current actions of the system" (Martinelli, 2001, p. 78). Martinelli characterizes these systems as being able to alter their own configuration, but unable to alter their identity.

- **Evolutionary**

  The evolutionary system has the capacity to alter its structure and its identity, as well as modifying their environment. Martinelli describes evolutionary systems as continuously assessing, reviewing, and recreating themselves and defining new control rules as necessary.

2.4.7. An Evaluation of Martinelli Using the Research Criteria

Like the structures defined by Boulding, Martinelli's hierarchy provides a linear increase in complexity, in the form of interaction. At each level, the criteria of the lower level are re-integrated and then re-integrated in the proceeding level. While the hierarchy does demonstrate an increase in the complexity of interactions, it provides no meaningful distinctions between the systems that it represents. Further, many of the characteristics involving social interrelations and image sharing that are prominent in Boulding's classifications are lost in the Martinelli structure, making it far less ***inclusive*** in its examination of total systems.

Finally, while the development of the approach in Martinelli's work makes reference to other literature in systems theory, it fails to integrate much of it into the final product. This leaves major gaps in the hierarchy that are not seen in the structures of Boulding.

2.4.8. The Perspective of Management Cybernetics (Stafford Beer)

The Viable Systems Model (VSM) is a topological construct developed by Stafford Beer to describe the various elements within a 'viable' system and how these elements or functions interact with one another and with the larger environment. Much more than a representation of physical entities or activities, the viable systems model concerns itself with the purpose of elements within the system and how they must be employed (or constrained) to ensure both system continuity and mission achievement (Beer, 1984).

The reader would be justified in questioning whether the Viable Systems Model qualifies as a taxonomy or as a mechanism for system classification – particularly when compared to the other approaches discussed in this section. Notably, while the viable system model does not attempt to classify a system based on its external representation, it does provide a mechanism for dissecting a system based on its internal constituents according to their functions, relationships, and objectives, vis-a-vis the system's viability. While it offers a different perspective *(inside-out)* on system examination, the VSM's approach provides meaningful insight into how a system may be classified.

In discussing the Viable Systems Model, Espejo (2003) states that Control and Ashby's Law of Requisite Variety are central components to this models design. In short, requisite variety dictates that in order to control a system and keep it on track, the controller must be able to recognize and respond to every consequential change that emerges from either the system or the environment. As long as the controller has the versatility to adjust the system to correct for changes, everything will continue on course. However, when a condition emerges that is outside of the controller's power to accommodate (when the variety from the system exceeds the variety of the controller), the system becomes uncontrollable and may depart from the intended path (Ashby, 1956).

In addition to illuminating the roles and relationships of elements within a viable system, the VSM also discusses the importance of recursion to a system's resilience. Beer (1984) states plainly that 'every viable system contains and is contained in a viable system.' If this is accepted, then the rules, restrictions, and pathologies that determine the performance of a viable system are applicable at every level, and are not restricted by size, complexity, or longevity. This idea is borne out by the varied applications of the VSM since its original inception in the 1950's (Medina, 2006).

To understand the Viable System Model, an essential first step is to appreciate the five system levels and their relationships to one another, to the organization, and to the environment.

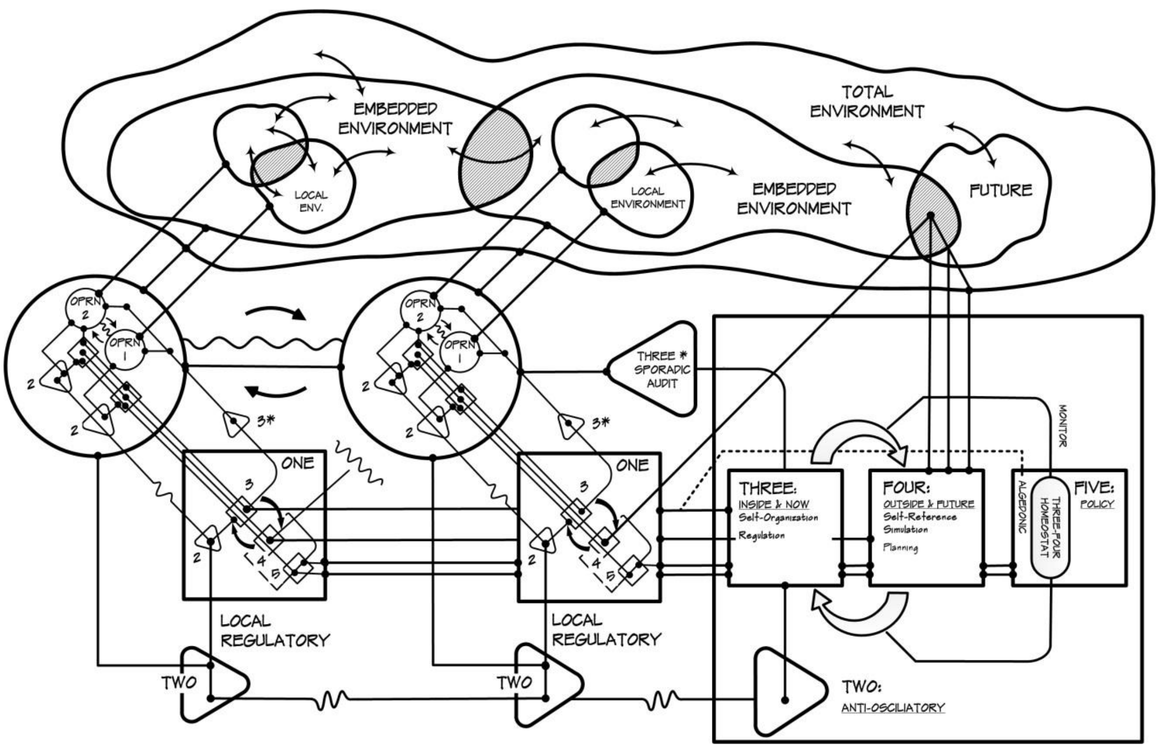

Figure 3. Viable Systems Model – Adapted from Beer (1984)

- **System One – Implementation**

  System one consists of all of the operational entities that perform the mission of the system. In short, without the functions in system one, there would be no reason for the organization to exist. This system level also contains sufficient management to conduct operations under normal conditions. Notably, using the principle of recursion, each one of these operational units also constitutes a viable system in its own right (Beer, 1984).

System one elements receive their resources from the upper level systems and are subject to their intervention when necessary to maintain control. They are accountable to the upper levels and communicate status information on a regular basis. While somewhat isolated from the total environment, the system one entities do communicate with each other and with a local subset of the environment, which Beer (1984) refers to as the embedded environment.

- **System Two – Coordination**

  This system level provides a regulatory system for each system one, as well as an overseeing regulatory system at the highest level (Hilder, 1995). The system two activities are designed to coordinate activities among the various operational activities, effectively reducing or eliminating oscillations that occur when they are in conflict.

  In many ways, system two represents a communication conduit between operating entities. As such, coordination activities at the lower level are often informal and may be able to resolve conflict with little or no intervention from the higher level systems.

- **System Three – Control**

  While there are many forms of control at work within a viable system, Beer (1979, p. 199) refers to system three control as being "inside and now." This is the senior management within the collection of operational units and it is responsible for responding to deviations or aberrations in overall performance. The control systems are also responsible for supervising the coordination activities of system two.

  Beer later expanded the system three responsibilities to include periodic spot checks and audits of the operational units to ensure that actual performance was consistent with the performance that was being reported. These monitoring operations are referred to as system 3* (three-star) (Hilder, 1995). Because of the high level of power that system three has over the lower levels, system three entities must exercise restraint to avoid becoming overly authoritarian. By exerting too much detailed control over system one, system three can damage autonomy and can eliminate emergent improvements in efficiency that result from self-determination.

- **System Four – Intelligence**

  Where system three is responsible for looking *inside and now*, system four must look *outside and ahead*. Highly connected to the total environment, the system four entities watch for changes outside the system, and predict when modifications must be made in order to adapt to the emergent environment.

System four communicates continuously with the system three controls to maintain an understanding of the current configuration of the system. This internal model of the system is essential to determine the system's current state and how it will be impacted by environmental changes.

- **System Five – Policy and Identity**

  In system five, the ethos of the organization emerges. This might be best represented as an institutional identity that governs the decisions and actions made at all of the lower levels. This system level, though, is not only responsible for giving identity to the larger system, but it also serves as the governing system that monitors the balance between system intelligence and system control (systems 4 and 3).

  Finally, when a significant aberration occurs in system one, an algedonic signal is sent directly to system five – which is then responsible for spurring systems three and four to take emergency action to resolve the issue.

2.4.9. An Evaluation of Management Cybernetics Using the Research Criteria

In discussing the use of the Viable Systems Model as a mechanism for managing natural disasters, Anja Reissberg (2012) states that one of the greatest weaknesses of the approach is that it does not provide a prescriptive solution. When applied to a case application, the VSM will explain why things do not work, which she rightly identifies as a "critical but not necessarily constructive outlook" (p. 250).

She furthered argued that the Viable System Model relies on a functional abstraction that basically removes humanness from the equation. The VSM, she claims, requires a "complete real-time information system with free information flow" (Reissberg, 2012, p. 251) and in disaster circumstances, it is entirely unrealistic to expect all participants to be honest at all times. Further, because the VSM is at its heart a metaphor, it does not have the ability to address human behavior, personnel fluctuations, individuals with their own self-interests, and a host of idiosyncrasies that are part of the "human mess" (p. 251).

Ackoff and Gharajedaghi (2003) also discussed the challenges of the Viable Systems Model as being restricted by the fact that Beer "took the requirements for effective individual and organizational behavior to be the same" (p. 6). The authors concluded that this approach resulted in difficulties because it ignored the purposeful nature of the parts of the organism. As a result, organismic models, such as Beer's, could rarely be usefully applied to social systems unless the purpose of the parts was either limited or irrelevant. Therefore, an organismic approach is most likely to be applicable only in social systems that are managed or ruled autocratically.

In considering the Viable Systems Model within the context of the stated research criteria, it is clear that the system provides both ***structure*** and ***rigor*** that dictate how system components are distributed within the framework. Further, it has a strong ***basis in systems theory***.

Unfortunately, as Ulrich (1981) points out in his discussion of Beer's work in Chile, management cybernetics is unlikely to be effective in system-pluralistic environments where the governing entity cannot generate both *intrinsic control* and *intrinsic motivation*. Checkland (1980) reinforces this idea when he says that Beer's approach fails to understand that there is a fundamental difference between an organization and a machine. He identifies a significant weakness in the Viable Systems Model: its inability to comprehend components that "can attribute meaning to their situations" (Checkland, 1980, p. 423) and notes that, to accommodate this, they will have to be regarded as more than mere machines, but as social groupings, appreciative systems, and power struggles. This argues that, while management cybernetics systems may be viewed as ***holistic***, they fall far short of being all ***inclusive***.

Finally, regarding the ability of management cybernetics' to be ***transformative***, there are significant examples in the literature of this approach being effectively used to classify systems for the purpose of transformation. With case studies ranging from information systems development (Kawalek & Wastell, 1999) to waste management (Dodis, Kitis, & Panagiotakopoulos, 2005), the viable system model has been deployed against a vast array of environments with the stated objective of enhancing organizational performance.

2.5. Section Summary and Identification of Gap

The following table is based on the assessment and critique of the various approaches which were conducted in the preceding sections. As is demonstrated, each of the methodologies or structures addresses *some* of the stated evaluation criteria, but no individual solution satisfies them all.

	Structured	Rigorous	Holistic	Inclusive	Transformative	Systems Based
System Dynamics Archetypes	X				X	
Kenneth Boulding Models	X	X	X			X
Ackoff – Gharajedaghi Model	X	X	X			X
Martinelli Model	X		X			
Viable Systems Model	X	X	X		X	X

Table 1. Reviewed Taxonomies Compared to Evaluation Criteria

More telling, however, is the reality that, with the exception of Senge (1990) and Braun (2002), all of these approaches, at some level, view the systemic universe as a hierarchy either of increasing authority or of increasing complexity, which culminates with a system of interest at the highest level. For Boulding, Ackoff, and Gharajedaghi these are *social systems*; for Martinelli, they are *evolutionary systems*; and for Beer, they are *viable systems*. Within the realm of system theory, none of these authors directly discriminate between the characteristics of any of these systems once they have reached their ultimate level – although Senge and Braun struggle to achieve this goal in the domain of systems dynamics.

While the work in management cybernetics does provide powerful tools that may be useful for diagnosing a system, the author of this study leaves it largely in the hands of the practitioners to *work out* the condition of a system under study. This is particularly difficult in systems that do not fit the natural mold of a *viable system,* or are in the *system-pluralistic* environments that were described by Ulrich (1981).

It is these areas in the existing literature that create the gap which this research is designed to close. To achieve this, the resulting product is a well-structured and systems-based architecture of complex system archetypes which are rigorously defined and generally applicable. These archetypes provide a descriptive continuum at the highest level which can be used to distinguish systems based on key characteristics. Further, the archetypes provide a mechanism for guiding the transformation of a system under study.

3. RESEARCH METHODOLOGY

3.1. Introduction and Rationale

Selection of the research methodology is driven by the first research question, specifically, what system-based framework can be developed to identify complex system archetypes? At its core this questions requires *theory building* and therefore is best served by an inductive approach. Because of this, this research explores the subject area using grounded theory techniques.

According to Scott (2009, p. 1), "Grounded Theory is a research method that will enable you to develop a theory which offers an explanation about the main concern of the population of your substantive area and how that concern is resolved or processed." While Scott's statement is both broad and sweeping, Glaser (2007), in his critique of grounded theory versus qualitative research, is more specific in describing the approaches that are used. He prescribes a general process for conducting grounded research that consists of a sequence of operations including data collection, open coding, selective coding, analysis, and finally, theory creation. While the application of classical grounded theory for this research may not be a perfect match, the methodology has sufficient flexibility to engage the subject area fully. Some areas of general concern are discussed below.

First, it is recognized that the selection of this approach requires a significant departure from the data sources that are traditionally used for grounded research: specifically, firsthand accounts and interviews. Instead, this study leans heavily on Glaser's (2007, p. 1) assertion that "All is data", and that data sources need not be limited to individual correspondence, but may be expanded to include the entire realm of literature. Of course, this does represent a challenge because, as Glaser (2007) has stated, an early literature review is anathema to performing good grounded theory. This opinion is derived from an expectation that the researcher is likely to prejudice the literature review by exploring material that is limited to what he or she expects to be appropriate to the substantive area rather than by allowing theory to emerge from the data itself. While Glaser emphasizes that "the pre study literature review of Qualitative Data Analysis is a waste of time and a derailing of relevance for the Grounded Theory Study" (Glaser, 2007, p. 58), he does allow that the methodology can be successful if it "treats the literature as another source of data to be integrated into the constant comparative analysis process once the core category, its properties and related categories have emerged and the basic conceptual development is well underway” (Glaser, 2007, p. 58).

This raises the question of whether using grounded theory to address the research questions is even possible after a significant literature review has already been conducted. The literature review conducted here can be justified as follows:

First, the material that was examined within this literature review was largely associated with existing attempts to classify systems and develop system hierarchies. The review considers early attempts and discusses their strengths and weaknesses. However, the data and literature that are used to drive the research are actually from the vast expanses of system theory that were not touched upon in the literature review.

The total body of knowledge that represents system theory is constantly expanding and is addressed by an ever-increasing number of research areas. In discussing the data that was used for this research, the author refers to the catalog originally developed by Adams et al. (2014) whose structure is illustrated in figure 4.

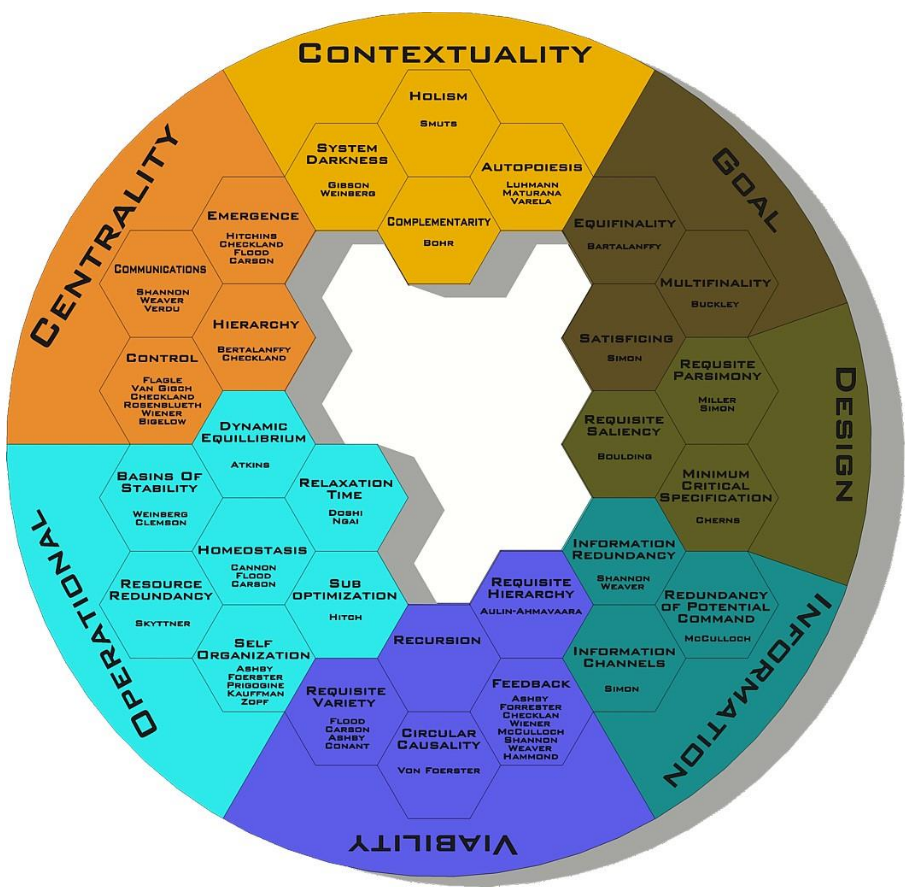

Figure 4. A Model of the Adams Catalog of Systems Theory

3.1.1. The Adams Catalog of Systems Theory

In their approach, Adams et al. (2014) defined seven axiomatic areas which were used to collect and categorize the various disciplines within systems research. While their catalog is not all-encompassing, it provided a comprehensive starting point for identifying the literature that was used as data. Notably, in the exploration of the literature, many more data sources emerged from the underlying references.

A brief description of each of the axiomatic areas and the parts that comprise it is provided below:

- **The Centrality Axiom**

  The initial definition of a system focuses on the elements of system hierarchy, communications, and control. While emergence is a key component of centrality, its presence is assumed and therefore is not evaluated independently.

  This axiom is not only used to refine the system boundaries, but also provides the basis for key diagnostic rules. Inappropriate or inefficient system hierarchies can lead to identifiable pathologies. Further, failures to control, improper control, and poor communication are often at the root of system problems.

- **The Contextual Axiom**

  In exploring the system, this axiom provides particular limitations on what one can know through observation. In particular, the principle of holism (Smuts, 1926) dictates that the system is more than a collection of entities – that they must be properly arranged and related in order to constitute a system. As a result, one cannot necessarily understand the purpose of the system by merely knowing what parts constitute it. The axiom also reinforces the idea that one's view of the system is always contingent on the perspective of the observer. In most cases, there is no single vantage point that can provide a comprehensive understanding. Finally, this axiom dictates that there is always darkness within a system and that no system can be fully known through observation (Gibson, 1964).

- **The Goal Axiom**

  Systems, by definition, engage in purposeful behavior to achieve specific goals (Adams, Hester, Bradley, Meyers, & Keating, 2014). Examining the system under study within the context of this axiom allows the observer to determine the level at which the system's outcome is governed by both initial conditions and changes in process. This axiom also considers the process by which the system determines when it has satisfactorily achieved its objective. In effect, does the system seek an optimal result, or does it *satisfice* by accepting the first solution that satisfies its fundamental requirements (Simon, Rational choice and the structure of the environment, 1956)?

- **The Operational Axiom**

  This axiom dictates that in order to obtain a realistic understanding of a system, one must observe it in its indigenous environment, where it is engaged in purposeful behavior (Rosenblueth & Wiener, 1950). This is essential because the emergent characteristics of a system's behavior are frequently a response to environmental factors and changes. The state of the environment, the availability of resources, and the presence or frequency of perturbations are all key factors in the system's ability to achieve stability. If an open system is removed from its natural environment, its observed behavior should be expected to quickly diverge.

- **The Viability Axiom**

  This axiom dictates that the viability of a system is a direct result of tensions that exist between stability versus adaptation and between individual autonomy versus systems integration. In short, the viability axiom dictates that a systems success is determined by whether its sub-system's control, autonomy, and adaptability are appropriately balanced to address its environment (Beer, 1979) (Beer, 1981).

- **The Design Axiom**

  The idea behind this axiom is that the design of the system must be as purposeful as its behavior. That is to say that it must be designed to balance and allocate resources in a manner that is consistent with effectively achieving its goals. The axiom also dictates that the system design must take into account the limitations that are intrinsic to its constituents. The description of such limitations is particularly focused on human capability.

  In examining these design factors, Adams et al. (2014) detail the concerns involved with both requisite parsimony and requisite saliency. In discussing requisite parsimony, the work of George Miller (1956) is essential. His experimentation demonstrates that human beings can only deal with between five and nine observations simultaneously.

This limitation immediately contributes to the concern of requisite saliency. This concept states that the factors observed during the design or exploration of a system are rarely of equal value and that the ordering of these factors is dependent on a deeper examination of the system and its conditions (Boulding, 1966).

A final key element that is drawn from the design axiom is the concept of minimal critical specification. This principle states that when the system is designed, only the essential requirements should be dictated to the sub-systems that will perform the functions. These sub-systems should have the autonomy to alter the way they achieve these goals, allowing them to integrate their understanding of current operating conditions as well as their past experience in order to improve performance (Cherns, 1976).

- **The Information Axiom**

  Information is the final axiom that is addressed. This concept is tightly coupled to the viable systems model (Beer, 1979) and is concerned with the number and type of communications channels that exist within an organization. These channels (used for command, coordination, alerts, and more) must be appropriately balanced within each level of the viable system to ensure efficient operation.

  Much of the design associated with this axiom is to ensure thrift. A system that provides too many commands from too high a level is likely to sacrifice the autonomy that is essential for improved performance. Similarly, too much information being transmitted from the operational level to the coordination level is likely to mask critical warning signals.

Starting with this outline of the data that informs the research, this study employs the grounded theory methodology to derive a new theory of complex systems archetypes by evaluating the existing literature. The following sections discuss the specific approaches that were used, and describe how the validity and reliability of the research was maintained.

3.2. Research Validity and Reliability

In her treatise on Rigor in Grounded Theory Research, Susan Gasson (2003) discussed various approaches that can be employed to evaluate the validity and reliability of grounded research. She addresses these issues from both a positivist and an interpretive worldview, to describe various approaches that may be employed.

3.2.1. Objectivity vs. Confirmability

Silverman (1993) asserts that the development of grounded theory cannot be totally objective because of the nature and experiences that the researcher brings to the exploration. Specifically, he says

> *"We come to look at things in certain ways because we have adopted, either tacitly or explicitly, certain ways of seeing. This means that, in observational research, data-collection, hypothesis-construction and theory-building are not three separate things but are interwoven with each other" (p. 46).*

This suggests that raw objectivity, where the findings are free from researcher bias (Gasson, 2003) may not be an achievable. Confirmability, however, may be a different story.

Confirmability can be achieved in part by using constant comparison to parse, segregate, and distribute observations into categories. The reasoning or justification for each grouping decision is maintained in memos that provide a roadmap for others to evaluate the decision making rationale. Gasson (2003) also describes reflexivity as a method for minimizing researcher bias. Specifically, she asserts that the researcher must demonstrate self-awareness in the evaluation of the data and, for each piece of data, must identify and document where the concept came from: the literature, one's experience, or the analyzed data.

To address the issues of confirmability, this research fully documents each element of data retrieved from the literature and from the study environment. Coding decisions resulting from constant comparison were evaluated reflexively to illustrate if the sorting decisions were driven by literature, experience, the data, or a combination of the three.

3.2.2. Reliability vs. Dependability

Gasson (2003, p. 90) differentiates between reliability and dependability by saying that reliability dictates that "the study findings can be replicated, independently of context, time or researcher," while dependability is more interpretive and only requires that "the study process is consistent and reasonably stable over time and between researchers."

In the conduct of this research, the concept of dependability is pursued throughout. Whenever possible, though, the positivist approach to reliability was also striven for, particularly in documenting the reasoning behind relationships between elements of the literature and between observations and the theoretical framework.

3.2.3. Validity vs. Consistency

Another differentiation that Gasson (2003) draws is between validity and consistency. In the pursuit of validity, the researcher must identify statistically-significant relationships that demonstrate the association between various observations. Such linkages may either be direct or be the result of triangulation. Alternately, consistency is achieved by ensuring that all of the parts of the theory fit with each other and appear to explain the data (Strauss & Corbin, 1998).

At its heart, the research requires consistency – without it, the study cannot stand against itself. Just as importantly, though, the research must strive for validity in terms of justifying – as much as possible – the causal relationships between the elements of systems theory and the emergent complex system archetypes. Without this, the resulting product will be lacking in both generalizability and applicability.

3.3. Research Design

Scott (2009) provides a framework for employing grounded theory in research. The methodology she describes has been extended to make it applicable to this research. The methodological approach is described below.

3.3.1. Identify the substantive area

The substantive area of this study is the development of a collection of complex system archetypes that are well structured and governed by a set of rules that rigorously dictate how systems are distributed into the categories. Each archetype is representative of the complete system, and the collection of archetypes is broad enough to represent any system. Finally, the resulting product has a solid basis in the literature of systems theory and is designed with the objective of supporting the transformation of a system, based on the objectives of its governing body.

3.3.2. Collection of data pertaining to the substantive area

The data used for this study is drawn from literature in the field of system theory as described in the introduction to this chapter. The initial collection of data follows the catalog that was established by Adams et al. (2014), and all of the sources that are referenced therein. The pursuit of relevant literature was then expanded to collect additional literature that was referenced in the preceding works or whose relationship was established in ancillary research.

Because of the breadth and depth of literature within the domain of systems theory, the criterion for inclusion or exclusion of literature was a particular challenge. In identifying the initial block of literature to be explored, the material referenced within Adams et al. (2014) provided a strong starting point. However, as the principles of systems theory were examined and their origins and lineage were traced, it became apparent that the progenitors of these ideas were represented in many different disciplines - from anthropology to botany, and from psychology to all the branches of engineering. Here it became necessary to reach across the disciplinary boundaries and delve into other domains in an attempt to understand the underlying motivations that contributed to the systems theory that we have today.

Of course, if any chain of ideas is followed far enough, eventually it will expand into a massive, interconnected web that exceeds our ability to fully appreciate it. More importantly, though, when the web of connections spans too far, it no longer contributes to the search for system archetypes. Such a condition would go far beyond the necessary state of saturation for performing this research.

The search for saturation in this research is demonstrated by the concept models provided in Appendix A. In developing these models, the exploration of the literature began with an effort to identify each of the major contributors who wrote on a systems principle. As these individuals discussed each principle, they provided their own citations and links to other systems concepts and established a relationship with other authors. This related literature became a first-order contributor to the study and garnered a place in the annals of included data.

Moving onward, in many cases, the referenced source may describe non-system concepts that were major contributors to understanding how or why the system principle was developed. These concepts are essential because they establish the context that motivated the initial development of the principle and they help provide meaning to the author's interpretation of them. Further, if enough relationships exist between the catalog of principles provided by Adams et al. (2014) and an existing external principle, then that principle might eventually garner inclusion. This external, related literature can be considered a second-order contributor to the data used in this study.

From this secondary literature, the number and types of relationships and their disciplines undergo a geometric expansion that defies cataloging and documenting. Where each of the primary principles may have been derived from concepts outside of systems theory, the contributing concepts were a product of yet other ideas that spanned all disciplines of human endeavor. It is here that the most judicious pruning of the tree of knowledge was required. Therefore, the literary paths that extended away from systems theory were rarely followed unless there was clear justification. This is illustrated in the examination of Circular Causality, which is provided in Appendix A and briefly discussed below.

In exploring the principle of Circular Causality, Forrester's (1961; 1969; 1971) System Dynamics is a primary connection which is linked to Causal Loop Diagrams (Meadows, 1972) as a second-order connection. In addition to being a major contributor to Peter Senge's (1990) system archetypes, Causal Loop Diagrams also yield a relationship to Path Analysis (Wright, 1921), which is a progenitor of the Program Evaluation and Review Technique (Fazar, 1959) and the Critical Path Method (Kelley & Walker, 1959). By allowing inclusion of literature at this granularity, the study is able to provide a richer context for appreciating the meaning and parentage of systems ideas without creating a dataset that is unwieldy.

The need to identify connections and relationships between system characteristics is essential in the development of this framework. These primary and secondary relationships create a context that allows the interplay between system principles to be revealed. Taken individually, the collection of system principles exist in a largely disconnected web where only their nearest neighbors can be observed and considered. As these webs are linked, shared concepts emerge that help to reduce the collection of budding system archetypes from one that is impossibly large to one that is meaningful, manageable and comprehensible. Accordingly, from this approach to literature and data, a few meaningful archetypes are drawn from the many, many contributing principles.

3.3.3. Visual Coding

Using a hybrid of Object Modeling Technique (Rumbaugh, Blaha, Premerlani, Eddy, & Lorensen, 1991), the Unified Modeling Language (Rumbaugh, Jacobson, & Booch, 1999), and a collection of new symbolic relationships specific to literature analysis, the author developed a collection of models that describe the various concepts within systems theory. This modeling approach was continuous and was performed throughout the open-coding, selective coding, and theoretical sampling processes. The objective of the modeling process was not only to document the relationships that are immediately observable, but also to reveal new relationships as they emerge. Figure 5 shows a sample of the visual-coding technique as applied to the concept of *holism*.

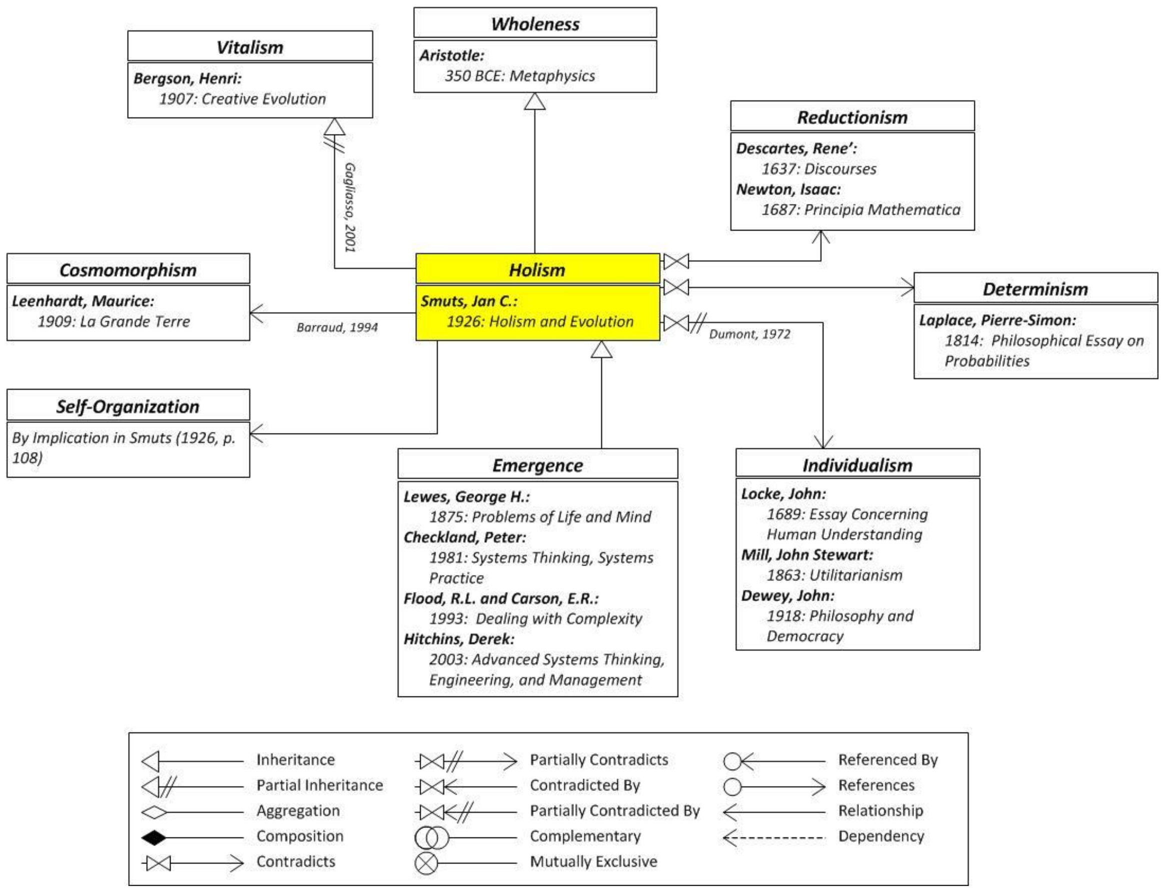

Figure 5. *A visual-coding model of holism in relation to system literature*

Here, the principle of holism (Smuts, 1926) is related through inheritance to Aristotle's writings on *wholeness* (350 B.C.E) as well as to the principles of *vitalism* espoused by Bergson in Creative Evolution (1907). Contradictions with the concepts of *reductionism*, *determinism,* and *individualism* are specifically identified along with holism's cooperative relationships with both emergence and self-organization. A relationship with *cosmomorphism*, developed by Maurice Leenhardt (1909), is also shown.

The reader should note that referential data is sometimes included on the connecting lines. This is done when the relationship or the contradiction is not explicitly declared in the source literature, but is instead identified by a third party. An example of this is the relationship between *holism* and *cosmomorphism,* which is not discussed by either Leenhardt or Smuts, but is identified explicitly in the later works of Gagliosso (2001).

This visual-coding approach has proven to be of great benefit in both documenting and demonstrating the relationships that emerged during the grounded theory research. Further, the author believes that these models will benefit other researchers who examine this material in the future.

3.3.4. Open Coding

The open coding process can be described as an effort to identify, name and categorize the phenomena that occur in the data (or literature) as it is being introduced into the study. As one might imagine, this process begins even as the data collection process is being undertaken. In an effort that has been described as *constant comparison*, every element of data is compared against every other element in order to discern the relationships and linkages that exist. Through the process of memoing, all of these emerging relationships and characteristics were recorded in a database (provided in Appendix A) that identifies the data sources and the nature of the entry.

Glaser (1998) advises that, for each piece of data, the researcher should ask questions like, 'What category does this incident indicate?', 'What is actually happening in the data?', and 'How does this relate to the main concern?' This process of questioning and verification allows each data point to be placed in a category, and ensures that the emerging theory remains relevant to the research question. This ongoing process allows the researcher to see the direction that the data is taking before becoming too focused on selective coding.

For the purpose of this research, the questions driving the research included the following. *Note that this is not an exhaustive list of questions and that the term 'characteristic' is used to represent any data point being evaluated in the open coding process.*

- **Is the characteristic a property of all systems?**

  This question is designed to identify the characteristics that relate to the nature of systems and to what the fundamental requirements are, for something to be considered a system. Characteristics that are in this category are likely to float above the archetypes and provide a framework that supports their unique properties.

- **Can the characteristic vary in state or condition? If so, how?**

  The objective of this question is to identify the different *states* that a characteristic may have. By knowing these states, the researcher can assess if a change in the state of the characteristic can cause a transformation of the entire system or a transition of one or more of its sub-components or relationships.

- **Is the characteristic transformative?**

  For the purpose of this research, a transformative characteristic is one that, when modified, changes a fundamental property that constitutes the identity of the system. When these characteristics change, the nature of the system changes with them.

- **Is the characteristic transitional?**

  Transitional characteristics differ from transformative ones in that, when they change, it does not alter the fundamental nature of the system, but rather its behavior, constituents, or relationships.

- **Do dependencies exist between this and other characteristics?**

  The presence of dependencies among the system characteristics are expected to be a critical element in the development of archetypes. Such dependencies tend to suggest a hierarchy among the characteristics and may also suggest arrangements of properties that are mutually inclusive or mutually exclusive in nature.

- **Does the characteristic contradict others that have already been collected?**

  The principles of system theory are conceived such that any proposition should be supported in either existing theory or empirical observation. It is possible, even likely, that a characteristic emerging from the data may contradict other information that has been collected. When this occurs, the conflict must be identified, so that a resolution process can be considered.

- **How are contradictions between characteristics resolved?**

  - **Through segregation?**

    When contradicting characteristics emerge, it is possible that the conflict may be resolved by segregating the characteristics across multiple archetypes or domains.

- **Through elimination?**
  Under examination, one of the characteristics may not be viable, and the contradiction can be eliminated by removing it from consideration.

- **Through mitigation?**
  In examining the characteristics, it may be possible to identify conditions that drive the contradiction. If these conditions can be eliminated or discounted, then the contradiction will not occur.

  Note that removing possible conditions from the domain of the research may create limitations in applicability that reduce the inclusiveness of the resulting methodology.

- **Through acceptance?**
  In some cases, it may be appropriate to accept the contradiction, particularly if the impact is minimal. However, this is not recommended, because allowing a contradiction to permeate the research results in an indefensible flaw in the resulting methodology.

It is important to note that the objective of the open coding process is to identify the 'core categories.' These are a subset of categories that, through data saturation, have distinguished themselves from the others (Phondej, Kittisarn, & Neck, 2011). Holton says that a core category should have the following characteristics: "it is central, it relates to as many other categories and their properties as possible, and it accounts for a large portion of the variation in a pattern of behavior" (Holton, 2007, p. 280).

The core categories within this study are those that are documented in Appendix A. These are the system principles that were either part of the catalog of Adams et al. (2014) or those external principles that were promoted because of the significant number of relationships that they shared with the existing principles.

3.3.5. Memoing

Concurrent with data collection and coding is the process of writing memos. Memos are descriptive texts that detail the emergent relationships within the data (Strauss & Corbin, 1998). Not limited to just describing data, the memos also include the decision points that have guided the exploration in new directions. These memos serve as the foundation for the development of the grounded theory that will result from the research.

The work product that is generated by the data collection, open coding, and memoing process is a database of principles, relationships, and memos that are directly linked to the systems theory literature. Additionally, the process generates the core categories that are passed on to the selective coding and theoretical sampling process.

3.3.6. Selective coding and theoretical sampling

According to Holton (2007), the process of selective coding is one of delimitation. Here, delimitation refers to an effort to direct further data collection toward only the data that is relevant to the emergent core categories. The selective coding process governs further exploration into public, private, and online records and continues until the core categories are saturated and firm, documented relationships between the data have been established. Glaser (1998) calls this point *theoretical saturation*. He describes this as the point in the process of constant comparison when no new properties or dimensions are emerging from the data.

As before, the results of the selective coding process are integrated into the visual coding database that is provided in Appendix A.

3.3.7. Development of theoretical codes and integration

At this point, the selective coding process should have led to the emergence of theoretical codes which represent the emergent theory of the study. For the purpose of this study, these are the complex system archetypes.

The pursuit of these archetypes was undertaken with an objective of inclusiveness, wherein any and all systems must be represented by one or more of the archetypes. Still, the research was driven by a respect for requisite saliency (Miller G. , 1956) and was moved forward with a goal of developing a manageable and comprehensible collection of archetypes. In the end, both of these goals were achieved, as the study generated a set of six archetypes that were sufficiently generalized to be applicable to all complex systems.

3.3.8. Case study

As a final step in the research, the theory will be deployed in a field setting. As discussed by Yin (2014) and Phondej et al. (2011) , the following process will be employed:

- **Theory Development**

  The development of the theory for this case study is represented in the grounded theory research that is being used to develop the system archetypes and in the methodology for analyzing systems for distribution into the resultant catalog of archetypes.

- **Case Selection**

  The criteria for case selection were aimed at examining a functional area of a large to mid-sized organization. To provide breadth, an organizational division that consisted of multiple departments having a relatively diverse mission was desirable. This had the benefit of allowing each of the subordinate divisions to be independently allocated into the catalog of archetypes using innate or behavioral characteristics. To satisfy this objective, a facilities management department within a large industrial facility was selected as the subject of the study.

- **Data Collection**

  Data was collected from multiple, objective sources including organizational charts, mission statements, annual budgets, financial reports, project plans, and labor distributions. In order to maintain the confidentiality of the study organization, the original data is not provided within the case study. Still, all of the data pertinent to understanding how the systems were assessed is summarized in the report.

- **Case Analysis**

  The case analysis applied the discriminating characteristics that are discussed in the findings to distribute the department's workgroups into their archetypical categories. For each workgroup, a discussion and justification is provided to illustrate how and why the decision was made.

- **Conclusion**

  In the conclusion of the case study, the fit of the various elements to their archetype is assessed. In particular, because the design of the methodology is driven by a desire for *transformativeness*, the nature of the archetype where each entity is placed should suggest transformations that could be made at a systemic level to alter its position in the continuum of archetypes. The possibility and potential value of making these transitions is also discussed.

3.3.9. Research Process Model

A model that details the various elements of the research design is included in figure 6.

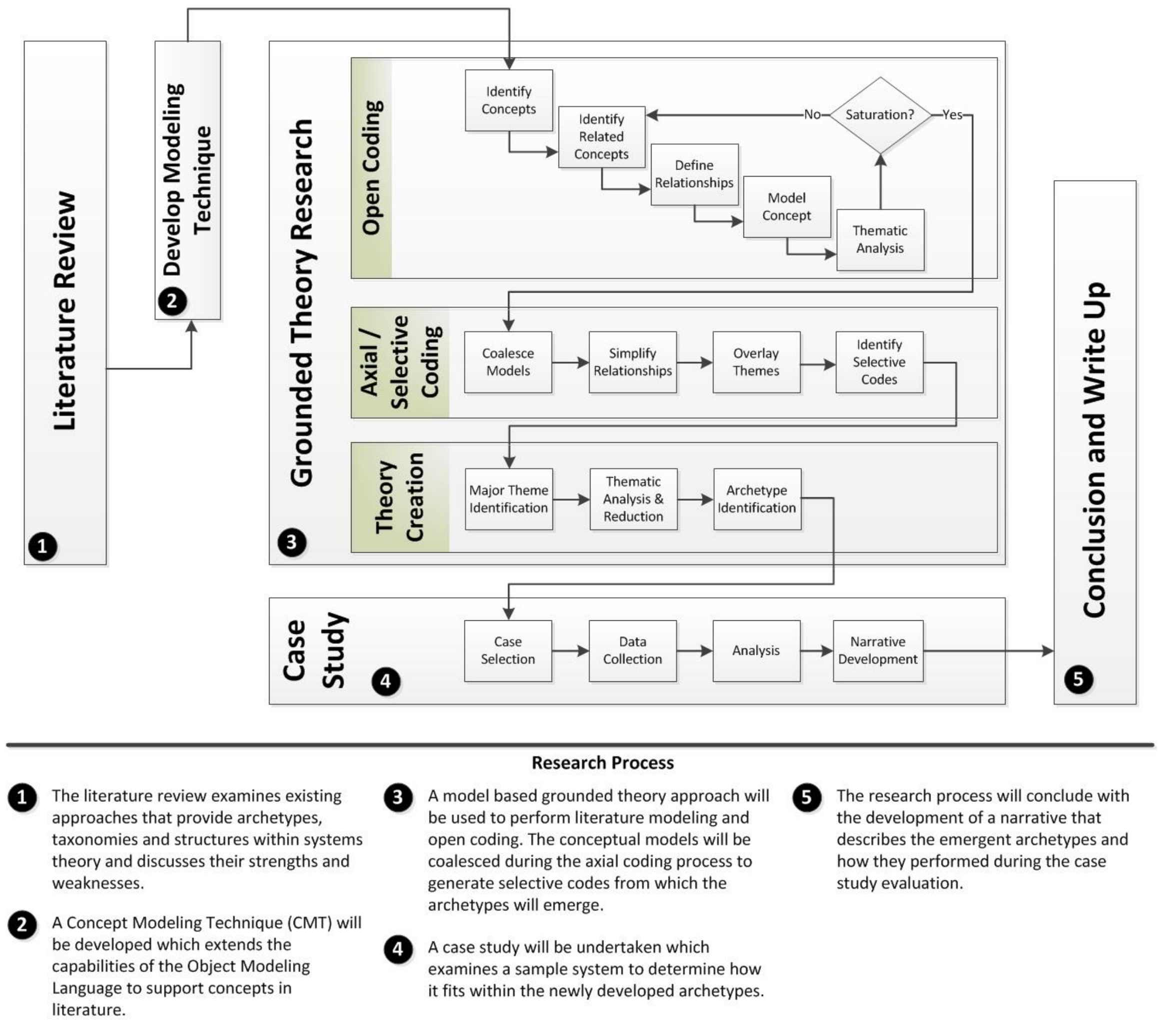

Figure 6. A Model of the Research Process

3.3.10. Summary

While the research approach in this study follows the well-worn path of grounded theory and case study, it does introduce some novel ideas. Using systems literature as data, this study explores the origination, meaning, and relationships that contribute to each of the system principles and uses that data to create a collection of visual coding models. These models provide a visual perspective, allowing the reader to examine the collected literature from a high level while still seeing the relationships and connections which bind them together. As these models are developed, published, and exchanged, they have the potential to generate impacts far beyond this research. If used and extended by other researchers, they can form the basis for creating a shared view of the ideas that comprise this and other disciplines.

For this research, however, the visual coding approach contributes to the development of a grounded theory. The grounded theory developed here follows the relationships and interactions that exist within system theory to develop a collection of system archetypes. These archetypes are devised to be comprehensive and applicable to any system, justified through their relationship to the systems literature, and compact enough to satisfy the requirements of requisite saliency.

The research ends with the application of the newly developed archetypes against a sample case. This examination is not undertaken to prove or disprove the validity of the archetypes, as such validity should be established by their relationship to accepted literature. Rather, the purpose of the case study is to demonstrate that the archetypes can be intelligently applied to a real world system and that their application provides some insight into how that system behaves. In order to achieve that goal, a multi-function facilities management department in a large industrial organization was selected for the study. The case study will dissect the department, distribute its various working groups into their appropriate archetypical categories and, finally, discuss the relationships and interactions that are implicit with those archetypical relationships.

4. RESEARCH FINDINGS

4.1. Introduction

This chapter begins with a discussion of the data that was collected as part of the grounded theory research and a discussion of how it was used to explore the nature of system archetypes. The collected table of models and memos provided in Appendix A will be discussed, along with the reasoning that was used to assign relative significance to each of the underlying principles. Principles that were escalated in importance, specifically those not contained in the catalog of Adams et al. (2014), will be defined, and their significance will be documented.

Using this collection of key principles, the research will then proceed to group each one into a classification that best describes its nature and its relationship to systems theory. Following a brief quantitative discussion of the number and types of *connections* that exist between the principles, a table of key principles and definitions that are at the heart of the system archetypes will be provided. This data will provide a foundation for the development of the archetypes.

The study will continue by using these principles and definitions to describe a system environment. While abstract and somewhat theoretical, this system environment will contain the fundamental characteristics that motivate the archetypical systems and result in their unique behaviors. From the context of this environment, each of the system archetypes will be identified and its contextual behavior will be described.

Finally, the study will examine the collected archetypes as a continuous, related, and ordered group of entities. Their relationship to each other in terms of energy, entropy, and their internal and external impacts will be discussed. From this discussion, a continuum of system archetypes will be provided which will address the demands and constraints of the system environment in which they exist.

4.2. Analysis of the Model Based Grounded Theory Data

The exploration and modeling of systems theory principles was rooted in the catalog of systems principles created by Adams et al. (2014). Using a model-based grounded theory approach, these principles were explored in the literature. The theories that contributed to their development were identified, along with the scholars who espoused or supported these ideas. Similarly, other theories and concepts that were outgrowths or descendants of the established system principles were integrated into each of the models.

Although the Adams catalog provided a broad cross section of the field, there were cases where other, non-included principles made a significant contribution as either a predecessor or a descendent. When one of these non-included principles achieved a threshold of significance, defined as having had a contributing relationship to four or more of the principles identified by Adams et al. (2014)), they were considered to be independently significant. Such new principles were then subject to the same model-based exploration as the original catalog entries.

For each of these system principles, models were developed that were directly related to referenced citations in the systems literature. Appendix A of this dissertation contains the complete catalog of models, along with the collected references and quotations from the literature that establish their relationships. In the interest of brevity, this section will not repeat the information included in the appendix. Instead, Table 1 provides a synopsis of the data by categorizing each principle into one of five types, providing the principle's definition and listing the other key system principles to which it is related. Emergent principles that were not included (or were implicit) in the original catalog are marked with an asterisk.

The principles are distinguished into the following categories.

Functional Characteristics: These are principles that address a fundamental and innate behavior of a system.

Mechanisms: These are principles that identify a tool or capability that a system uses to perform a function.

States: These are principles related to the end-state that a system achieves or pursues within its environment.

Conditions: These are principles related to environmental or contextual conditions that have an effect on the system.

Rules/Limitations: These are principles that describe the rules that govern system behavior or limitations to a systems capacity.

While, in some cases, these categories may not represent a perfect match for a principle, an expanded list of types has been avoided in order to maintain a reasonably compact set.

Notes are provided in the table when a principle's assignment to a category requires additional justification.

As touched upon earlier, in Table 2 a list of primary connections is included for each principle. These primary connections are explicit principles (those defined in Adams et al., 2014) and implicit principles (related principles that were recurrent during the examination of the literature). For the purpose of this table, a *primary connection* is a documented, cited relationship that exists between the principle being examined and any other principle of systems theory, either explicit or implicit. These connections are documented in Appendix A as part of the visual coding models.

Table 2. Interrelationships Between Core Principles

Self-Organization		*11 Primary Connections*
Type:	Functional Characteristic	Adaptation
Definition:	The process by which a system moves beyond self-regulation, to alter its internal structure to increase its level of adaptability (Leonard, 1990)	Autopoiesis Basins of Stability Circular Causality Emergence Holism Minimal Critical Specification Redundancy of Potential Command Requisite Hierarchy Requisite Variety Viability
Homeostasis		*10 Primary Connections*
Type:	Functional Characteristic	Adaptation
Definition:	A coordinated system of physiological reactions that maintain the steady-state of key variables within the system (Cannon, 1929)	Dynamic Equilibrium Equifinality Feedback Heterostasis Homeorhesis Negative Entropy Negative Feedback Self-Regulation Stability

Table 2 (Cont'd): Interrelationships Between Core Principles

Stability *		*10 Primary Connections*
Type:	State	Adaptation Autopoiesis Basins of Stability Dynamic Equilibrium Equifinality Feedback Homeostasis Instability Negative Feedback Viability
Definition:	The tendency of a system to return to equilibrium (or for its amplitude of motion to decrease) following a disturbance or perturbation (Hurt, 1965)	
Note:	*Stability is considered a state because it is not a function of the system, but rather an interaction between the system, and its environment that causes the system to reach a specific condition or endpoint.*	
Feedback		*9 Primary Connections*
Type:	Mechanism	Circular Causality Communications Control Homeostasis Information Channels Negative Entropy Negative Feedback Positive Feedback Stability
Definition:	A control mechanism that detects the system state using a receptor and then transmits signals to an effector to facilitate changes based on the new conditions (Von Bertalanffy, 1968)	
Self-Regulation *		*8 Primary Connections*
Type:	Functional Characteristic	Holism Homeorhesis Homeostasis Negative Feedback Redundancy of Potential Command Requisite Hierarchy Requisite Variety Viability
Definition:	The ability of living beings (or systems) to maintain their own stability in the face of the colossal, often adverse, forces which surround them (Cannon, 1929)	
Adaptation *		*7 Primary Connections*
Type:	Functional Characteristic	Dynamic Equilibrium Homeostasis Minimal Critical Specification Positive Feedback Self-Organization Stability Viability
Definition:	Modification of an organism or its parts that makes it more fit for existence under the conditions of its environment (Merriam Webster)	

Table 2 (Cont'd): Interrelationships Between Core Principles

Control		*6 Primary Connections*
Type:	Mechanism	Communications Emergence Feedback Instability Negative Entropy Requisite Variety
Definition:	The mechanisms that are used to move a system between two equilibrium states or into a non-equilibrium state (Benson, 2002)	
Dynamic Equilibrium		*6 Primary Connections*
Type:	Functional Characteristic:	Adaptation Heterostasis Hierarchy Homeorhesis Homeostasis Stability
Definition:	The maintenance of stability in a complex system by altering its internal equilibrium points in response to internally or externally generated disturbances (Skyttner, 1996)	
Hierarchy		*6 Primary Connections*
Type:	Mechanism	Dynamic Equilibrium Emergence Heterostasis Holism Recursion Requisite Hierarchy
Definition:	A system that is composed of interrelated subsystems which are, in turn, hierarchic structures continuing downward until a lowest level of elementary subsystem is reached (Simon, 1962)	
Note:	*While hierarchy might be considered a structural characteristic of a system, it is also a mechanism by which control and communication are deployed throughout the system.*	
Circular Causality		*5 Primary Connections*
Type:	Condition	Autopoiesis Emergence Feedback Recursion Self-Organization
Definition:	The presence of causal loops that perpetually create emergence within a system through their simultaneous top-down and bottom-up interactions (Witherington, 2011)	
Communications		*5 Primary Connections*
Type:	Mechanism	Control Feedback Information Channels Negative Entropy Recursion
Definition:	The process by which information is exchanged between individuals through a common system of symbols, signs, or behavior (Merriam Webster)	

Table 2 (Cont'd): Interrelationships Between Core Principles		
Emergence		*5 Primary Connections*
Type:	Condition	Circular Causality Control Hierarchy Holism Self-Organization
Definition:	Qualities or characteristics that arise in the higher levels of a system that are dependent upon, but not present in, the lower levels (Alexander, 1922)	
Equifinality		*5 Primary Connections*
Type:	State	Homeorhesis Homeostasis Multifinality Negative Feedback Stability
Definition:	The ability of an open system to reach the same final state from different initial conditions and in different ways (Von Bertalanffy, 1968)	
Note:	*While equifinality might also be considered a condition-based process, it is included here because its primary focus is on the final state of the system.*	
Heterostasis *		*5 Primary Connections*
Type:	Functional Characteristic	Dynamic Equilibrium Hierarchy Homeostasis Multifinality Satisficing
Definition:	The process by which a system maintains the steady-state of a homeostatic variable by altering or adjusting another, heterostatic variable (Davis, 1958)	
Information Channels		*5 Primary Connections*
Type:	Mechanism	Communications Feedback Information Redundancy Redundancy of Potential Command Viable Systems Model
Definition:	The distinct communication path or medium through which information is transmitted from a source to a destination (Shannon, 1948)	
Negative Feedback *		*5 Primary Connections*
Type:	Mechanism	Equifinality Feedback Homeostasis Self-Regulation Stability
Definition:	A property of deviation-counteracting systems which causes them to respond to a perturbation by attempting to return to their prior state (Maruyama, 1963)	

Table 2 (Cont): Interrelationships Between Core Principles

Requisite Variety		*5 Primary Connections*
Type:	Rule/Limitation	Control Requisite Hierarchy Self-Organization Self-Regulation Viable Systems Model
Definition:	The variety of a controller must match the variety of the system being controlled and the variety of the environment (Ashby, 1956)	
Holism		*4 Primary Connections*
Type:	Rule/Limitation	Emergence Hierarchy Self-Organization Self-Regulation
Definition:	The principle that whole things differ from parts, in that wholes are an arrangement of parts in a definite structural arrangement with mutual activities that constitute a whole (Smuts, 1926)	
Homeorhesis *		*4 Primary Connections*
Type:	Functional Characteristic	Dynamic Equilibrium Equifinality Homeostasis Self-Regulation
Definition:	A system behavior where the system is not drawn to a point of stability; rather, it tends to return to an invariant trajectory or ensemble of trajectories (Waddington, 1968)	
Multifinality		*4 Primary Connections*
Type:	State	Equifinality Heterostasis Positive Feedback Satisficing
Definition:	The ability of an open system that begins at similar initial conditions to reach a variety of dissimilar end-states (Maruyama,1963)	
Note:	*While multifinality might also be considered a condition-based process, it is categorized as 'state' because its meaning focuses on the end-state of the system.*	
Negative Entropy *		*4 Primary Connections*
Type:	Functional Characteristic	Communications Control Feedback Homeostasis
Definition:	The process by which a system absorbs free-energy in order to reduce the accumulation of entropy (or disorder) within the system (Flear,1948)	
Recursion		*4 Primary Connections*
Type:	Rule/Limitation	Circular Causality Communications Hierarchy Viable Systems Model
Definition:	The fundamental laws governing the processes at one level are also present at the next higher level (Adams et al., 2014)	

Table 2 (Cont): Interrelationships Between Core Principles		
Requisite Hierarchy		*4 Primary Connections*
Type:	Rule/Limitation	Hierarchy Requisite Variety Self-Organization Self-Regulation
Definition:	A lack of regulatory ability within a system can be compensated for, to some extent, by increased hierarchy in its organizational structure (Aulin-Ahmavaara,1979)	
Viability		*4 Primary Connections*
Type:	State	Adaptation Self-Organization Self-Regulation Stability
Definition:	The capacity of an organism to maintain a separate existence, that is, to survive regardless of the changes in its environment (Perez Rios, 2010)	
Viable Systems Model *		*4 Primary Connections*
Type:	Rule/Limitation	Information Channels Recursion Relaxation Time Requisite Variety
Definition:	A system of interlocking Ashbean homeostats that can be used to model any viable system in terms of its operational units, coordinators, and governing metasystem (Beer, 1984)	
Note:	*More appropriately categorized as a tool, the Viable Systems Model is included in the rule category to avoid unnecessarily expanding the catalog of types.*	
Autopoiesis		*3 Primary Connections*
Type:	Functional Characteristic	Circular Causality Self-Organization Stability
Definition:	A system that is capable of producing or regenerating the functional elements within its system boundaries (Luhmann, 1990)	
Instability *		*3 Primary Connections*
Type:	State	Control Relaxation Time Stability
Definition:	The tendency of a system, when disturbed, to continue in the direction of displacement, or increased oscillation, rather than to return to equilibrium (Hurt, 1965)	
Minimal Critical Specification		*3 Primary Connections*
Type:	Rule/Limitation	Adaptation Self-Organization System Darkness
Definition:	The minimum set of core requirements with which an operable unit can produce a satisfactory result without external control of its internal functions (Herbst, 1974)	

Table 2 (Cont): Interrelationships Between Core Principles		
Positive Feedback *		*3 Primary Connections*
Type:	Mechanism	Adaptation Feedback Multifinality
Definition:	A property of deviation-amplifying systems which causes them to respond to a perturbation by continuing in the direction of the change (Maruyama, 1963)	
Redundancy of Potential Command		*3 Primary Connections*
Type:	Rule/Limitation	Information Channels Self-Organization Self-Regulation
Definition:	Power and control should be vested in the location that has the most information or is best equipped to use it (McCulloch, 1965)	
Basins of Stability		*2 Primary Connections*
Type:	Condition	Self-Organization Stability
Definition:	Regions of stability within a volume of space that are physically bounded by regions of instability (Clemson, 1984)	
Relaxation Time		*2 Primary Connections*
Type:	State	Instability Viable Systems Model
Definition:	The time required for a system to return to a steady-state after being perturbed (Goodwin, 1963)	
Satisficing		*2 Primary Connections*
Type:	Functional Characteristic	Heterostasis Multifinality
Definition:	Rather than optimizing, an organism will general seek the first solution that adequately satisfies all of its needs (Simon, 1956)	
System Darkness		*2 Primary Connections*
Type:	Rule/Limitation	Complementarity Minimal Critical Specification
Definition:	No system can be known completely (Clemson, 1984)	
Complementarity		*1 Primary Connections*
Type:	Rule/Limitation	System Darkness
Definition:	Viewing a system from different perspectives will reveal information that is neither entirely independent nor entirely compatible (Bohr, 1928)	

Table 2 (Cont): Interrelationships Between Core Principles		
Information Redundancy		*1 Primary Connections*
Type:	Mechanism	Information Channels
Definition:	The use of additional, redundant data during a communication transaction in order to overcome noise or information entropy (Shannon, 1948)	
Requisite Parsimony		*0 Primary Connections*
Type:	Rule/Limitation	
Definition:	The theory that a normal person can successfully manage between 5 and 9 concepts in his or her short term memory (Miller, 1956)	
Requisite Saliency		*0 Primary Connections*
Type:	Rule/Limitation	
Definition:	Factors involved in system design are rarely of equal importance, and there is an underlying logic awaiting discovery that will reveal the relative saliency of each factor (Warfield, 1995)	
Resource Redundancy		*0 Primary Connections*
Type:	Rule/Limitation	
Definition:	Maintenance of stability under conditions of disturbance requires redundancy of critical resources (Clemson, 1984)	
Sub-Optimization		*0 Primary Connections*
Type:	Rule/Limitation	
Definition:	If each subsystem, regarded separately, is made to operate with maximum efficiency, the system as a whole will not operate with utmost efficiency (Skyttner, 2005)	

4.2.1. Interpretation of the Tabular Data

In the definitions and categorization of each of the key principles in table 1, the reader should observe that specific themes are recurrent throughout the data. These themes are the basis for the types that were used to categorize each principle. The presence and recurrence of these themes is a critical element in isolating the system archetypes because, by definition, the archetypes are recurrent imagery or representations that are manifested across both time and location. The relationship that these themes have to the underlying archetypes is provided below.

- **Functional Characteristics**

  Principles that were identified as functional characteristics of a system were dominant in terms of interconnections with an average of six connections per node. The most connected principle, *self-organization*, had a total of 11 connections to other key principles. Not merely self-connected, in all but two cases (*dynamic equilibrium and homeorhesis),* more than half of the principles to which these characteristics were linked were of other types. This demonstrates that these principles extend beyond a single related group, but also span out to touch many principles that are not otherwise related.

  The high level of connectedness seen in these *functional characteristics* suggests that systems theory has a tight focus on the behavior of the systems, with a particular emphasis on how systems act in response to changes in their environment. This is an important distinction that plays a key role in the identification of the system archetypes.

- **Mechanisms**

  The principles identified as mechanisms, though fewer in number, also had a high number of average interconnections. It is worth noting that in this analysis *feedback, positive feedback and negative feedback* were all viewed as independent principles, resulting in an average of five connections per node. If all feedback types are merged into the single *feedback* category and redundant connections were eliminated, then it would also have an average of six connections per node.

  The high number of interconnections among mechanistic principles suggests that system scientists are highly concerned with the tools and mechanisms that systems employ to perform their functions. Notably, the relationship between mechanisms and functions also serves to reinforce the importance of the functional characteristics.

- **States**

  Principles involving the state of the system are fewer in number than either mechanisms or functional characteristics. The various state categories have an average of 4.7 connections per node, with the principle of *stability* standing dramatically above the others with a total of ten connections. In determining the relative significance of state, the reader should consider that *stability* and *instability* are considered independently, rather than as a single continuum. If the two are combined and redundant connections are removed, *stability* would increase to 11 primary connections – more than twice as many as any other principle in the group. This suggests that the concept of *stability* stands distinctly from the others in this category with regard to its significance in the systems literature.

- **Conditions**

Principles characterized as conditions had the fewest number of included principles of any group. Notably, those principles had an average of four connections per node, which positions the conditions group at the 66th percentile relative to the connectivity of its peers. The reason for its relatively low performance may not be that environmental conditions are unimportant to systems theory. On the contrary, it is more likely a result of environmental conditions already being an integral part of other principles. This is particularly evident in the cases of homeostasis, adaptation and dynamic equilibrium, each of which represents a system's response to changing conditions.

- **Rules and Limitations**

The principles in the *rules and limitations* category have two notable distinctions. First, the group has more included principles than any other category. Secondly, the group has the lowest average number of connections per node of all of the categories examined (2.3). This low level of connectivity is likely related to the stand-alone nature of many of the principles. *Requisite parsimony, requisite saliency, resource redundancy,* and *sub-optimization* each have zero connections to other key principles.

A notable distinction in this group is the principle of *requisite variety,* which is connected to 5 other key principles. The volume of relationships associated with this principle suggests that, as a rule, it has a significant impact in governing other research in the field.

4.3. Establishing the Theoretical Foundation for the Archetypes

In describing the goal of a grounded theory study, Helen Scott (2009) states that the primary objective is to identify the main concern of the population of your substantive area. Through the examination of system principles and the consideration of their significance based on the volume at which they are referenced and interrelated in the literature, a preliminary theory emerges regarding what the recurrent, persistent theme is, in systems theory. This researcher argues that the major themes in systems literature are *the functions and mechanisms that systems use to maintain continuity and viability in the midst of change*.

This directs the research to pursue underlying archetypes that are associated with the distinct ways that systems behave in order to survive.

With this preliminary thesis established, the next step in the research was to a) describe, in overarching terms, the nature of change that all systems must address, and b) to identify, through selective coding and further exploration of the literature, the ways in which a system's struggle against change would be manifested. Accordingly, this section will begin by describing an environmental continuum that represents the effects and impacts of change in terms of energy and entropy. Once this is established, the previously defined system principles, as well as related literature from other disciplines, will be examined from that perspective.

4.3.1. The Relationship Between Change and Variety, Entropy and Free Energy

In addressing the effects and impacts that change has on a system, we must begin by describing change from a systems perspective - as a type of *variety* (Ashby, 1956). While Ashby (1956) defines variety as the number of potential states of a system, this definition does not apply exclusively to the system under study, it applies equally to the environment, or context, in which the system resides. This precept is the foundation of Ashby's Law, or the Law of Requisite Variety, which states that only variety can destroy (or absorb) variety (Ashby, 1956). Notably, this statement explicitly identifies two domains of variety, that of the system (the destroyer) and that of the environment (the producer). While the manifestations of variety within the system will be a fundamental element of the systems archetypes, the nature of variety in the environment must also be addressed.

- **Entropy and the Environment**

  In developing a generalized perspective of variety within the environment, it is helpful to consider environmental variety in terms of the impact that it has on the system. In "Requisite variety and its implications for the control system", Ross Ashby (1958) specifically related the Law of Requisite Variety with the accumulation of entropy within a system. Although definitions of entropy span the fields of thermodynamics, communications and systems theory, for our purposes entropy can be defined as a process by which the universe moves from a state of maximum concentrated energy to one of maximum dissipation (Clausius, 1867).

  Along those lines, Flear (1948) describes entropy as the disorder that accumulates in a system over time. Likewise, Von Bertalanffy (1932) states that open systems are in a constant struggle to rid themselves of the effects of entropy, and maintain a time-independent state, by continuously consuming component materials from the environment. It was Schrodinger, however, who defined the resistance to entropy as the defining characteristic of life and originated the term negative entropy. He states, "What an organism feeds upon is negative entropy. Or, to put it less paradoxically, the essential thing in metabolism is that the organism succeeds in freeing itself from all the entropy it cannot help producing while alive." (Schrodinger, 1946, p. 25).

It is with this foundation that the research identifies the *accumulation of entropy* as a well-established expression of variety's impact on a system. Whether manifested in terms of age, damage, or decay, the accumulation of entropy represents a system's decline into an inert state of equilibrium. (Schrodinger, 1946). It is only through resistance to the accumulation of entropy that a system can endure. As the following section will discuss, this resistance to entropy is often expressed in terms of negative entropy and free energy.

- **Negative Entropy and Free Energy**

First described by Schrodinger in 1946, negative entropy is the mechanism by which an open system displaces entropy in order to remain viable. Negative entropy is analogous to free energy that is available in the environment which is consumed by open systems and then used to decrease local entropy (Rapoport, 1968). For organic systems, Von Bertalanffy describes this as the process of "importing complex organic molecules, using their energy, and rendering back simpler end products to the environment" (1950, p. 26). Notably, this definition does not dictate that the consumption process is completely efficient and, the *'waste-products'* generated by one system as part of its neg-entropic process may still contain free-energy that can be consumed by other systems. Further, as a system declines into inviability, if it does not consume all of its remaining energy stores, those, too, will be consumed by other systems. This hierarchy of consumption creates a level of almost perfect efficiency in the use of free energy that is not present, or even possible, in the constituent systems.

Therefore, in all of its manifestations, free energy can be described as the functional inverse of entropy at a universal level. Free energy feeds open systems and allows them to maintain themselves, even as that energy gradually degrades into a final, inert state, having been fully consumed.

These perspectives on entropy and free energy can be combined to reformulate our original statement of the main concern of systems theory. Rather than "*the functions and mechanisms that systems use to maintain continuity and viability in the midst of change*," we can say that the main concern of systems theory is *"the functions and mechanisms that systems employ to maintain viability by using free energy in their environment to resist the accumulation of local entropy."* While a subtle distinction, this statement provides a meaningful framework for understanding the open system's *place* in the universe. By combining the statements of Clausius (1867) and Schrodinger (1946), we can state that open systems exist in a region of time bounded by maximum concentrated energy in the past and maximum entropy in the future, where they maintain viability by collecting free energy from the environment and using it to displace local entropy. It is this definition that will frame the search for complex systems archetypes within this study.

4.3.2. Identifying the Archetypes Through Selective Coding and Theoretical Analysis

With the study domain appropriately framed, the research continued by pursuing the archetypes through the use of selective coding and an examination of the literature, guided by the *main concern* as stated in the previous text. This section will discuss and rigorously detail how the grounded theory, and the resulting archetypes, emerged from the study. In doing this, the archetypal forms will be ordered, identified and described in the same sequence in which they emerged from the data. This approach has been selected to make it easier for the reader to appreciate how the archetypes were discovered. Later in this work, the archetypes will be reordered into a continuum that represents a logical progression from one to the other in terms of energy consumption and the nature of their interaction with the environment.

In beginning the process of selective coding, the literature was reexamined from the perspective of *how* a system interacts with the environment in order to overcome entropy and remain viable. The availability, accessibility and consumption of free energy was considered to be positive, or favorable, variety and the occurrence of risks, threats, and damage to the system were considered to be negative, or unfavorable, variety. Archetypical forms emerge from distinct behaviors that a system exhibits to incur favorable variety and displace unfavorable variety. For the earliest archetypes, these forms were immediately evident from the models produced during open coding. As these first archetypes were examined, the search for supporting and reinforcing literature began to expand into the fields of general, ecological, and biological systems, as well as into the disciplines of risk management and threat/trauma response.

The inclusion of risk and threat related literature is deserving of a brief examination. While some of the earliest discussion of risk identification and administration can be seen in legal sources (Douglas, 1929) (Andersen, 1940), the concept of risk management also has roots that extend into the field of insurance (Hedges, 1965). Notably, the identification, calculation and management of risks have been integral parts of operations research, systems engineering and project management from their inception (Chapman, 1979) (Kerzner, 1979) (Hatfield & Hipel, 2002). A meaningful description of risk that can be directly related to this study is provided by Ben-David & Raz (2001, p. 14), who define risk as an "exposure to the probability that an event with adverse consequences might occur." For the systems archetypes, this exposure to adverse consequences represents the negative variety that they must overcome (or be prepared to overcome) through the use of their functions and mechanisms. Both addressing risk and preparing for potential risk are efforts that require the system to consume energy, even if those risks never materialize.

The concepts of threat and trauma response were selected as a representation of the variety that occurs when risks manifest themselves. In the event of threats, the risk transforms from a potential condition to a real situation which threatens the viability of the system. Trauma represents a threat that cannot be avoided, whose impact causes the system to incur damage or injury. While the term trauma is strong, it was selected because of its prevalence in the literature regarding human reaction to the impact of negative variety (Levin, 1997) (Brantbjerg & Jørgenen, 2001)(Perry, Pollard, Blakely, Baker, & Vigilante, 1995). For this study, trauma represents not only physical injuries, wounds and damage, but also less tangible impacts, such as experiences that are distressing or disturbing to the system.

It is through the prism of these perspectives, in concert with the principles of systems theory that were explored earlier, that the complex system archetypes are derived. In the following sections, the literature and relationships that resulted in the emergence of each of the complex system archetypes will be specifically discussed.

- **Self-Regulation**

  While not one of the original principles that was included in the Adams et al catalog, self-regulation is highly manifested in the literature. Further, although this research shows that self-regulation has only 8 direct connections to other primary principles, when it is combined with the principles of homeostasis and heterostasis, both of which are mechanisms of self-regulation, the number of interconnections doubles. Based on this data, self-regulation becomes the preeminent response to variety which is represented in the canons of systems literature.

Cannon (1929) defines self-regulation as the ability of living beings (or systems) to maintain their own stability in the face of the colossal, often adverse, forces which surround them. This definition dovetails well with the theoretical *main concern* that is being pursued within this literature, as it contains a direct expression of both the pursuit of viability and the resistance to variety and entropy that characterize open systems. Likewise, Willmer, Stone, & Johnston (1999, p. 12), provide a concrete definition of self-regulating systems when they say, “regulators maintain some or all of the components of their internal environment close to the original or ‘normal’ level, irrespective of external conditions.” In the *Principles of Ecology*, Putnam & Wratten (1984) differentiate these regulator organisms from conformer organisms, stating that regulators have strict tolerance limits that are governed by outside conditions and their ability to maintain homeostasis, whereas conformers are limited only by environmental ranges over which specific enzyme systems are operative.

Beyond biological systems, the process of self-regulation also appears in the context of threat response. According to Levine (1997), the process of *orientation* is one of the first natural responses to a threat situation. Here the body undertakes a self-regulatory process that increases the organisms sensitive to changes in the environment, as well as adjusting enzymes to prepare the organism to take immediate and decisive action, if necessary. Steven Porges (2001), describes this in his discussion of Polyvagal Theory, where the heart rate and cortisol levels are internally adjusted as an organism enters into a state of threat or suspected risk. In a different perspective on this type of self-regulation, Brantbjerg & Jørgensen (2001) describe the *freezing* response to a threat as an element of the orientation process. In this case, the sudden regulatory changes within the organism cause it to become immobilized briefly while, at the same time, arousal and brain activity are enhanced. In essence, this boosts the organism’s ability to assess and evaluate the situation, and allows it to make the best possible decision before taking action.

It is these distinct behaviors, characterized by a system or organism's self-regulation of its internal parameters to either address or prepare for variety in its environment, that become the basis for the ***regulator*** archetype.

- **Self-Organization**

Self-Organization is one of the principles from the Adams et al. (2014) catalog and, with a total of eleven primary connections, it had the highest level of individual connectedness of any principle that was evaluated in this research. Alena Leonard (1990) describes self-organizing systems as those that change their internal structure to increase their level of adaptation in order to achieve a state where its collected parts are unified with the goal of becoming better suited to its environment. This capacity for adaptation for the purpose of maintaining viability is a critical component of self-organization, because it provides the mechanism by which a system can change to accommodate environmental changes.

The earliest discussions of the concept of self-organization is found in Smuts treatise on holism where he states, "holism in all its endless forms is the principle which works up the raw material or unorganised energy units of the world, utilises, assimilates and organizes them" (Smuts, 1926, p. 108). Here, Smuts links the principle of self-organization to the ongoing process of collecting and using free energy from the environment. Murray Gell-Mann directly describes the relationships of self-organization, negative entropy, and a system's struggle for viability, when he states, "the second law of thermodynamics, which requires average entropy (or disorder) to increase, does not in any way forbid local order from arising through various mechanisms of self-organization" (Gell-Mann, 1995, p. 19).

Owing to its capacity for adaptation, self-organizing systems also receive consideration from Ervin Laszlo (1969) who differentiated them from those systems that used manipulative functions to alter the environment around them. He made special reference to the concept of learning as part of the self-organizing process when he wrote, "learning adapts the cognitive organism to the environment by evolving the codes which map its changing states within the nervous system, and manipulation adapts the environment to correspond to the existing codes of the organism." (Laszlo, 1969, p. 46) Further, in the domain of ecology, self-organizing systems are represented by conformers as described by Putman & Wratten (1984) and Willmer et al. (1999). The authors describe conformers as organisms that do not maintain a homeostatic condition for the whole body, but rather undergo changes of internal state to conform to the changes of state imposed externally.

It should further be noted that inherent differences between the self-regulating and self-organizing system impact their ability to collect and assimilate energy. Because the self-regulating system does not have an innate capacity for adaptation, it is limited to being able to collect and assimilate only the forms of energy that are consistent with its current configuration. Self-organizing systems, however, may be able to adapt to consume new and varying types of energy. This capability is a particular advantage in an environment where energy sources are dynamically changing.

In summary, it is the capacity of self-organizing systems to alter their internal configuration to accommodate and, potentially, exploit changes in the environment in order to remain viable that differentiates them from the self-regulating systems. These distinct capabilities become the basis of the ***organizer*** archetype.

- **Mobility**

The concept of mobility, or self-relocation, is introduced in the works of Willmer, Stone and Johnston (1999) who broadly categorize systems as either regulators, conformers or avoiders. While regulators and conformers have been discussed as representatives of self-regulation and self-organization respectively, avoiders take a different approach to addressing environmental variety. Willmer et al. describe avoiders as having "some mechanism for getting away from an environmental problem either in space (e.g. seeking unstressed microhabitats in crevices or burrows, or larger scale migration) or in time (using torpor or diapause, or producing a resistant egg, pupa, or cyst to survive difficult times)" (Willmer, Stone, & Johnston, 1999, p. 12).

Although the capacity for system mobility is not addressed as a specific principle in the Adams et al. (2014) catalog of systems, it is an implicit characteristic of many other system principles. Examples of these include: homeorhesis, basins of stability, control, stability, and instability. The principle of homeorhesis is of particular interest in examining the concept of mobility. According to Waddington (1968), homeorhesis is the inclination of a system in motion to return to the same trajectory or set of trajectories. Reid (2007) extends the discussion of homeorhesis, by describing it as an analog of homeostasis. He states that homeostasis allows an "organism to persist in its being while exploring new environments, and acquiring habits that might otherwise tend to disequilibrate its internal milieu" where, under similar conditions, homeorhesis tends to "obstruct anatomical change by conserving the integrity of the original form" (Reid, 2007, pp. 189-190). A system theory concept of mobility is further reinforced by the research of Enver, Pera, Peterson, & Andrews (2009) who directly equate Waddingtons research on homeorhesis, or canalization, with the principle of basins of attraction, where systems in motion tend to return to "bowls or valleys" in the landscape. Notably, these concepts bind the idea of mobility to the concept of basins of stability which is contained in the Adams et al. (2014) catalog of system principles.

The concept of mobility in the form of risk avoidance is described in the legal writings of Douglas (1929) and Anderson (1940), in the domain of insurance by Hedges (1965), and in the realm of Project Management by Kerzner (1979) and Ben-David & Raz (2001).

Perhaps the most notable example of mobility as a reaction to negative variety is represented in the hyper-arousal continuum, or the 'fight-or-flight' response, first described by Walter Cannon (1932). Here, when confronted by a threat, an organism will elect to either engage it directly or avoid it by attempting to flee. Cannon discusses both of these responses from the perspective of homeostasis, describing the body's release of adrenaline as a precursor to either fighting or fleeing in the face of adversity.

Still, negative variety is not the only motivator for system mobility. In discussing migratory birds, the Cornell Lab of Ornithology (2006) describes their motivation as one of positive variety. The lab states that birds will migrate in order to move from areas of low or decreasing resources to those of high or increasing resources. Further, such migrations are also driven by nesting cycles, where birds will relocate to produce hatchlings in areas with high insect populations and budding plants.

As these examples have demonstrated, mobility is used by some systems to either avoid negative variety or to exploit positive variety in order to increase their likelihood of survival. This behavior is the basis of the ***migrator*** archetype. The author will note at this point that much of the work in the literature referred to this type of organism as an avoider. While the this term and several others were considered in naming the archetype, the term migrator was selected because it reflected the systems effort to seek the benefit of positive variety as well as avoid the impacts of negative variety.

- **Manipulation**

As touched on in the discussion of self-organization, when describing adaptive behavior in systems, Ervin Laszlo (1969) directly differentiated it from manipulator behavior. He described systems that exhibit these behaviors as follows, "The manipulative function of self-stabilizing and self-organizing systems is exhibited by most organisms in conditioning their environment. By building nests, digging burrows and ultimately working the land and building cities, organisms adapt their environment to themselves" (Laszlo, 1969, p. 14). Such behavior represents a massive departure from the archetypical behaviors that were identified earlier. Where self-regulating, self-organizing, and mobile systems change either themselves or their locations to address environmental variety, manipulative systems change the environmental conditions to satisfy their needs. Laszlo also suggests that this capacity for manipulation actually negates the need for a system to adapt in many cases. This is because environmental conditions that might force adaptation can frequently be eliminated through the process of manipulation.

The concept of manipulation as a tool to eliminate hazards is demonstrated prominently in the Hierarchy of Hazard Controls (NYCOSH, 2014). This document describes a hierarchy of behaviors that can be used to address a hazardous condition. In this hierarchy, elimination is synonymous with manipulation. They state, "The best way to control a hazard is to eliminate it and remove the danger" (NYCOSH, 2014, p. 1). Similarly, the Irish Health and Safety Authority (IHSA) describes the manipulative process as combatting the risks at their source. They state, "Here you are trying to deal with the hazard at its root. For example if you have a noisy machine in your workplace, giving employees hearing protection is not dealing with the root of the problem. If you enclose the machine so that it is not noisy or if you replace the machine with a quieter one, then you are combating the risk at source" (IHSA, 2011, p. 1). This reference to manipulation is particularly significant, because it directly differentiates the concept of manipulation from that of insulation, where the system is merely shielded from the effects of an ongoing hazard.

The concept of manipulation is also derived from Cannon's discussion of the *fight-or-flight* response (1932). In the case of the fight response, rather than fleeing the source of danger, the system engages it directly and attempts to neutralize or eliminate the threat. This concept of the fight response as a mechanism to address an adverse condition by changing it is reiterated in Levine's (1997) description of trauma response and in Porges' (2001) discussion on Polyvagal Theory.

While these examples demonstrate that manipulation is used by systems to eliminate negative variety, environmental manipulation is also used to generate positive variety. This is touched on by Laszlo (1969) who speaks of humans building cities and working the land. This idea can be extended to include efforts to divert water for agricultural purposes or for energy generation. In these cases, the system is modifying its environment not only to eliminate hazards, but also to facilitate the collection of energy. These characteristics dictate that manipulation is a distinct mechanism by which systems deal with environmental variety, collect energy and eliminate entropy in order to remain viable. This becomes the basis for deriving the ***manipulator*** archetype.

- **Insulation**

The idea of insulation was briefly touched on in the discussion of manipulation, wherein the IHSA (2011) stated that insulating people from hazards was not the same as eliminating the hazard. Along similar lines, the New York Committee on Occupational Safety and Health describes insulating through the use of engineered controls as follows,

> *"If a hazard cannot be eliminated or a safer substitute cannot be found, the next best approach is to use engineering controls to keep the hazard from reaching the worker. This could include methods such as using noise dampening technology to reduce noise levels; enclosing a chemical process in a Plexiglas "glove box"; using mechanical lifting devices; or using local exhaust ventilation that captures and carries away the contaminants before they can get in the breathing zone of workers." (NYCOSH, 2014, p. 1)*

While these activities might be viewed as forms of environmental manipulation, they are distinct in that they do not eliminate the hazard; they merely mitigate it or insulate the system from direct impact.

The concept of insulation is also prevalent in the domain of risk management. Termed risk shifting, risk transfer or risk mitigation by various sources (Douglas, 1929) (Hedges, 1965) (Ben-David & Raz, 2001) (Libuser, 1994) , each of these approaches involves reducing the consequences associated with a risk, without actually eliminating the risk itself. A notable distinction is raised in the discussion of risk transference, particularly in the realm of project management. Kerzner (2010, p. 262) describes transference as "choosing to transfer the risk to a third party, usually at a cost." In the case of insulating systems, the third party receiving the risk acts as a shield or protective filter which incurs the impact of the risk, thus reducing the system's exposure to harm.

Because of this, insulating systems are those that employ external material to reduce or minimize the effects of negative variety, without actually eliminating the variety itself, in order to avoid the accumulation of entropy and extend their viability. It is from these factors that the ***insulator*** archetype emerges.

- **Endurance**

The final archetypical form emerges from the question, 'what if a system takes no action to address negative variety, but merely absorbs it?' This is a very common response in biological systems, particularly when the variety or risk is slow moving or rare enough that efforts to address it are more expensive than the damage that will be incurred. Within the domain of risk management, Kerzner calls this acceptance and describes it as "choosing to accept consequences of unmanaged risk" (Kerzner, 2010, p. 262). In the project management world, acceptance is categorized in two ways: active acceptance and passive acceptance (Furia, 2008). Active acceptance is when the system recognizes the risk and considers contingency plans that can be employed should the event occurs. Passive acceptance means that the system will make no preparation for the event, but rather will address the repercussions after the event occurs.

A common example of passive acceptance is often seen in how humans deal with the aging process. Each of us recognizes that we must eventually succumb to old age and inviability (death), and there are no steps that can be taken to eliminate the accumulation of entropy over time. In response to this, we recognize that this risk exists, we endure the damage and degradation that gradually accumulates over time, and we address (medically) threats that can be identified and dealt with.

The idea of endurance as a systemic response to trauma is also raised in the work of Brantbjerg & Jørgensen (2001). They describe the freezing and collapse responses that are related to an organism's reaction to an approaching threat. Freezing, they say is closely related to the orientation response that described as part of self-regulation. Here the organism freezes long enough to assess the situation and make a determination regarding what action should be taken next. Collapse, on the other hand, occurs as the *ultimate reaction* –where an organism has given up and is preparing to die. In both of these situations, the organism's viability is dependent on its capacity to endure the variety until it a) can take other action, or b) the variety ends.

The process of endurance is the most rudimentary response that a system can have. It is commonly represented as a system's efforts to continuously collect and consume available energy in order to remain viable in the face of the (potentially) slow, regular accumulation of entropy. It is from behavior that the ***endurant*** archetype emerges.

In considering the endurant archetype, there are some special considerations that should be mentioned. During the early formulation of the archetypes, this author did consider the use of collector and maintainer archetypes, as an alternative to the endurant. The collector would be represented by any system that accumulates free energy in order to maintain its viability; and the maintainer would be any system that used autopoiesis in order to maintain and repair elements within its system boundaries. In the end, these two types were merged into the endurant archetype for the following reasons. First, the process of collecting free energy and using it to displace entropy is a defining factor of all open systems. Consequently, it would be redundant to create an archetype whose only function was fully represented in the others. Secondly, all open systems, in some way, use energy to displace entropy. In some cases this is merely increasing the capacity of stored energy, in others it is repairing and regenerating components within the boundaries of the system. For the purpose of this research, drawing a distinction between these two internal operations did not add any benefit to the resultant archetypes. As a result, the endurant archetype manifests both the collection of free energy and the maintenance of internal components.

4.3.3. The Resulting Grounded Theory of the Complex System Archetypes

Based on the results of the open coding, selective coding and theoretical analysis of the system theory literature, as well as related literature from across other disciplines, the following grounded theory emerges:

The behavior of complex systems, vis-à-vis their efforts to collect energy, displace entropy, and remain viable can be characterized by six distinct archetypes: the endurant, the regulator, the organizer, the migrator, the insulator and the manipulator.

While the system-based archetypes that are described here are directly related to functional characteristics: the *'how'* of the behavior, it should not be assumed that there are no other perspectives. Maslow's (1943) *Hierarchy of Needs* suggests that another type of system archetypes might be derived based on motivation, or the *'why'* of the behavior. Others might evolve that discuss the selection criteria that determine which issues are addressed: the '*which'* of the behavior, or the timing factors that govern a systems response: the '*when'* of the behavior. Still, it is the goal of this research to demonstrate that, regardless of the reason, prioritization or timing that motivates a systems action, there are a fundamental collection of underlying archetypes that describe the nature of its action, or *how* the system responds.

To demonstrate this, this paper will expand on this grounded theory by first discussing the environment in which the archetypes exist and operate. This environment will be described using system terminology and will identify all of the key attributes that contribute to understanding the archetypes and their behavior. Next, the research will identify, define, and develop each of the system archetypes, beginning from the most rudimentary behaviors and then moving toward the more complex modes of operation. Finally, the paper will examine the archetypes as an interrelated collection where the system must, in some cases, select the most effective, efficient, or employable course of action from a variety of alternatives.

4.3.4. Assessing the Validity and Reliability of the Resultant Theory

In section 3.2 of this dissertation, several factors were identified that would influence the validity and reliability of this research. Specifically, this author stated that the integrity of the research would be achieved through the pursuit of confirmability, dependability, validity, and consistency. The following text discusses how each of these criteria were satisfied.

- **Confirmability**

  Confirmability was achieved in this grounded theory study by using the approach of constant comparison to evaluate each element of data as it was drawn from the literature. The data and illustrations generated in Appendix A of this study demonstrate the rigor with which concepts were collected and then interrelated with one another to form a model of each major principle. Further, a unified model of the system principles was created that illustrates the relationships that exist between all major concepts and allows the reader to have a holistic view of systems theory.

Likewise, in the discussion of how each archetype was derived from the literature, the references from both the field of systems theory and related fields were provided in detail. This approach allows the reader to independently confirm that the resulting archetypes were generated both rigorously and in compliance with the tenets of good grounded theory

- **Dependability**

  Gasson (2003, p. 90) defines dependability as using a study process that is "consistent and reasonably stable over time and between researchers." The visual grounded theory approach that was documented in this study was followed rigorously and the resulting models and quotes are provided are provided for the readers review. Other researchers can follow the process that was used to conduct this research and can objectively assess the data that was collected and evaluated in pursuit of the underlying complex systems archetypes.

- **Validity and Consistency**

  In the pursuit of validity, this study endeavored to demonstrate and document the relationships that exist between the concepts and principles of systems theory, and then used those relationships as the basis for deriving the system archetypes. The relational models of systems theory that were produced in this process are included in Appendix A, along with quotes, references and commentary that support the validity of the relationships and of the conclusions.

  Consistency was achieved by meticulously ensuring that all elements of the resultant theory were consistent with one another, and with the data that was collected during the execution of the study. The *meaning* that was drawn from the data in order to derive the complex systems archetypes was detailed in the proceeding text and references were provided to demonstrate that these archetypal definitions were consistent with one another and with the literature from which they were derived.

4.4. The Environment of the Archetypes

In approaching this research, it will be difficult for the reader to fully appreciate how the complex systems archetypes emerged without first understanding the environment in which they were assumed to exist. Accordingly, even though the definition of the complex system environment is not a formal element of the findings, it is included here to provide a context whereby the reader can appreciate the distinctions between each of the emerging archetypes. It is within this context, and from the execution of the research design, that these archetypes emanate.

A discussion of the environment of complex systems should begin with the two governing factors that define the natural world: time and entropy. The arrow of time flies unerringly from the past to the future (Eddington, 1928), and with the passage of time, the universe moves from a state of maximum concentrated energy to one of maximum dissipation or entropy (Clausius, 1867). For open systems to persevere within this domain, they must continuously collect free energy and use it to divest themselves of entropy within their own systems through a process of negative entropy (Schrodinger, 1946) (Flear, 1948).

In general, one can use the term *variety* to describe all of the phenomena that are manifested in the natural world. Regardless of their source or cause, these phenomena unwittingly conspire to increase the entropy of an open system (Ashby, 1958). For the purpose of describing the environment of the system archetypes, the variety that impacts them will be divided into two categories: the temporal variety and the contextual variety.

4.4.1. Temporal Variety

The concept of temporal variety used in this paper differs from the one used by others, such as Heylighen (1991), where temporal variety is defined as changes in the system itself over the course of time. In the case of the environment of systems archetypes, temporal variety applies to changes and emergence, both predictable and unpredictable, which flow across the temporal horizon from the future into the past.

Figure 7. The Temporal Horizon and Temporal Variety

The temporal variety with which a system must contend falls into two major categories, potential variety and actual variety, which are defined in the following sections:

- **Potential Variety**

  These are all of the things that could happen. Although not certain, this variety is foreseeable or predictable by the system. Potential variety is comprised of an unlimited collection of possible events representing the vast, unknown future. It should be stated here that emergence is notably absent from the domain of potential variety. This is because even though emergence has a high degree of uncertainty, it is, by most definitions, unpredictable (Lenk & Stephan, 2002).

  For the open system that is striving to minimize the use of any energy which does not directly reduce its entropy, the universe of potential variety is daunting. On one hand, if the system is unprepared for potential variety that crosses the temporal horizon into reality, then it is likely to be overwhelmed by its impact. Conversely, any energy that the system expends to prepare for potential variety that does not materialize is wasted. In this regard, the efficiency of the system in dealing with uncertainty and risk is a major contributor to its longevity, whether the worst happens or not.

- **Actual Variety**

  Actual variety is composed of two distinct types: change and emergence. The distinctions between these types of variety are described below:

  - **Change**

    Change is the subset of potential variety that actually happens. In most cases, change is relatively routine and represents cyclic variations in the system's environment. Examples of this include seasonal variations, daytime temperature swings, lunar cycles, and tides. While some variation exists in each of these, they are generally constrained to a regular range, and departures are usually minimal. Nonetheless, change can be sweeping and catastrophic, even when it is foreseeable. This is demonstrated by tidal flooding and storm surges that occur in the wake of a hurricane or by aerial flooding that accompanies torrential rains.

  - **Emergence**

    Unlike ordinary change, emergence occurs when there is a change that is unforeseeable and, generally, outside of normal variety. Here the term *unforeseeable* deserves additional examination. Take, for instance, the storm surge and extreme tides that were discussed earlier. With the approach of a major storm, those events are frequently foreseen and predicted, placing them within the domain of change - dramatic change, but change all the same. The global weather patterns that produce those hurricanes, however, remain largely beyond our ability to predict. As a result, even though the storms themselves may be emergent events, many of their effects are not.

- **Emergence and the Temporal Horizon**

  Regarding emergence, it has been stated that emergence only occurs within the domain of actual variety because it is unforeseeable. This does not mean, however, that the system does not recognize an emergent event until after it crosses the temporal horizon and collides with it. On the contrary, emergence occurs at the moment of recognition – not at the moment of impact. Take, for example, an astronomer who looks out into the night sky and sees a comet plummeting toward the Earth. Although it might be days or weeks before the astronomer meets the comet first-hand, the moment of emergence is already upon him. It transpired at the time of discovery. Accordingly, from this emergent event, he now has the ability to predict many future changes, based exclusively on this new knowledge.

4.4.2. Contextual Variety

The next type of variety that is at work in the environment of the system archetypes is that of contextual variety. For the purpose of this research, contextual variety is defined as the varying environmental conditions that exist all around the system, but that have no impact until the system chooses to interact with them. This concept is best described in terms of basins of stability.

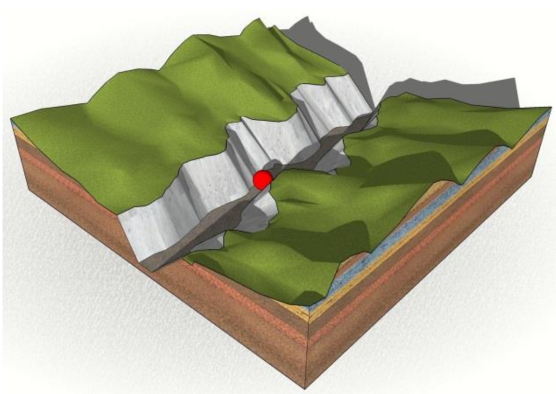

Figure 8. A Basin of Stability

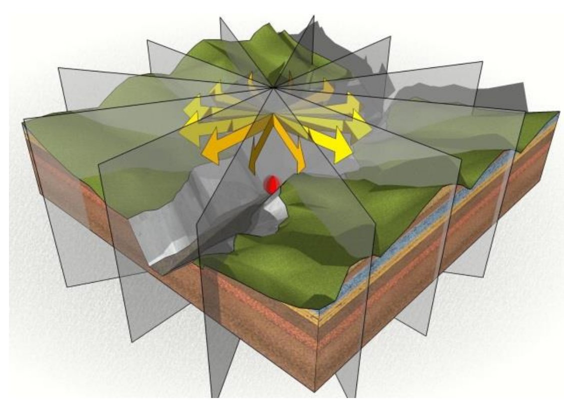

Figure 9. Alternative System Paths

In examining figure 8, the reader sees the system, a red ball, resting in a basin of stability. As long as the red ball traverses the basin and remains at the bottom of the trough, it will encounter little resistance and will not have to expend a great deal of energy. However, even though remaining in the bottom of the basin is perhaps the easiest solution, it is not the only alternative.

Figure 9 demonstrates the myriad paths that the red ball could take to leave the basin of stability and move to a different plane of existence. Further, figure 9 only shows direct, straight-line paths. In reality, there are an infinite number of curved paths that the ball could take. In each of these cases, the ball will experience the contours of the environment's terrain in a different way and will have to expend energy differently in order to traverse them. Figure 10 shows the different contextual varieties that result from just those paths that are shown in figure 9.

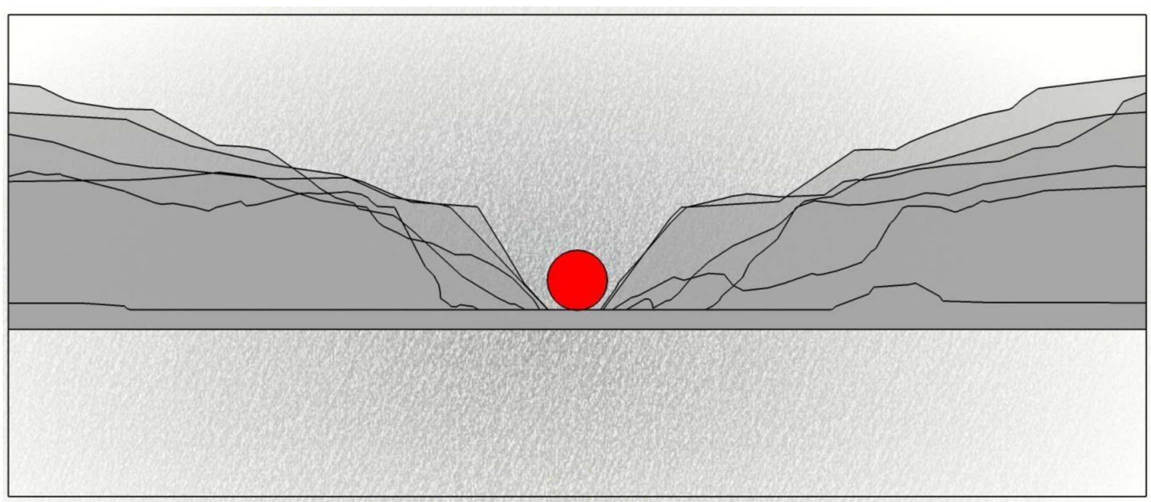

Figure 10. Contextual Variety Found in Different Paths

As demonstrated in figure 10, even though the terrain surrounding the system is invariant, variety arises from the path that the system chooses to follow – if it elects to move at all. Additional variety is introduced as the system interacts with the environment. The reader should recognize, however, that the variety which emerges from the system's interaction with the environment is not necessarily contextual variety. Take, for example, a man crossing a frozen lake. In this case, all of the relatively static factors that represent the frozen lake (altitude, ice thickness, depth of the water) are contextual variety. If, however, the ice breaks while the man is crossing it, then, in addition to very cold water, he also finds himself exposed to temporal variety, because a change has occurred and has crossed the temporal horizon to affect the system.

It should also be noted that contextual variety may sometimes be emergent in nature. For this research, this will be called *contextual emergence.* It occurs when static or largely invariant conditions exist in the environment, but are beyond the observation of the system. As the system traverses the environment, it eventually encounters these unforeseen conditions and it must deal with their unforeseen impacts. Such situations differs from temporal emergence in that, even though the system wasn't aware of it, this variety has always existed, it is constant across an interval of time, and it represents a static impediment that the system must avoid, circumvent, or overcome. An example of this would be a sheer cliff or precipice which is beyond the view of a traveling system until the system arrives at its edge.

4.4.3. The Dissipative Model of the System Environment

In addition to the continual impacts of contextual and temporal variety, the system must also deal with the dissipation of its own energy and the slow decline toward total entropy. In the dissipative model of the systems environment, the open system floats in a homeokinetic plateau (Van Gigch, 1991) that exists between maximum concentrated energy (the past) and maximum entropy (the future). This environment is shown in figure 11.

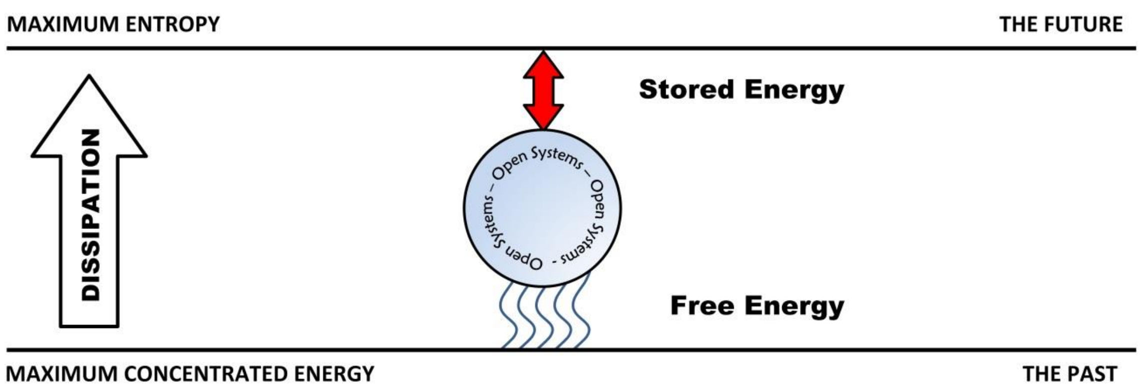

Figure 11. The Dissipative Model of the System Environment

In order to remain viable, the open system must continuously collect and use free energy to reduce internal entropy (Schrodinger, 1946) (Flear, 1948). During periods of abundant free energy, the system may be able to create a cache of stored energy that can be used to maintain its functional processes during times of low free energy availability. Notably, even though the system may have a continuous abundant supply of free energy, this does not guarantee its survival. Quite the contrary: the principle of homeokinesis dictates that in every open system, a sufficient amount of un-displaceable entropy will eventually accrue and the system will depart the *homeokinetic plateau* into a domain of positive feedback that eventually leads to the system's demise (Van Gigch, 1991). Nonetheless, the ability of the system to maximize its time in the homeokinetic plateau, and its lifetime, is to efficiently consume and convert free energy and to displace entropy.

In summary, the archetypes that will be described in the following section are a direct outgrowth of the environment that has been described. They exist in a world full of variety, change, and emergence, all of which are continually assaulting them, degrading them, and pushing them toward entropy. The variety that they face is both temporal, where affecting events emerge across the temporal horizon, and contextual, where affecting conditions exist, but are only realized when the system acts to encounter them. To varying degrees, these events and conditions continually erode the system's viability. Their only defense is to dispose of this variety, minimize its impact, and resist the accumulation of entropy that will result in their inevitable demise. In short, the system archetypes that will be described here are a reflection of the system's own mortality, and each archetype is distinguished by the behavior that a system exhibits in its struggle to remain viable.

4.5. The System Archetypes

Based on the system environment that has been developed, this section will identify the six distinct system archetypes that emerge from the research. For each of these archetypes, its archetypical behavior (the manner in which it absorbs variety and displaces entropy) will be described. This will be followed by a discussion of the system principles that underlie the archetype and how they are uniquely manifested within systems of this type. Finally, examples and manifestations of each archetype will be provided. In progressing through the collection of archetypes, the study will proceed from the most rudimentary of the group, the endurant, to the most complex, the manipulator.

4.5.1. The Endurant Archetype

The endurant archetype can be thought of as a system with a tough outer shell whose survival depends on its ability to deflect impacts from the environment. The system has no capacity for self-regulation or internal reorganization, meaning that it has no way of adapting to changes in the outside world. During normal conditions, such a system may suffer little damage from external variety, and it is capable of maintaining itself using stores of energy that it collects from the environment. In the event of severe changes, however, it may be overwhelmed by external impacts if they exceed its structural durability or its remaining energy capacity.

- **Archetypical Behavior**

Like all system archetypes, the endurant collects free energy from the environment and uses it to displace entropy. As with biological systems, endurant systems fall into two broad categories: autotrophs and heterotrophs. The autotrophic systems are analogous to plants which use photosynthesis to convert sunlight to energy, in that they are able to directly collect and convert free energy for use or storage. Conversely, the heterotrophic systems must collect energy that has already been converted for use by another system or process. In short, the autotrophs consume free energy and the heterotrophs consume the autotrophs.

The collection of energy allows the open system to displace entropy and to keep as much distance as possible between itself and the threshold of inviability or *system death*. To accomplish this goal, the endurant engages in the systemic process of *autopoiesis*, an internal process by which it maintains and regenerates all of the components that exist within its system boundary (Luhmann, 1990). Further, it engages in a rudimentary form of *resource redundancy* by which it collects and stores energy for future use (Clemson, 1984). When examining the endurant's use of energy, we find one of its first distinguishing characteristics. Because the endurant does not have the capacity for self-organization or self-regulation, it can only collect, store, and disperse energy in the manner that is dictated by its current configuration. In this regard, the endurant is analogous to an uninterruptable power supply which has a fixed battery capacity and can only deliver power of a specific voltage for a finite amount of time after its source of energy is disrupted. Also, like the uninterruptable power supply, over time the effect of entropy eventually degrades the system so that it can no longer maintain its original level of performance (ex. its batteries don't hold a charge), and it becomes inviable.

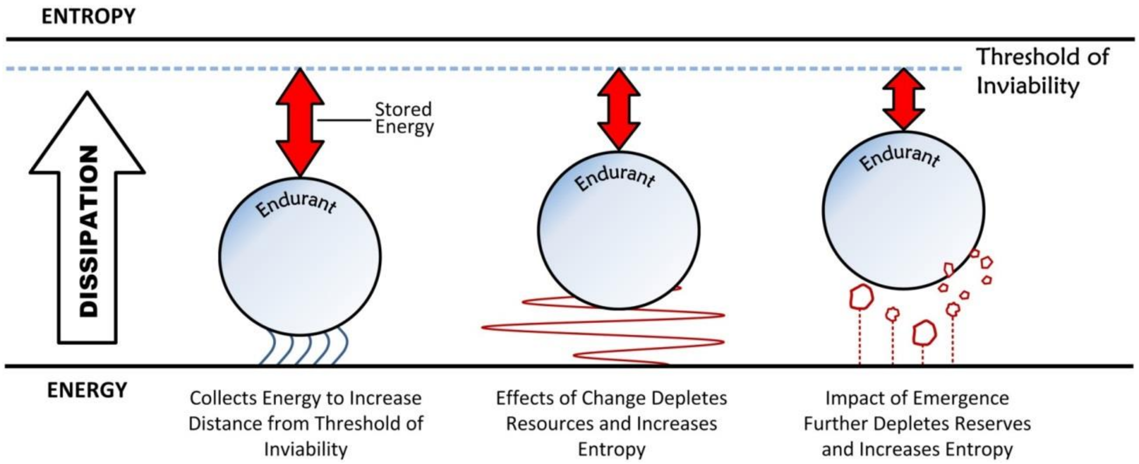

Figure 12. The Endurant Archetype

Figure 12 shows the endurant archetype's behavior relative to energy consumption, change, and emergence. During normal operations, the endurant collects energy and uses it to maintain the system. Although it can increase its distance from the boundary of maximum entropy, it is kept in check by the continuous effects of change-based entropy that flows across the temporal horizon. To maintain entropic equilibrium, the endurant must collect as much energy as it needs to maintain itself and to dispose of entropy. At the same time, emergent conditions arise and continue to pound against the endurant. In the face of this ongoing barrage, it is eventually consumed by entropy and sinks into a state of inviability.

- **Governing System Principles**

In addition to *autopoiesis* and *resource redundancy,* which were discussed earlier, the endurant archetype is also governed by a number of other key system principles. These include:

- **Requisite Variety**

The principle of Requisite Variety, or Ashby's Law, states that in order to remain viable, a system must be able to absorb (or destroy) at least as much variety as circumstances present to it (Ashby, 1958). This concept is reflected in the discussion of temporal variety that was provided earlier. As variety emerges across the temporal horizon, in order to remain viable, the system must be able to accommodate it. In the case of the endurant archetype, it deals with variety by being able to deflect or absorb it and by having sufficient stored energy to outlast it.

- **Relaxation Time**

  Another system principle that is present in the endurant archetype is *relaxation time.* This is defined as the amount of time that it takes for a system to return to a state of equilibrium after it has been perturbed (Goodwin, 1963). In the case of the system archetypes, the conditions of change and emergence that the system encounters are merely perturbations, and relaxation time is the amount of time necessary for the system to recover after each impact. If changes come too fast, then the system cannot recover and is eventually overwhelmed. For the endurant archetype, relaxation time is largely dependent on two factors: 1) the amount of time necessary for it to replenish energy reserves, and 2) the amount of time needed to perform autopoietic repairs and maintenance.

- **Viability**

  Finally, the principle of viability is the most critical aspect of the endurant archetype. Viability is the capacity of a system or organism to survive and maintain a separate existence regardless of the changes in its environment (Perez Rios, 2010). In short, viability is the underlying motivator behind all of the system archetypes and the efforts that they exert to survive in an environment of emergence and change. Because the endurant has no capacity for self-regulation or re-organization, its viability relies on its capability to endure incoming variety.

▪ **Manifestations of the Endurant Archetype**

The endurant archetype and endurant behavior is an underlying characteristic of virtually all systems. Although endurant behavior is not always the prevalent course of action for a system, there are circumstances where it is most likely to be encountered.

- **Stable Operations**

  During conditions of high stability and low emergence, unless driven by other factors, systems are able to collect free energy, convert it to energy stores, and then use it to dispose of entropy. Because this is a very economical mode of operation, other archetypical behaviors are likely to only be employed when circumstances demand them.

- **Early Emergence**

  When an emergent condition crosses the temporal horizon and impacts the system, the system's endurant capacity is often the first defense. In cases like this, the system does not have advance notice of the emerging variety until it is directly impacted. When this occurs, the system must rely solely on its structural integrity and its existing energy stores to survive long enough for one or more of the archetypical behaviors to be activated and employed. In this case, either the system will have enough endurant capacity to endure the initial impact and mount a response, or it will be overwhelmed.

- **The Last Resort**
  Systems will also rely on their endurant capacity as a last resort in dealing with emergence and change. This is demonstrated in the situation in which a system is confronted by emerging variety and it responds by employing all of its other archetypical defenses. One by one, these capacities are overwhelmed by variety until, finally, the system has no further mechanisms that it can use to defend against the advancing emergence. At this point, the system's only remaining option is to rely on its existing energy stores and its capacity for autopoiesis (its endurant capacity) to survive until the assault subsides.

- **By Election or Default**
  During a system's lifetime, it may gain experience that allows it to better understand the potential impact of incoming variety. In such cases, rather than mount a more expensive response, the system may elect to use its endurant capacity to 'power-through' emergence and variety. While there are risks associated with this type of response, it is often the most cost-effective approach in terms of energy and long-term viability.

4.5.2. The Regulator Archetype

The regulator archetype distinguishes itself by having the capacity to alter its internal settings in order to accommodate variety. This is not to say that it is able to reconfigure itself internally. On the contrary, it is possessed of a fixed set of alterable parameters that it can adjust, based on its own priorities, in order to stave off the impacts of external variety.

▪ **Archetypical Behavior**

The regulator archetype is analogous to the biological regulator as described by Willmer They say, "regulators maintain some or all of the components of their internal environment close to the original or 'normal' level, irrespective of external conditions" (Willmer, Stone, & Johnston, 1999, p. 12). This means that when the regulator archetype experiences external variety, it compensates for it by adjusting the values of its internal system settings. These set-points are arranged in a hierarchy whose order is governed by each sub-system's criticality relative to system survival.

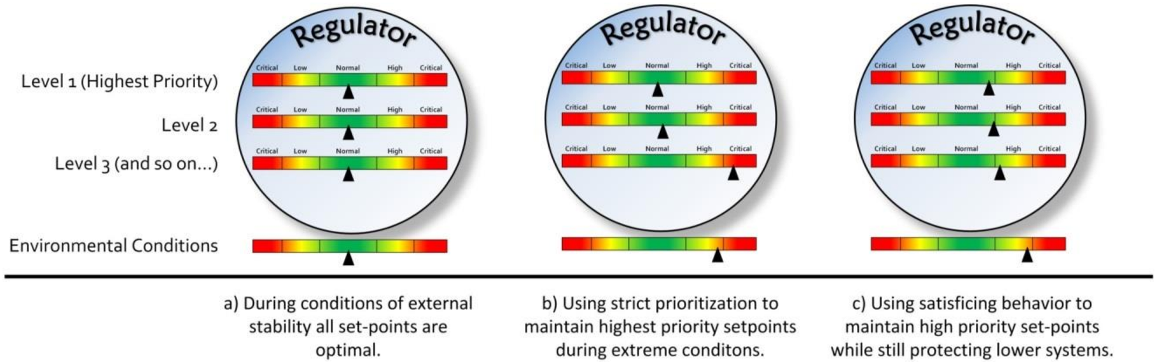

Figure 13. Variations of the Regulator Archetype's Behavior

As shown in figure 13, the regulator archetype can be thought of as a collection of temperature gauges that are organized in descending order of importance. The goal of the regulator is to maintain the set-points of these gauges at or near their optimal temperature. When external conditions begin to change, the regulator will respond by varying the internal set-points in an attempt to compensate for the new conditions. The reader should note that, as a system departs from optimal conditions, there are two distinct approaches to regulation which are shown in figure 13; these are strict prioritization and satisficing.

The strict prioritization approach is based on rational choice theory (Von Neumann & Morgenstern, 1944). Here, the system will endeavor to keep the high priority set-points as close as possible to their nominal values (figure 13-b). To achieve this, lower priority values may be shifted to critical levels in order to maintain optimal conditions at the top. This type of approach is warranted in a number of conditions; it is particularly warranted when the higher level set-points are critical to survival or when damage to those sub-systems is more costly to repair.

In the satisficing mode of operation (figure 13-c), more flexibility is allowed in the variation of high priority set-points. Using this approach, the system will only vary low priority parameters to the level necessary to keep the high priority set-points within an acceptable range. While this approach may tend to reduce damage to low level sub-systems, it does carry additional risk. Where the strict prioritization approach quickly alters the internal settings to address the most important factors, the satisficing approach must take the time to consider the level of impact system-wide. In situations of extreme or rapid variation, the time required to balance all of these factors may not be available.

Notably, any type of system regulation or variation of set-points is a time-consuming process. This means that all regulator systems must have some level of endurant capacity which allows them to survive changes in the environment long enough to compensate with internal adjustments. Further, when environmental conditions or variety exceed a system's level to compensate, it does not necessarily mean that the system will die. Again, the system's endurant capacity may be sufficient to carry it through a period of uncompensable variety and allow it to endure.

- **Governing System Principles**

The regulator archetype is governed by the following system principles:

- **Homeostasis**

  Homeostasis, or the physiological reactions that maintain the steady-state of key variables within the system (Cannon, 1929), is one of the defining capabilities that underlies the regulator archetype.

- **Self-Regulation**

  Encompassing homeostasis, self-regulation represents all of the mechanisms that a system uses to maintain stability in the face of the colossal, often adverse, forces that surround them (Cannon, 1929). This extends beyond simple set-point management to include mechanisms of governance and decision making which dictate how a regulatory course of action is selected.

- **Heterostasis**

  Heterostasis is a complementary process of homeostasis. It is described by Davis (1958) as the process by which a system maintains the steady-state of one variable by altering or adjusting the value of another variable. In the regulator archetype, the lower level sub-systems in the control hierarchy function as the heterostatic controls, in order to maintain stability in the higher level components.

- **Feedback**

  System feedback is critical to the regulatory process. Using a collection of receptors (or sense organs), system changes are detected, evaluated, and forwarded to an effector which is responsible for adjusting the systems settings based on the new information. Following each iteration, changes are again detected by the receptor and a continuous feedback cycle is created with the objective of maintaining system stability (Von Bertalanffy, 1968) (Maruyama, 1963).

- **Control**
  The process of control is defined by Hurt (1965) as a mechanism for moving a system between varying states of stability and instability. In the regulator archetype, control is used to impose instability on components lower in the hierarchy with an objective of maintaining stability of the most critical elements. This is an achievable objective if the system is well-balanced, and the range of the variables is sufficient to absorb the variety in the environment.

- **Satisficing**
  In addition to simply maintaining the integrity of a single variable, self-regulating systems may employ a satisficing approach when pursuing stability. The process of satisficing was originally proposed by Simon (1956) as an alternative to rational decision making where the system seeks to optimize a single outcome. In the case of satisficing, the system recognizes that in addition to having an optimal value, each of its parameters has a range of operation which is safe. By allowing the key variables to undergo some safe level of variation, the system may be able to loosen restrictions on variables that are lower in the hierarchy, protecting them from damage. This satisficing approach allows the system to adequately protect the key variable while still maintaining the integrity of the system as a whole.

- **Hierarchy**
  In order to support homeostasis and heterostasis, the components of a regulator system must be organized in a hierarchy that delineates the priority of each component in relation to the others and to the well-being of the overall system. This is also a fundamental principle of holism as described by Smuts (1926).

- **Requisite Hierarchy**
  The presence of system hierarchy may result in the system incurring the benefits of the law of requisite hierarchy. Conceived by Aulin-Ahmavaara (1979), this principle states that the presence of greater hierarchy within a system may, by itself, compensate for a shortage of regulatory ability.

- **Requisite Variety and Viability**
  Finally, as with the endurant archetype, the regulator is also governed by the law of requisite variety (Ashby, 1958) and the principle of viability (Beer, 1979) (Perez Rios, 2010). These principles define viability as the capability of a system to maintain a

separate existence, and assert that a system may only remain viable if it has sufficient variety to compensate for all of the variety that it encounters.

- **Manifestations of the Regulator Archetype**

  The regulator archetype can be found in many rudimentary control systems, and it is also a key element in biological systems. The following are several examples of regulatory systems:

  - **Automobile Cruise Control**

    In the domain of mechanical systems, an automotive cruise control system is an example of the regulator archetype. In this case, constant vehicular speed is maintained by the automatic application of the throttle or brakes.

  - **Endothermic regulation**

    Examples of the regulator archetype are very common in the domain of organisms. Self-regulation and homeostasis are fundamental components of endothermic regulation. This is the process by which warm blooded animals maintain and regulate their body temperature through metabolic processes.

  - **Osmoregulation**

    Another biological example is the process of osmoregulation. In this regulatory process, organisms adjust water and ion balances within their system to ensure that chemical concentrations in fluids remain at a safe level.

  - **Glucoregulation**

    This is a biological process that is responsible for maintaining the glucose level in living organisms. The system homeostatically controls glucose levels by varying the release of insulin and glucagon (Aronoff, Berkowitz, Shreiner, & Want, 2004).

4.5.3. The Organizer Archetype

It is with the organizer archetype that we first see a capability for internal reorganization and the potential for adaptation. The organizer can modify its internal structure, relationships, pathways, and configuration to address external variety. It is not restricted to retaining its original configuration, but may alter itself, perhaps permanently, to address changing environmental conditions.

- **Archetypical Behavior**

The organizer is somewhat analogous to Willmer et al.'s *conformer*, which has the capability of undergoing "changes of internal state similar to the changes of state imposed externally. [...] Conformers do not attempt to maintain a homeostatic condition for the whole body." (Willmer, Stone, & Johnston, 1999, p. 12)

The organizer archetype, however, goes beyond merely changing its internal state in order to accommodate external changes. It has the capacity to reorganize and restructure itself in response to external variety. This demands that the hierarchical, functional, and communications connections within the organizer archetype are not fixed and, in some cases, may be fluidly altered in response to change. This internal flexibility provides a new capacity to the organizer that was not present in either the endurant or the regulator: the ability to independently adapt. Where the prior archetypes had the capacity to collect and use energy to maintain their viability or to regulate their internal settings to absorb variety, the organizer is able to make meaningful changes to itself in response to a changing environment. Some examples of these reconfigurations are shown in figure 14 and are described below.

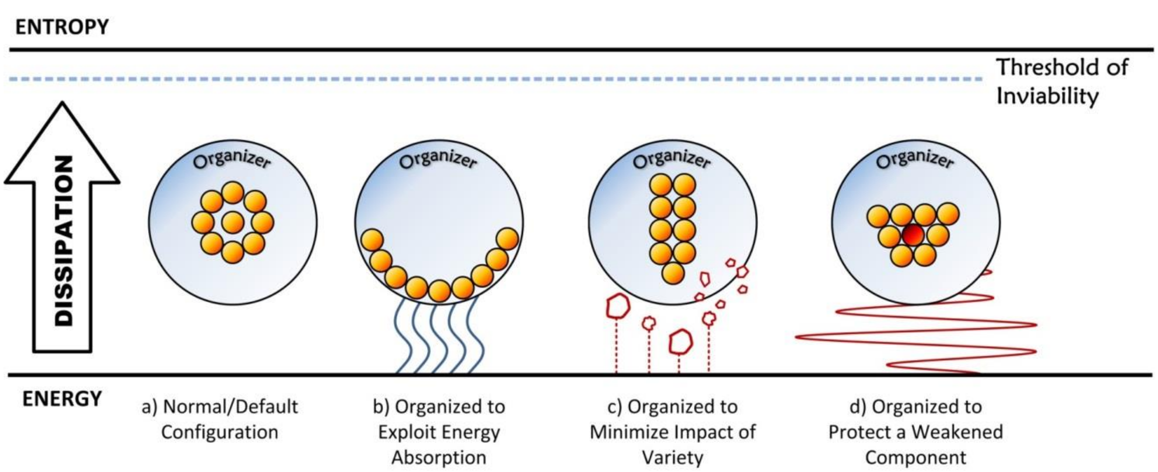

Figure 14. Variations of the Organizer Archetype's Behavior

If one considers figure 14-a to represent the normal or default configuration of the organizer archetype, sub-figures b, c, and d represent other configurations that one might expect to see in response to external variety. Figure 14-b, for instance, shows an example of how the organizer archetype might restructure itself for energy collection. Here, its sub-components are arranged in a manner that allows them to optimally absorb free energy (shown as waves) from the environment. This configuration, however, is not well suited to all environmental conditions.

In figure 14-c, the organizer archetype is exposed to emergent temporal variety (shown as boulders). In this case, the system has departed from the configuration that was used for energy collection and has moved into a formation that minimizes its exposure to risk. While such a configuration will not prevent the system's components from being impacted by the variety, this adapted arrangement allows the system to minimize the impact and 'prioritize' the sub-component that is most likely to incur damage.

Finally, figure 14-d shows the organizer archetype arranged in a protective or guarding formation. In this case, one of its sub-components has sustained damage, perhaps from the impact of emergent variety in figure 14-c. The system has now reorganized to protect the damaged component against environmental variety (shown as a wave of varying amplitude) until it can be repaired or restored.

Of course, the configurations shown in figure 14 only touch on the most fundamental capabilities of the organizer archetype. Because of its ability to alter or reconfigure its internal structure, it has the capacity for adapting to the loss of sub-components by reorganizing or re-tasking other components to accommodate the loss. This gives it a distinct advantage over the endurant and the regulator archetypes, because it is not completely reliant on repairing damaged components to remain viable.

Further, the flexibility of configuration that the organizer archetype possesses may allow it to operate in a geographically distributed manner. This ability is beyond the capacity of either the endurant or the regulator archetypes. This means that the components of an organizer system, although physically separated, remain a connected, cohesive entity which is linked by communication and logistic channels. Of course, with geographic distribution comes the need for distributed command. As a result, it is with this archetype that system concepts such as redundancy of potential command are first seen. The following section discusses the system principles that are dominant in the organizer archetype and how they are related to the system's archetypical behavior.

- **Governing System Principles**

  - **Self-Organization**

    The capacity of self-organization is described by Allena Leonard (1990) as the process by which a system moves beyond self-regulation, to alter its internal structure to increase its level of adaptability. This principle is the defining characteristic of the organizer archetype. Through the self-organization process, this system has the capacity to adapt to environments that were never conceived of at the system's inception. Beyond reorganizing its own sub-systems, the organizer's capacity for self-organization leads to a capacity for integration. Because it is not limited to simply repairing and maintaining its current configuration, the organizer may also integrate elements from the environment as sub-components within its system boundary. This ability is one of the major contributors to the organizer's capacity to adapt and evolve based on environmental conditions and material availability.

- **Adaptation**
  Adaptation is a natural extension of self-organization and is a fundamental property of the organizer archetype. This principle is manifested by the ability of a system to modify itself (or its parts) to make it more fit for existence under the conditions of its environment (Merriam-Webster, 2015). For the organizer archetype, the process of adaptation may be as simple as the rearrangement of connections within the same hierarchical layer or as evolutionary as a structural change in the system that allows it to address and overcome massive changes in the environment. In all cases, however, systemic adaptation within the organizer archetype is limited to changes within the organism, or the system itself, and does not intentionally compel adaptations in the environment outside of the system. This is an important distinction that separates the organizer archetype from other archetypes that will be described later.

- **Redundancy of Potential Command**
  Redundancy of potential command is a governing principle which states that power and control should be vested in the location that has the most information or is best equipped to use it (McCulloch, 1965). This principle may be realized in the organizer because it is the first archetype that possesses the capacity for reorganization – a capacity which is necessary to delegate command authority. Inherent in this principle is the capacity for systemic distribution that was discussed earlier. Here, elements of the system may be physically separated, yet maintain connected through communication and logistic channels. This separation of system components is at the root of the need for redundancy of potential command, because it dictates that information requiring action may arrive at the system in different places. To remain viable, the component or

location where the information is received must have the ability to initiate a systemic response.

- **Holism**

  The concept of holism was advanced by Jan Smuts (1926) and asserts that whole things differ from a mere collection of components, because wholes represent a specific arrangement of those components in concert with their related activities. Here, Smuts draws from Aristotle's principle of wholeness, which famously asserts that the whole is greater than the sum of its parts (Aristotle, 350 B.C.E).

  For the organizer archetype, holism is an essential element of the system, because holism is at the root of emergence. Therefore, only when the system acts as a whole and reorganizes itself in response to environmental conditions can emergent properties arise that are not present in any of the components alone.

- **Emergence**

  Described by Samuel Alexander (1922), emergence is the qualities or characteristics that arise in the higher levels of a system that are dependent upon, but not present in, the lower levels. The concept of emergence applies equally to systems whose components are distributed within a multi-layered hierarchy as it does to the systems that are in a flat structure of interconnected elements. The essential element in emergence is not the complexity of the organization, but rather the fact that distinct characteristics do not arise until the elements are unified into a system.

  For the organizer archetype, emergence is a direct result of the self-organization and adaptation that occurs when a system changes itself in response to the environment. While the emergence is manifested within the system, it is driven by a dynamic interchange between the system and its environment. As a result, the total emergence that any system is capable of cannot be known without first knowing the amount of variety that its environment can generate.

- **Minimal Critical Specification**

  The principle of minimal critical specification was espoused by P.G. Herbst (1974) who described it as the smallest set of core requirements with which an operable unit can produce a satisfactory result without external control of its internal functions. While minimal critical specification is not an intrinsic capacity of the organizer archetype, it should be a guiding light to those who are trying to manage or govern such systems.

Because of the diverse configurations that an organizer archetype is capable of attaining, it is unlikely that a governing entity could know what the optimum configuration will be in advance. In light of this, if the governing system limits itself to just specifying the goals and objectives that need to be obtained, then the system is free to seek a functional approach that achieves those goals in the most efficient manner. Further, by working with a minimal critical specification, the system leverages its ability to employ redundancy of potential command. As a result, real-time decisions can be made at the place best equipped to make such decisions.

- **Dynamic Equilibrium**

  Lars Skyttner (2005) describes dynamic equilibrium as the manner in which a complex system maintains overall stability by altering its internal equilibrium set-points to better correspond to internally or externally generated variety. While the regulator archetype does exhibit some degree of dynamic equilibrium in its heterostatic adjustments, those changes are always undertaken with the objective of maintaining the stability of set-points that have higher priority in the system hierarchy. This is not necessarily the case, in the organizer archetype. Here, the system may permanently alter one or more of its internal set-points to match a 'new normal' that arises in the environment. An example can be seen in the environmental balance between foxes and rabbits.

  Assuming that rabbits are the sole prey available to foxes within the environment, the size of the fox population is limited to the availability of rabbits for food. While the size of the fox population may oscillate around a balancing point, over time it remains at a level consistent with the size of the rabbit population. Of course, the rabbit population is not strictly limited by the number of foxes that are consuming them, but is also limited by the availability of grasses and other food necessary for their subsistence. In the event that a climate change dramatically alters the availability of grass, the rabbit population will immediately begin to decrease. Accordingly, the shortage of rabbits will then impact the size of the fox population. Eventually, however, both populations will reach a new point of equilibrium which balances the number of animals with the capacity of the altered environment to support them.

- **Requisite Variety and Viability**

  As with the other archetypes, the organizer is also subject to the law of requisite variety and the goal of maintaining viability. The manner in which it achieves these goals, however, is significantly different. Unlike earlier archetypes, the organizer archetype is not forced to address variety with a strict, unflinching set of parametric responses. On the contrary, the organizer can absorb environmental variety by addressing it with its own emergent variety, which is created in direct response to the change. This gives the organizer archetype the capacity to maintain its viability in emerging conditions that were never envisioned at its origination. Therefore, the organizer's ability to adapt to its changing environment through self-organization and internal modification gives it an evolutionary advantage in maintaining its own viability.

- **Manifestations of the Organizer Archetype**

  - **Insect Colonies**

    In discussing self-organizing software, Serugendo et al. (2011) discuss the colonies constructed by ants, bees, wasps and termites as examples of self-organizing natural systems. Here, the animals are able to seamlessly integrate their individual activities, while each of them appears to operate independently, without any centralized supervision, to accomplish a unified goal. Such behavior extends beyond the construction of their burrows and hives to include the manner by which they cooperatively establish paths for the collection of food. Serugendo (2011) points to the activities of foraging ants that leave chemical markers between their colony and a discovered food source. Over time, the paths created by many ants eventually converge to a path that is optimal, based on the environmental conditions. This path, in totality, cannot be seen by the individual ants, but can only be perceived by an outside observer.

  - **Government**

    Governments are another example of emergent mechanisms for self-organization that arise to provide structure and accountability to social collectives. As members of the organizer archetype, governmental systems have the capacity to dynamically change to address the needs of the populace. Ranging from early monarchies to totalitarian states to democratic collectives, governments emerge within a social collective in order to allow the population to confront emerging conditions (variety) that they are unable to address individually. As time and conditions change, the power structure and authority of the governing entities also evolve, often by force, to better match the needs of its constituency.

- **Pedestrian Traffic**

  A final example of the organizer archetype can be seen in pedestrian traffic. In their analysis of pedestrian flow, Hoogendoorn and Daamen (2005) discuss the examples of self-organization that can be found in pedestrian traffic. They describe traffic lanes that organically emerge in the event of bi-directional foot traffic. Further, they provide examples of how groups of pedestrians moving at the same speed tend to form channels of overlapping layers, each of which matches the speed of the collective. The authors also describe diagonal, cross-cutting pedestrian flows that emerge within the larger traffic patterns to support the traversal of non-conforming pedestrians. In all cases, these patterns are not part of a collective decision making process or plan; rather, they are an emergent quality of interacting individuals.

4.5.4. The Migrator Archetype

Where the first three archetypes focused on the system and how it adjusted or adapted its internal structure to accommodate external variety, the final archetypes take a different approach. Beginning with the migrator, these archetypes focus on making changes outside of the system in order to avoid, deflect, or eliminate variety.

The migrator archetype addresses environmental variety by avoiding it. When faced with change or emergence that is likely to negatively impact the system, the migrator will move away from the risk. This behavior is also holds true in pursuing better environmental conditions. The migrator is not restricted to remaining at its current position, but may move to a location that better suits its needs for energy, resources, and stability.

- **Archetypical Behavior**

  The migrator archetype is similar to Willmer's *avoiders,* which are characterized by mechanisms that allow them to escape from environmental changes by changing their position in space or in time (Willmer, Stone, & Johnston, 1999). Willmer, of course, is not implying that these systems are capable of time travel, but rather, that such systems may employ hibernation, torpor, or diapause in order to avoid a hostile environment. The reader should note, though, that for the purpose of these system archetypes, Willmer's time avoidance behavior is better represented by the endurant archetype. Still, the process of spatial avoidance that he describes is an important characteristic of the migrator.

When faced with environmental changes, the migrator archetype traverses its environment to find better conditions. While this behavior might be attributed to the migrator's efforts to avoid negative variety, it applies equally well to the system's efforts to relocate in order to afford itself improved conditions. This is illustrated by a system that migrates to a new location in order to take advantage of a more abundant energy supply.

While the earlier archetypes were largely concerned with temporal variety (changes and emergent conditions that occur over time); the migrator must be equally concerned with issues of contextual variety (the static variety that it must overcome if it chooses to traverse its environment). Figure 15 shows the migrator archetype sitting in a basin of stability. Each of the surrounding contours represents a path that it may take to leave the basin and the contextual variety it will encounter as it travels. The paths shown here are derived from the terrain which was illustrated in figure 9.

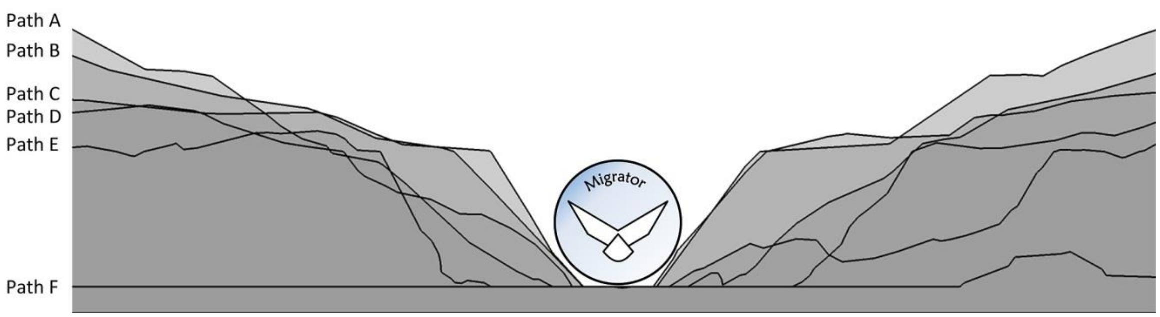

Figure 15. The Migrator Archetype and Paths of Contextual Variety

As an example, assume for a moment that the migrator object shown in figure 15 represents a mouse that is living at the bottom of a crevasse. Through some mechanism, the mouse becomes aware that water will soon flow into the crevasse and flood the valley. In order to survive, it will need to move to higher ground. In looking around, the mouse can see that there are a number of paths that lead to higher ground – some of them more challenging than others. It is the task of the mouse to identify the path that a) it can successfully traverse, b) will bring it to a safe location and c) it can follow with the minimum use of energy and the least accrual of damage. These are a just a few of the challenges that are faced by the mouse – and by the migrator archetype.

Of course, figure 15 represents an environment where the migrator archetype has perfect knowledge of its surroundings. This is rarely the case. As with temporal variety, the physical variety that surrounds the migrator – the variety which it can see or predict – can be described as contextual change. In this case, even though the migrator does not have perfect knowledge of the surrounding environment, future conditions can be predicted based on past experience.

There is, however, contextual variety that is beyond the experience of the system. These might be represented by stark changes in topography which cannot be predicted until they are encountered. Examples include a path that is blocked by a sheer cliff face, or another that ends on the shores of an ocean. Even though these are static conditions that may have always existed, from the perspective of the migrator archetype they represent *contextual emergence* that must be discovered and dealt with.

Along the same lines, the contextual variety surrounding the migrator archetype may also create boundary conditions which are a result of the systems own limitations. For example, a fish is limited to being in a body of water. This fish, in some cases, may move between different bodies of water, but it cannot migrate from the ocean to the dry land. Amphibians, on the other hand, do not suffer from that constraint and are able to traverse water and land interchangeably. Similarly, flightless creatures must travel along the ground, and air breathing animals must remain in an environment with adequate levels of oxygen. These are all examples of the contextual boundaries that govern the migrator archetype.

- **Governing System Principles**
  - **Basins of Stability**
    The concept of basins of stability is defined by Clemson (1984) as regions of stability within a volume of space which are physically bounded by regions of instability. This principle dictates that as a system attempts to move between two stable positions, it must traverse (and overcome) regions of instability. A natural extension of this concept is the idea that the system may have some choice in the path that it follows between two basins of stability. In selecting a course through the regions of instability, the system makes tangible decisions that will affect the impact that it will experience in terms of energy consumption and increase of entropy.
  - **Stability/Instability**
    Where earlier archetypes focused on maintaining stability within the system itself, this archetype is more concerned with traversing intervals of instability to find a point of equilibrium between itself and the environment. The nature of this archetype and its

relationship to stability is well represented in Tom Benson's discussion on flight controls. He states, *"there are two modes of aircraft control: one moves the aircraft between equilibrium states, the other takes the aircraft into a non-equilibrium (accelerating) state. Control is directly opposed to stability"* (Benson, 2002, p. 9).

In describing control as being opposed to stability, Benson makes a notable point. All systems are driven by the laws of entropy to eventually achieve stability in the form of maximum dispersion. Left to their own devices, all systems will inevitably find a point of stability, usually by the most expeditious path. However, the quickest path to stability is rarely the one that is in the best interest of extended system viability. As a result, the system must exercise control to maintain the system's fragile position of instability which allows it to resist entropy, collect free energy and maintain viability.

- **Control/Feedback**

The discussion of stability and instability leads directly to the concept of control. Control is described by Benson (2002) as the mechanisms which are used to move a system between two equilibrium states or into a non-equilibrium state. For the migrator archetype, control is represented by all of the mechanisms that the system uses to maintain its trajectory along a selected path. There are times, however, when a system may attempt to traverse a path only to discover that it lacks the energy or functionality to overcome the obstacles that it encounters. In these cases, the system must use its system of feedback and control to alter its current path and chart a new course through the environment.

- **Dynamic Equilibrium**

The principle of dynamic equilibrium for the migrator archetype is closely coupled with the concept of basins of stability. Because the migrator exists within a domain that has many basins of stability, each of those locations represents a distinct point of relative equilibrium in which it may rest. By using its system of control and feedback, the migrator can navigate between these unique points of equilibrium at the expense of energy and increased entropy. In making the decision to move between points of dynamic equilibrium, the system must consider the relative costs and benefits of moving versus remaining in place, with an emphasis on maintaining the long term viability of the system.

- **Equifinality**

  Von Bertalanffy (1968) described equifinality as the ability of an open system to reach the same final state from different initial conditions and in different ways. This concept is particularly true of the migrator archetype. Because the migrator is largely governed by the contextual variety in its terrain, these systems are subject to the effects of basins of attraction. These basins are described by Kauffman (1993) as an arrangement of attractors within a volume of space, creating regional basins to which systems will be attracted over time. This means that if a system finds itself moving along the wall of a valley, it will be attracted to the lowest point. Unless the system exerts sufficient energy to overcome this attraction, it will eventually find itself sitting at an equifinal position within the valley.

- **Multifinality**

  The concept of multifinality is the antithesis of equifinality. Maruyama (1963) describes multifinality as the process by which similar initial conditions and/or routing by different paths may lead to dissimilar end-states. For the migrator archetype, this is illustrated by a system that is travelling along a ridgeline. The system is equally attracted to the basins of attraction on either side and, as a result, will eventually reach one of several possible outcomes when it stops expending energy to maintain its position on the ridge. While perfect knowledge of all environmental conditions might allow an observer to calculate which path the system will follow, environmental complexity and contextual variety makes such determinations difficult.

- **Homeorhesis**

  The principle of homeorhesis can be thought of as a form of dynamic homeostasis with one notable exception. Where homeostasis is the process by which a system (or variable) returns to a specific set-point, homeorhesis is the process whereby a system returns to a specific trajectory (Waddington, 1968). Akin to basins of attraction, homeorhesis suggests that when a system is being carried along a path (by a system flow), if it attempts to leave that path, a system of attractors will draw it back. Therefore, in order for a migrator system to escape from a flow within its environment it must expend sufficient energy not only to escape the flow, but also to move beyond the influence of its attractors.

- **Requisite Variety and Viability**

The migrator archetype has a truly unusual challenge when dealing with requisite variety. On the surface, it has the capacity for avoidance, which gives it an ability to avoid the impact of temporal variety and emergence by getting out of the way. However, choosing to traverse the environment forces the system to deal with the challenges that are presented by the contextual variety which surrounds it. In deciding what course of action to take, the migrator must evaluate the cost of remaining where it is and enduring the incoming variety or suffering the expense of energy and the impact of contextual variety that results from avoidance. For better or worse, each of these decisions has a direct effect on the system’s long term viability.

▪ **Manifestations of the Migrator Archetype**

- **Migratory Birds**

According to the Cornell Lab of Ornithology (2006), the primary motivation for bird migration is not to avoid the negative impacts of weather, but rather to incur the positive impacts of food. The lab states,

> *“Birds migrate to move from areas of low or decreasing resources to areas of high or increasing resources. The two primary resources being sought are food and nesting locations. Birds that nest in the northern hemisphere tend to migrate northward in the spring to take advantage of burgeoning insect populations, budding plants and an abundance of nesting locations. As winter approaches, and the availability of insects and other food resources drops, the birds move south again.” (Cornell Lab of Ornothology, 2006, p. 1)*

While the authors point out that changing weather is a motivator for some types of birds, the most significant driver is the quest for food, or the collection of free energy from the environment.

- **Springbok Pronking**

An example of the migrator archetype being used to escape a hostile situation is provided by the African springbok’s response to the cheetah. The springbok is a type of gazelle that avoids predators using a form of stylized jumping called pronking or stotting. When startled, the springbok will leap nearly two meters in the air, bounding and rebounding repeatedly while changing direction on each leap. After as many as six bounds, the springbok will gallop away at speeds up to 88 kilometers per hour (Estes, 1991).

This pronking behavior serves two major purposes. First, it helps the springbok to avoid predators by allowing it to bridge the transition from a complete halt to a full gallop by using quick-paced, rapidly changing bounds to come up to speed. Where most predators are designed for brief, linear bursts of speed, the springbok's quick changes of direction help it to elude predation. Secondly, when a predator observes routine pronking behavior in a springbok, it recognizes that the animal is fit and capable of escape. This increases the likelihood that the predator will seek another, less challenging target (Estes, 1991).

4.5.5. The Insulator Archetype

The insulator archetype protects itself from external variety by adopting and using an external entity for protection. Unlike the organizer, which may incorporate external material into its system boundary, the materials employed by the insulator remain distinct and separate from the system. They are used to absorb variety and to transfer the accumulation of entropy from the system to the insulating material.

- **Archetypical Behavior**

  Where the other archetypes have been engaged in the effort to absorb or avoid environmental variety, it is with the insulator archetype that, for first time, we see the system use the environment itself as a defensive mechanism against variety. The insulator archetype is defined by its ability to use material within its environment to shield, insulate against, or filter the variety that would otherwise increase its own entropy. In effect, the insulator transfers the risk of damage from itself to external materials that it acquires and adapts for its protection.

  An important distinction should be made here. Even though the insulator may fully utilize, and perhaps integrate, the external material for its protection, the underlying system is not transformed, nor are external environment conditions altered. While, from the outside, the insulator and its protective insulation may appear to be an integrated system, they are characterized by the fact that they incur the effects of entropy separately and that the insulator can shed its insulation without changing its underlying identify; e.g. a bear is a bear whether it is hibernating in a cave or it is fishing in the river.

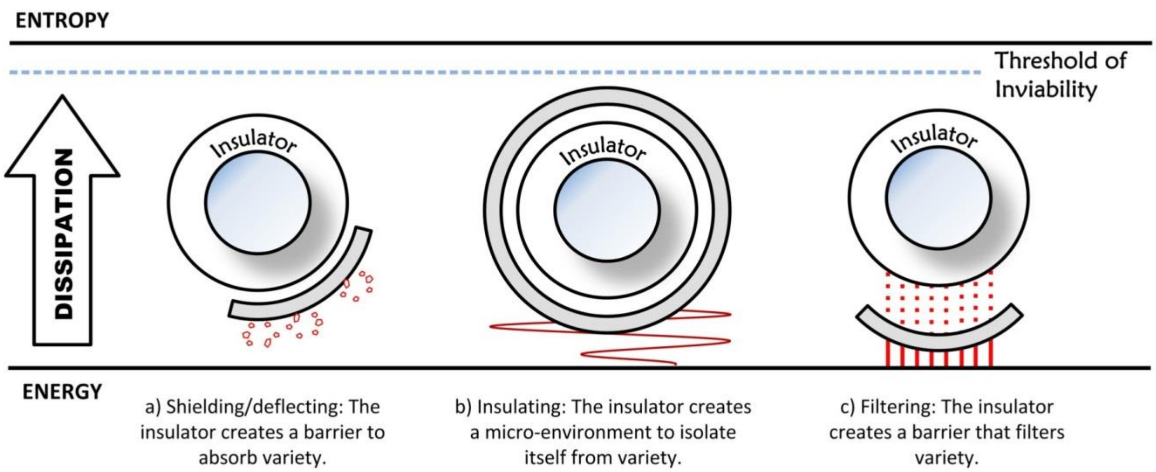

Figure 16. The Insulator Archetype

Figure 16 shows three typical ways that an insulator may employ its protective insulation. These approaches (shielding, insulating, and filtering) are described in the following sections.

- **Shielding**

  In figure 16-a, the insulator uses an external mechanism as a shield against the impact of emergence and change. This shield may be fixed or movable. As conditions change, the shield is positioned to take the brunt of the impact, leaving the system protected. The shield, of course, will incur the effects of entropy, and the insulator is likely to have to replace the shield periodically.

  When considering the material chosen for the shield, one might assume that it would be inert matter, incapable of self-repair or autopoiesis. This is not necessarily the case, though. An insulator may have a symbiotic relationship with another system which allows it to be used as a protective shield. Such an arrangement has both its benefits and its drawbacks. While an open system has the capacity for self-repair and maintenance to increase its longevity, it also has a requirement to collect free energy from the environment in order to remain viable. In an energy-scarce environment, this may place the insulator and its shield in contention for resources.

  Alternately, there are other examples in nature where such a relationship is mutually beneficial. This can be seen in the relationship between the shark and the pilot fish. The pilot fish uses the shark as insulation against other predators. The shark, on the other hand, uses the pilot fish as insulation against disease, as the pilot consumes parasites and debris that accumulate on its skin (Oceanic Research Group, 1995).

- **Insulating**

  Figure 16-b shows another manifestation of the insulator called insulating. In this configuration, the insulator wraps itself with the insulating material, in effect creating a protective, enclosed environment. The reader will note that this configuration in no way alters the external environment; it merely creates an entropy-absorbing barrier between the system and external emergence and change.

  Manifestations of this type of insulating behavior are common. The use of clothing by humans is a type of insulating behavior against a variety of environmental conditions. In frigid weather, protective garments allow heat to be encapsulated and held close to the body to retain warmth. Other examples include hibernacula, or the shelters that animals use for winter hibernation. Here the system, an animal, is encapsulated within a structure that allows it to maintain a safe, warm, and dry environment, even as external conditions dramatically change.

- **Filtering**

  The third type of insulating behavior is shown in figure 13-c. In the case of filtering behavior, the insulating material does not completely block the environmental change or emergence, but rather, it dampens its negative effect on the system. A very common example of a filtering insulator is sun screen. When applied properly, sun screen does not completely block light from reaching the skin. It does, however, diminish the amount of ultraviolet light that penetrates over time. The system (a person) can select the appropriate type of sun screen based on the amount of time that they expect to be outside, the time of year, and the amount of exposure that they desire.

  A more naturalistic example comes from the world of the pig. In addition to using mud for temperature regulation and parasite removal (insulating and shielding, respectively), wallowing also satisfies a filtering requirement. Because of the thin fur on pigs, they are particularly prone to sunburn. The coating of mud that they gather during their wallowing behavior provides a primitive sun screen for the animals during hot weather (Pappas, 2011).

▪ **Governing System Principles**

- **Allopoiesis**

  Perhaps the most significant system principle associated with the insulator archetype is that of allopoiesis. Varella, Maturana, & Uribe (1991) define this as the process of producing material entities other than those required for maintaining the system itself.

While not all insulator systems fabricate their protective insulation, the construction and maintenance of these external structures is common. While allopoietic behavior is prolific in human communities, notable examples can also be found in nature. The honey bee, for instance, works with its fellow bees to construct a hive. The structure of the hive is created from wax, which is chewed by the bee until it becomes soft and is then bonded into cells. When the worker bees crowd together into the hive, they maintain the interior temperature at 30 to 35 degrees Celsius by their presence and activity. This is the temperature that is required to maintain the texture of the wax (Orkin, 2003).

- **Allostasis**
  Allostasis is the process of maintaining system stability by actively adapting to predicted changes in the environment (Wingfield, 2005). This characteristic differs from normal homeostasis in that the system is preemptive in addressing the problem. Instead of waiting for changing conditions, the allostatic system recognizes that a change is coming, and then makes preparations for its arrival. In the case of the insulator archetype, the system will prepare for changing conditions by coopting, integrating, or incorporating itself into an insulating structure. This allows the insulator to avoid the initial impact of changing conditions and transfer the risk to the external entity that it uses for protection.

- **Requisite Variety and Viability**
  Depending on its imagination and on the richness of its environment, the insulator archetype may have a highly diverse capacity for dealing with variety. Because the system uses components outside of itself to block the impact of variety, it is largely limited by only two factors: availability of material and cost of incorporation. It is here that we encounter a notable difference between the earlier archetypes and the insulator. Where the organizer and regulator archetypes expend energy to make internal adjustments and dispose of incurred entropy, the insulator reduces the increase of entropy by using its energy to construct defenses. Therefore, the insulator must consider how much energy will be required to fabricate a protective barrier, as compared to the amount of damage that might be incurred without one. In environments where materials are scare, the insulator must also measure the energy cost associated with obtaining the source materials necessary to create an insulating

barrier. Because of this, the viability of the insulator system is often as dependent on the contents of its environment as it is on the variety that occurs within it.

- **Manifestations of the Insulator Archetype**

In addition to the myriad examples of insulators that have been discussed in this section, there are a few other varieties which each have interesting characteristics.

- **Hermit Crabs**

A master of recycling and innovation, the hermit crab is one of nature's true insulators. Incapable of producing its own shell, the hermit crab will co-opt the shells of other animals that live in its environment. In the (likely) event that there are no other shells available, the hermit crab will incorporate virtually any container that is large enough to protect its soft abdomen. As the hermit crab grows, it will eventually exceed the capacity of its adopted shell and will then be required to identify and relocate into another one (Tricarico & Gherardi, 2006).

Figure 17. The Hermit Crab

- **Aestivation**

Similar to winter hibernation, aestivation is a period of inactivity that occurs during hot weather. Vitt and Caldwell (2014) describe the challenges that are faced by amphibians in desert climates that face long periods of low humidity and no rain. In order to survive, these animals will retreat to deep burrows in moist soil that has a high level of humidity. Here they will become inactive and reduce their metabolisms, with some species remaining in this state for more than 90% of their lives. For these animals, the use of the aestivation habitat, or burrow, to protect themselves from the hostile environment is a clear illustration of insulator behavior.

4.5.6. The Manipulator Archetype

The manipulator archetype expends energy to alter its environment in an effort to reduce the negative impacts of change and emergence and to increase beneficial conditions.

- **Archetypical Behavior**

This archetype takes the next major step beyond the behavior of the insulator archetype. Where the insulator would utilize elements in its environment to protect itself from the change and emergence, the manipulator actually alters the environment to reduce or eliminate the negative impacts.

Figure 18 shows several manifestations of the manipulator archetype in conjunction with the environment. In figure 18-a, one can see the manipulator sitting in the environment as emergent conditions, shown as boulders, approach. Rather than avoiding or compensating for this emergence, the manipulator takes direct action to eliminate or reduce the threat, as shown in figure 18-b. Notably, the manipulator is not only capable of reducing dangerous change and emergence, it is also able to alter the environment for its own benefit, as shown in figure 18-c.

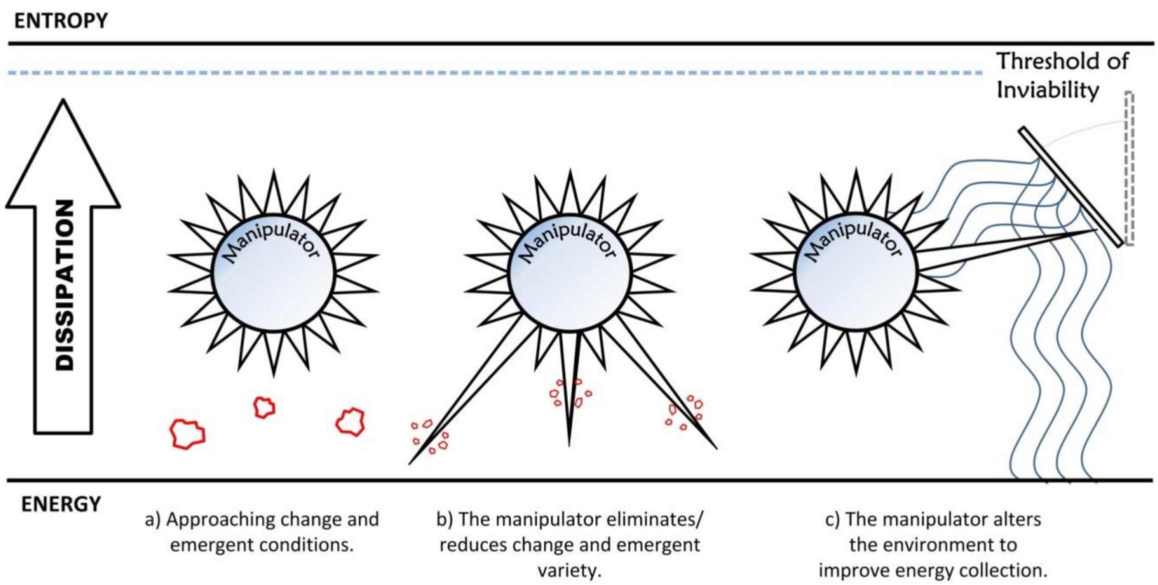

Figure 18. The Manipulator Archetype

While it might be argued that altering the environment is merely an expansion of insulating behavior that encompasses a larger area, there are several distinctions that should be drawn. While the insulator is able to isolate itself from negative influence, the influence remains and it continues to impact the environment and other systems. In the case of the manipulator, the system eliminates the negative influence from the environment. This means that any other system within the manipulator's sphere of influence will also experience the effects of this change. As a result, this expanded area of influence may result in the emergence of reinforcing loops and circular causality when competing systems struggle to adapt the environment to best meet their own needs.

Like the insulator archetype, the manipulator must consume energy in order to create change. The greater the change, the more energy will be required to affect it. Although not immediately obvious, this behavior might actually provide a strategic advantage for energy storage. As the system consumes energy to optimize its environment, it does so with the intention of creating a stable, long-term habitat. If the manipulator is successful in creating this habitat, then it will be able to safely reside there and collect energy for an extended period without suffering the acute impacts of change and emergence. For many biological systems, this process allows them to perform the expensive task of modifying their environment when they are young, thus creating a more tolerable environment for themselves and their progeny in later life.

Another notable distinction between the insulator and the manipulator is the concept of permanence. While insulating mechanisms that are fabricated or incorporated by the insulator may be used for the system's entire lifetime, they rarely have an impact beyond the immediate proximity or the life span of the system. The manipulator, on the other hand, is capable of creating *permanent* changes to the environment. This permanent change is a result of significant variety and emergent impact being redirected from one part of the environment to another. Over time, the diverted variety will create new and unique pathways that it will continue to follow even after the manipulator's environmental change has been removed. Diversion dams, where all or part of a river is directed to a new course, are examples of systems where the altered path will become the preferred path over time.

- **Governing System Principles**

Because the manipulator archetype is governed by the interaction of systems and environments, each trying to influence the other, the governing system principles become more expansive and interconnected than those discussed before. The following principles and theories are associated with the manipulator archetype.

- **Gaia Theory**

  This is the proposal that organisms interact with one another and with their inorganic surroundings to form a self-regulating system that maintains the conditions for life on Earth (Lovelock, 1972). As described earlier, manipulators within the environment are responsible for initiating interactions with the purposeful objective of making the environment more conducive to their continued viability. This goes beyond the passive changes that a system might introduce merely by its presence to real purpose-driven behavior and interaction.

Lovelock's proposition is that this interaction between living things, as they struggle to maintain a livable environment, is actually responsible for driving the self-correcting eco-system that we live in. If the changes introduced by one manipulator are too aggressive, the responses of the other attendant systems will tend to draw it back to a homeostatic mean.

- **Ecopoiesis**
  Ecopoiesis is an extension of Lovelock's Gaia Theory, which theorizes a process by which a sustainable ecosystem may be fabricated on a currently lifeless, sterile planet (Haynes, 1990). While largely the stuff of science fiction, the concept of ecopoiesis is a perfect example of the manipulator archetype at work – completely altering an unlivable environment to make it hospitable to living systems.

- **Morphogenesis**
  Maruyama (1963) describes morphogenesis as a deviation-amplifying relationship that exists between the system and its environment. It results in evolutionary system change. This is particularly apropos in the case of the manipulator archetype, because these systems epitomize the use of positive feedback to alter the environment. The manipulator identifies the area in the environment that must be changed, and then applies continuing pressure to move it beyond its current steady state to a new condition that is beneficial to the manipulator.

  One should note that this new state is not necessarily an equilibrium point, and that the system may not achieve dynamic equilibrium. In order to maintain satisfactory environmental conditions, it may be necessary for the manipulator to continuously expend energy to maintain stasis. Again, this is a cost/benefit decision that the manipulator must make when initiating and maintaining changes to the environment.

- **Punctuated Equilibria**
  The principle of punctuated equilibria states that most species exhibit very little evolutionary change over time, however, when significant evolutionary changes do occur they are rapid (Eldredge & Gould, 1972). The manipulator is likely to be either a causal agent or a contributor to the emergence of punctuated equilibrium. In the event that significant new conditions emerge in the environment, the manipulator is likely to

take corrective action to ensure its own viability. The changes that the manipulator makes to accommodate the environmental emergence are equally likely to force the adaptation of other proximate systems. Further, if a manipulator system moves into an area and begins to alter the environment, its presence is likely to create the emergent conditions which force other systems to react.

- **Purposeful Behavior**
  Rosenbleuth, Wiener, and Bigelow (1943) identify purposeful behavior as a fundamental precept of systems theory, defining it as the actions undertaken by an entity with the objective of achieving an identifiable goal or end state. This system principle is at the heart of the manipulator archetype. While other system archetypes may purposefully change their own configuration in order to remain viable, the manipulator purposefully changes the environment with the intent of assuring long-term viability.

- **Anthropization**
  In describing anthropization, Levins and Lewontin state,

  > *"In human evolution the usual relationship between organism and environment has become virtually reversed in adaptation. Cultural invention has replaced genetic change as the effective source of variation. Consciousness allows people to analyze and make deliberate alterations, so adaptation of environment to organism has become the dominant mode" (Levins & Lewontin, 1985, p. 69).*

  This is a fitting description for the function and effect of the manipulator archetype. Rather than merely being impacted by the environment, the manipulator alters the environment and then becomes, itself, the causal factor that drives adaption in the systems that coexist with it.

- **Manifestations of the Manipulator Archetype**

The world is replete with examples of the manipulator's impact on the environment. The following are a few noteworthy examples that illustrate how living systems alter the environment to their own benefit.

- **The Ecosystem Engineers**

  In describing ecosystem engineers, or animals that alter their environment for their own benefit, Jones, Lawton, and Shachak discuss the beaver as a prime example. They say "by cutting trees and using them to construct dams they [beavers] alter hydrology, creating wetlands that may persist for centuries" (Jones, Lawton, & Shachak, 1994, p. 373).

  It should be noted that in their discussion of ecosystem engineers, Jones, Lawton, and Shachak draw an important distinction when they separate autogenic engineers from allogenic engineers. They describe autogenic engineers as those who change the environment via their own physical structures, i.e. their living and dead tissues. Allogenic engineers, on the other hand, change the environment by transforming living or non-living materials from one physical state to another using mechanical or other means (Jones, Lawton, & Shachak, 1994). Either of these categories would be classified as a manipulator if, a) the result was purposeful, b) the activity was either intended to or effectively reduced the impact of change and emergence on the system, and c) the affected area extended beyond the boundary of the change to potentially impact other systems.

- **Agricultural Irrigation**

  Humans, as ecosystem engineers and manipulators, make significant modifications to their environment in order to make it arable and livable. Irrigation is one of the most noteworthy of these efforts. By diverting water to support agriculture, humans significantly alter the environment, support the growth of new plants, and frequently displace wildlife that already exists at the location. These agricultural efforts support the production of food or material for humans and their livestock and often make areas habitable that, otherwise, would not be.

- **Road Systems**

  The development of highway systems is another type of environmental manipulation by humans. While the immediate benefits of road construction are not as clear as those that result from irrigation, they still provide mechanisms for reducing the impact of change and emergence on human societies and they enhance human viability. The first such benefit comes because roads reduce the contextual variety (impediments to travel) that humans would encounter as they migrate. The presence of roads allows communities to quickly evacuate in the event of an approaching problem, thus saving lives and increasing longevity. Further, the road systems facilitate the transport of food and supplies between geographically separated regions. This allows communal areas to specialize in one or more key activities without being required to locally provide all of the services needed to survive; e.g. one region can focus on agriculture, while another focuses on mining.

4.6. Summary

By examining and synthesizing the principles that exist in the systems theory body of knowledge, this chapter has developed an environmental model that represents *the system universe* - a rudimentary model of the basic concerns of a system. While admittedly coarsely grained, this model describes the struggle of all open systems to collect energy, displace entropy, and deal with the change and emergence that occur over time and within the context of their environment. From this model, a collection of system archetypes were derived. These archetypes were developed based on *how* they dealt with environmental challenges, with a specific emphasis on the manner in which they absorbed variety and maintained their own viability. The archetypes that emerged from this study are shown in figure 19 and are summarized below.

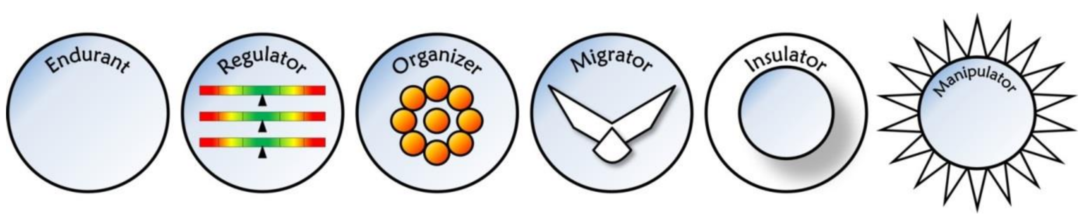

Figure 19. The System Archetypes

- **The Endurant**

  While it does have the capacity for autopoiesis and self-maintenance, the endurant archetype has a fixed internal configuration. The manner in which it gathers, converts, and distributes energy within its system boundary is firmly established and immutable. While it may have some internal redundancies to enhance its resilience in the face of environmental impacts, it cannot internally reorganize itself or adapt to changes.

  When faced with changing or emergent conditions, the endurant archetype relies on its own 'toughness' to endure the impact. Like a metaphorical turtle, endurant systems retreat within their own shell and hope that it provides adequate protection against whatever happens next.

- **The Regulator**

  The regulator archetype uses a system of adjustable internal set-points to compensate for environmental changes. Synonymous with the internal temperature regulation seen in mammals, the regulator will adjust the values of low-priority variables in order to maintain the stability of more critical ones. Incapable of adaptation, the regulator is limited to the total range of its internal variables. If external conditions exceed the regulator's capacity to adjust, then the system will suffer damage, an increase of entropy, and, potentially, death.

- **The Organizer**

  It is with the organizer archetype that we first see the capacity for adaptation. In the face of environmental changes, the organizer is capable of altering its internal configuration, connections, and relationships to deal with variety in new and emergent ways. While no system can handle unlimited variety, the organizer has the potential to deal with variety that was not conceived of at the time of its origination. Unlike the endurant and the regulator, the organizer has the capacity to modify its own configuration and, potentially, to eliminate or minimize the impact of internal components that have suffered damage and an increase in entropy.

- **The Migrator**

  The migrator archetype deals with the approach of change and emergence by avoiding it. Rather than remaining in a static location, these systems are capable of traversing their environment in an effort to reduce the impact of variety. While this approach allows them to side step some types of damage, it also requires that they deal with the impediments and contextual variety that surrounds them. Because of this, they may incur more damage by retreating than they might have from staying in place.

- **The Insulator**

  The insulator archetype deals with approaching variety by adopting or fabricating shields, insulation, or filters using material that is available within its environment. In doing this, the insulator transfers the risk of impact from itself to an external entity, allowing entropy to accumulate there, rather than within its own boundaries. As this defensive barrier is damaged by change and emergence, the insulator may have to discard it and locate another form of external defense.

- **The Manipulator**

  The most dynamic of the archetypes, the manipulator avoids the impact of emergence and change by altering its surrounding environment. Not limited to eliminating threats, the manipulator may also change its environment to increase beneficial conditions. Such efforts are likely to include altering the environment to increase the availability or accessibility of energy and resources, as well as eliminating competitors that threaten the environmental balance. Often the most expensive in terms of energy consumption, the manipulator relies on reducing the impact of entropy rather than accommodating its effects.

5. CONCLUSIONS

This chapter begins with an exploration and interpretation of the relationships that all of these archetypes share in terms of energy, entropy, and environmental impact. Here, the archetypes will be shown as a related continuum in which each of them deals with a common environment using their unique capabilities to survive. This is followed by an examination of the assumptions and limitations that were identified in the research proposal and the impact, if any, that these factors had on the study. After considering these issues, the implications of this study will be examined in detail. In discussing the implications, particular emphasis will be placed on theoretical, methodological, and practical contributions that this research may have on the domain of systems theory. Finally, the chapter concludes with a discussion of some of the future research opportunities that emerge from this study.

5.1. An Interpretation of the Archetypes as a Related Continuum

While the preceding sections have addressed the nature, distinctions, and capabilities of each of the archetypes independently, it should be noted that system archetypes are rarely found in isolation. For instance, while virtually all systems have endurant capabilities, a system will rarely employ that behavior if it is less expensive to use an alternative course of action. This section will examine the collected archetypes as they exist on a continuum and will discuss how they vary in their approaches to dealing with change and with the environment.

5.1.1. Energy versus Entropy

As discussed throughout this section, a system's behavior in relation to energy consumption and entropy accumulation are key aspects in understanding its categorization as an archetype. When the archetypes are collected into a continuum, they can be ordered in a manner that is consistent with their relative consumption of energy and, conversely, the relative importance of displacing entropy. Figure 20 shows the collected archetypes arranged in such a continuum.

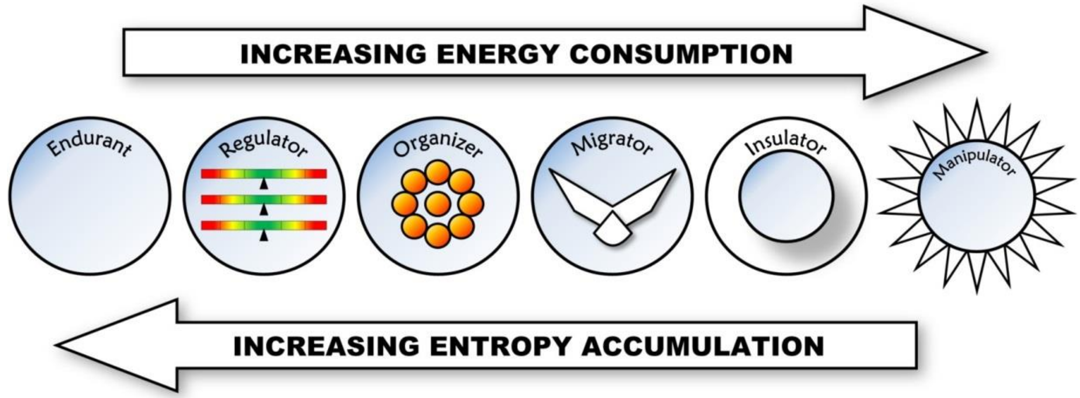

Figure 20. Energy and Entropy Relative to the System Archetypes

In figure 20, the two arrows illustrate the relative efficiency of each of the archetypes in terms of energy consumption and the accumulation of entropy. As the narrative below will explain, this inverse relationship is largely driven by the manner in which these systems address variety and the impact that change and emergence has on the system itself.

- **Relative Energy Consumption of the Archetypes**

  As shown by the top arrow in figure 20, archetypes on the left of the continuum are less driven by energy concerns than those to the right are. This can be explained by examining each of the archetypes and its relative energy needs. The following narrative discusses the archetype's use of energy as related to their archetypical behavior, beginning with the lowest (the endurant) and proceeding to the highest (the manipulator).

  - **The Endurant**

    The endurant archetype survives by relying on its ability to endure the impact of change and emergence. Its energy reserves are mostly used for functional performance, sustenance and autopoiesis; they are generally not used to directly confront variety.

  - **The Regulator and the Organizer**

    These archetypes consume some energy in performing the activities necessary to regulate or internally re-organize the system to address variety. Depending on the efficiency of the system, those activities may be significant consumers of energy reserves. Still, like the endurant, the energy consumed by these types of systems is largely related to its function, sustenance, and autopoiesis.

- **The Migrator**

  It is when we reach the migrator archetype that we see the first major transition in the consumption of energy. Because the migrator uses energy to escape the impact of change and emergence, it is highly reliant on energy reserves. In reality, if the migrator has sufficient energy and agility, it can avoid much of the temporal variety that might increase its entropy. This capacity to avoid temporal variety, however, comes at the expense of the contextual variety that impacts the system as it moves through the environment.

- **The Insulator**

  By using its energy to create shields, insulation, and filters, the insulator archetype can transfer the risk of emergence and change from itself to an external entity. Depending on the availability of material and the frequency of replacement, the construction of external defenses may be very expensive in terms of energy, thus making the system highly dependent on renewing its energy resources.

- **The Manipulator**

  Perhaps the heaviest energy consumer of all the archetypes, the manipulator uses its energy reserves to change the environment and to effectively eliminate the impact of variety. Because of this, the manipulator must maintain energy reserves that are large enough not only to sustain itself, but also to maintain the changes that it has created in its environment. Further, because of competition and actions that are taken by other systems (particularly those that wish to restore the environment to its previous state), the energy costs of maintaining the environment may be greater than those required for the initial conversion.

▪ **Relative Entropy Accumulation**

The lower arrow in figure 20 reflects the relative accumulation of entropy in each of the archetypes that occurs as a result of its efforts to absorb/destroy variety. As one might expect, the consumption of energy and the accumulation of entropy have a complementary relationship which is reflected in the figure. The following list provides a discussion of each archetype and its relative accumulation of entropy from the lowest (the manipulator) to the highest (the endurant).

- **The Manipulator**

  Because the manipulator archetype expends energy to eliminate or reduce the impact of change and emergence, it is likely to be subjected to less entropy than the other archetypes. This does not mean, however, that the manipulator is immortal. On the contrary, the manipulator is still subject to the impacts of temporal emergence that it is exposed to before it can make environmental modifications, as well as to the impacts of any change that it elects not to mitigate.

- **The Insulator**
  The shields and filters that the insulator constructs in order to absorb variety allow it to transfer the accumulation of entropy from itself to its protective mechanisms. As entropy builds up in these components, they can be shed or exchanged for other defenses. Regardless of how well the system is insulated, though, some level of entropy still filters through and gradually degrades the underlying system.

- **The Migrator**
  As the migrator traverses the environment, it can potentially avoid much of the impact of temporal variety. It is, however, still exposed to the contextual variety that it encounters during its travels. While one hopes that the contextual variety is less impactful than the emergence and change that the system is attempting to avoid, this is not always the case. Further, as the system escapes from one form of temporal variety, it may collide with other temporal variety at the new location. Ironically, in its efforts to avoid the impacts of variety, the migrator may receive even greater exposure.

- **The Regulator and Organizer**
  Somewhat more limited in their ability to absorb change, the regulator and the organizer archetypes are subject to more significant accumulation of entropy. Because these archetypes are inescapably bound to the conditions in their environment, they must absorb all of the variety that arises. Accordingly, even a single dramatic change may be enough to overwhelm them. Because of this, the bulk of their energy is likely to be used in eliminating the entropy that accumulates in their system.

- **The Endurant**
  With no mechanism for displacing or destroying variety, the endurant is subject to the full brunt of variety that occurs in the environment. Its lifecycle is a constant battle to remove the effects of entropy as they occur in order to maintain viability.

5.1.2. Allomorphosis versus Automorphosis

The terms automorphosis and allomorphosis have been used in both science and systems engineering (Yolles, 2006) (Niklas, 1994), still the use and application of these words is varied enough that their definitions require special attention here. For the purpose of this study, automorphosis represents the activities and effects that a system accomplishes by modifying itself or its own configuration. Alternately, allomorphosis describes the activities and effects that the system achieves by modifying things outside of itself; i.e., the environment. In considering allomorphosis, the author stipulates that all systems, simply by virtue of their existence, have some impact on the external environment. However, this discussion focuses on the *purposeful acts* that the system undertakes to change the environment.

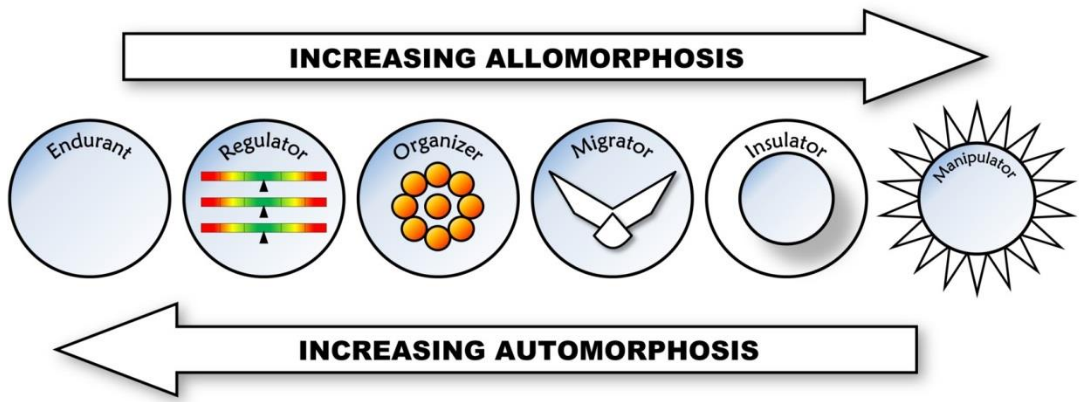

Figure 21. Allomorphosis and Automorphosis Relative to the System Archetypes

As with the consumption of energy and the accumulation of entropy, these two concepts have a complementary relationship which is illustrated in figure 21. The following text describes their manifestations in each of the archetypes along the continuum:

- **The Endurant**

  While the endurant archetype does not possess a high degree of automorphic capability, it does have some capacity for internal change. Specifically, it has the autopoietic ability of self-repair and it has the capacity to collect, convert, and store energy for future use.

- **The Regulator**

  The regulator archetype is highly automorphic. Its entire response to environmental change is prefaced on the ability to alter its internal set-points to accommodate change. Like the endurant, though, this archetype effects very little change to the outside world and, thus, displays little allomorphic ability.

- **The Organizer**

  Like the regulator, the organizer archetype also survives by making changes to its internal configuration – an automorphic behavior. However, while making these changes, the system also has the capacity for adaptation. Over time and with the proper stimuli, an organizer system may transform itself completely. Although passive, this does have an allomorphic impact on the environment. Instead of being comprised of the original system, the environment now contains the adapted system with all of its inherent characteristics.

- **The Migrator**

  The migrator archetype represents the transition point between systems that are mostly automorphic and those that are predominantly allomorphic. While the migrator archetype can be viewed as an allomorphic system, it requires some explanation. Because the migrator traverses its environment in order to avoid the impact of emergence and change, it is effectively changing its position relative to the environment. This means that, after it has moved it has altered two environments, the one where it used to be has lost something (the system) and the one where it has arrived has gained something. Depending on its mode of travel, the migrator may have also impacted the environments that it traveled through while in route from its original location to its destination. Still, any changes made to the internal structure or to the configuration of the migrator are generally limited to the collection and consumption of energy.

- **The Insulator**

  It is with the insulator that we first see a purposeful impact on the environment. In order to construct shields and filters, the insulator must take things from the environment and convert them for its use. During this application, the material is likely to be exposed to a greater amount of variety than it would normally have experienced. As the materials are exploited and shed by the system, there are additional allomorphic impacts to the surrounding environment.

- **The Manipulator**

  Finally, the manipulator archetype approaches the environment with the specific intention of making alterations. It is almost purely allomorphic in its behavior, making changes to the environment in order to reduce or eliminate the requirement for it to make changes to itself.

5.1.3. Which Archetype is the Right Archetype?

As this section has demonstrated, each archetype has different requirements in terms of energy, entropy, and impact within itself and its environment. For those who are observing or governing a system, it may be difficult to decide which approach is best, particularly if a system is possessed of more than one archetypical capability. While prescribing a specific solution is beyond the scope of this research, it should be noted that, in some cases, there may be one archetypical approach that is better suited than another.

At a minimum, one should have an understanding of which archetypical capabilities are represented within the system under study. Complex systems are likely to represent several archetypes at varying levels. With this in mind, one must then determine the system's current state in terms of energy and condition (accumulated entropy). For instance, a system that has already sustained significant damage is unlikely to benefit from an endurant approach. Nor will a system that is very low on energy have the capability to significantly manipulate its environment. Finally, one must examine the potential variety that is expected to be encountered and determine what measures are most likely to absorb or destroy it.

While there can be no perfect knowledge, and emergent conditions may present unexpected variety, it is possible to select an archetypical approach that is best suited to addressing the current conditions based on the available information.

5.2. An Evaluation of the Complex System Archetypes Using the Research Criteria

In approaching the existing archetypes and structures of systems theory, this research began with a set of research criteria defined in section 2.2 of this study. Each classification system was evaluated in terms of *structure, rigor, holistic nature, inclusiveness, transformativeness and basis in systems theory*. As this research has now developed a new collection of complex systems archetypes, it is appropriate that these archetypes be compared by the same metrics to determine their level of conformance with the research criteria. In this section, the collection of complex systems archetypes developed in this study will be evaluated against each of these criteria.

5.2.1. Structure

This research criterion asks if an ordered pattern of categorization exists within the collection of archetypes and if the meaning of the classification, or archetype, is sufficiently documented that an observer can draw consistent distinctions between them.

For these complex system archetypes, the response is a resounding yes. The research begins by stipulating that the archetypes are developed from a perspective of system behavior. This allows all viewers to begin their examination of the archetypes from a common vantage point. Using this behavioral perspective, the research draws specific distinctions between each of the archetypes. The particular behaviors that may be found in each archetypical form are detailed, and the reader can use this information to immediately distinguish between systems of varying types.

Notably, this research does not dictate that a system must be in one and only one category. Because of this, the descriptions of the underlying archetypes, and the case study provided in Appendix B, help to illustrate how a system may span archetypical forms.

5.2.2. Rigorous

The requirement for rigor in evaluating this classification system is driven by the need for the archetypes to have well documented, strict, and discernable criteria which can be used by an informed observer, regardless of his or her vantage point, to classify a system.

As described in earlier sections, these archetypes provide a highly rigorous evaluation scheme. Any open system can be evaluated and distributed into the collection of archetypes by objectively evaluating the manner in which it uses free energy to displace entropy in pursuit of its own continued viability. The requirements for categorization are distinct, well-defined, precise, and unbiased and should ensure a consistent categorization between observers.

5.2.3. Holistic

The concept of holism in evaluating each classification system was developed with the objective that a system under study be viewed as a whole entity, rather than as a collection of parts, each of which has distinct behaviors. In the case of the archetypical forms developed here, they are agnostic in terms of their level of application. For a system of systems, these archetypes may be applied either at the top-level, or to any of the component systems that reside within. In applying the archetypes to a system under study, the only requirement is that the subject be a distinct, open system which is evaluated according to its individual behavior and responses to variety.

5.2.4. Inclusive

This criterion asks if the classification system is sufficiently broad or generalized to be applied to any and all systems. In the cases of the complex systems archetypes, the answer is a provisional yes.

As noted throughout the research, these archetypes are derived from the behaviors of open systems, which are defined by their efforts to collect energy and displace entropy in order to remain viable. Because of this, the archetypes do not directly apply to closed systems which, by definition, do not exchange materials and energy with their environment. Here it should be noted that simple systems such as these, generally only exist in an abstract vacuum where the system boundaries have been drawn to specifically exclude complexity. Take a simple clockwork, for example. By most definitions, a clockwork would be a non-complex, closed system that starts with a finite amount of stored energy and then runs down. The complex system archetypes developed here are not well suited for describing the behavior of this system. However, if the definition of the clockwork is expanded to include the hand that winds it to provide energy, the craftsman that oils and tunes it to keep it in good repair, and the effects of temperature and humidity that slowly degrade it, then it becomes part of a larger open system that is addressed by this research.

Therefore, this research can be said to be inclusive of all systems that are properly framed within the environment to reflect the energy that creates and maintains them in the face of the steady degradation of entropy.

5.2.5. Transformative

The criterion of transformativeness was proposed as an alternative to flat catalogs and taxonomies, with the understanding that a system may be able to evolve between classifications. In taxonomies, a system is generally placed into a single category that strictly defines it and from which it cannot escape without fundamentally changing its nature. The complex system archetypes do not place that restriction on systems. Because these archetypes are behavioral in nature, a system can exist in more than one category and can move fluidly between categories by altering the manner in which they interact with the world around them. Because of this, the ability to change behavioral archetypes is wholly dependent on the system's capacity to perform the functions and behaviors that are included in the archetype's definition.

Further, the complex system archetypes are a continuum of definitions, each of which exists on the same hierarchical level. This means that systems are not bound to be merely one archetype or another, but like light, can fall across a spectrum that reflects many different characteristics, with varying levels of prominence.

5.2.6. Basis in System Theory

This criterion considers how well coupled a classification system is to the principles and concepts of systems theory. Accordingly, this research was initiated, founded, and derived from the systems literature. As the archetypes began to reveal themselves, new ideas were explored that expanded from the base literature to related material across many disciplines. In the end, though, the expanded concepts were related back to the systems literature and tightly coupled to existing theory. As a result, this research is intrinsically bound to systems theory and the archetypes can trace their origin and characteristics to the existing literature.

5.3. Reconsidering the Research Assumptions

In the development of the research proposal, there were three fundamental assumptions that governed the study. This section will examine each of these assumptions independently and will discuss any impact that they may have had on the conduct of the research.

5.3.1. Sufficiency of Existing Research

The first assumption that was identified in the proposal was that the existing research in the field of systems theory was sufficient to develop a meaningful collection of archetypes that would continue to be applicable as new information is garnered in the future. During the grounded theory phase of this research, an enormous amount of systems research was examined and correlated, with each principle's ancestry and progeny being documented in detail. The collected models of systems theory which are provided in Appendix A reference more than 300 books, papers, and studies. The concepts addressed in this literature are all linked to the principles of systems theory and they span virtually all fields of human thought - from philosophy and religion to science and engineering.

Even as the literature branches and flows through the various disciplines, there are common threads that continue to emerge: threads that bind the disciplines together. These threads represent the fundamental truisms which are intrinsic in the perspective of all human observers. To state them briefly:

1) Open systems and living creatures are not clockworks. They are not wound by some external force that attends to their continued operation. To survive, these systems must continually search for and acquire the fuel that they need to power and maintain themselves.

2) All things, be they systems or raw matter, incur damage over time. Driven by the law of entropy, everything slows down, breaks down, and eventually decays to some base state where it reaches minimum energy and maximum disorder. This law of entropy demands that *all things are mortal* and are moving toward an inevitable final state.

3) Open systems are defined by their resistance to the law of entropy. At the heart of all systemic endeavors is an ongoing and raging battle against inevitability. In defiance of nature, they collect energy to displace entropy and to remain viable.

These three concepts are recurrent in system theory and throughout the human experience. Arguably, regardless of what advances in research may occur, these ideas will remain at the heart of our future philosophy. Because this study is built on these fundamental building blocks, I believe that the existing research is adequate for the conclusions that were reached and that future research will continue to support those conclusions.

5.3.2. The Level of Abstraction is Acceptable

During the proposal, it was stated that the development of system archetypes would require some level of abstraction in order to produce a reasonably sized collection. Because abstraction comes at the cost of resolution, concerns were raised about the value and applicability of the resulting archetypes.

In examining the resulting set, it is clear that they are highly abstract and that each archetype represents a wide variety of different systems. However, the distinctions that are drawn between each archetype are specific, clear, and discernable. As a result, all systems that are possessed of a specific archetypical behavior will have common challenges and capabilities that are inherent in the type. Because these abstract types emerged from a concise, compact model of the system universe, they are thrifty in the factors that they address, and they can be examined and understood at a very rudimentary level.

The question then becomes, are they too simple to be of real value? I believe that the answer is no. The system archetypes provide a set of basic behavioral templates that reflect how systems may interact with their environment. While rudimentary, these models offer the researcher an excellent starting point for future system exploration. By discerning the different archetypical capabilities that a system possesses, the researcher can then ask, "why does the system prefer one approach over another?", "what are all of my options?", and "is one archetypical approach the best solution based on the current environmental and systemic conditions?" It is the simplicity of these building blocks that makes them ideal tools for pondering the very complex world that surrounds us.

5.3.3. The Purpose of this Research is Appropriate

In designing this research, a guiding purpose was the objective to bridge the gap between system examination and diagnostics. While the emerging archetypes are not specifically tailored to the objectives of system diagnosis, they do provide an underlying diagnostic capability that will be discussed later in the future research section. Interestingly, the system archetypes that have been developed in this research have introspective capabilities that go beyond the examination of system pathologies. In reality, there are many right ways in which a system may respond to emergence and change, or to variety and entropy. If a system selects the wrong approach, it is just as likely to be a simple error as it is to be a pathological failing. Having a structure that differentiates the myriad ways that a system can deal with variety provides insight and intelligence to the decision making process and can contribute to extended system viability.

5.4. Limitations of the Study

As discussed in the section titled "Establishing a Foundation for the Systems Archetypes", this study has focused on the development of archetypes through the prism of a single perspective: *how* a system behaves in response to external variety. There are, however, many other vantage points by which a system may be viewed. Archetypes based on structure, motivation, interconnections, and so forth are equally valid and would likely have little semblance to those developed in this research. Still, these archetypes are drawn from the literature and speak to a major concern of systems theory – that of the struggle for viability.

Notably, even if future researchers develop new and divergent collections of archetypes, the systems that comprise those collections will still be facing the underlying struggle to garner energy and to displace entropy. Because of that, the development of future, alternative system archetypes is more likely to augment this study than to supplant it. It is the limitations inherent in this study that offer opportunities for future research and exploration.

5.5. Implications

5.5.1. Theoretical Contributions

- **The System Archetypes**

  The primary theoretical contribution of this research is the development of the system archetypes within the context of the generalized system environment. Each of these archetypes is drawn from documented system principles that exist within the domain of our research discipline.

- **The Related Model of System Concepts and Principles**

  A secondary but equally significant contribution is the collected models of system theory which are included in Appendix A. For future researchers, this catalog provides a relational structure illustrating the many paths along which system theory emerged. Of course, no such catalog can ever be complete as long as researchers continue to push back the boundaries of system theory. Still, the collection of models included in this study can serve as a foundation for future researchers and as a starting point for future models.

5.5.2. Methodological Contributions

- **Model Based Grounded Theory**

  While there has been some discussion of using graphical models to develop grounded theory in the past (Glaser, 2007), the approach used in this study added significant new structure and rigor. By combining the approaches used in the Object Modeling Technique (Rumbaugh, Blaha, Premerlani, Eddy, & Lorensen, 1991) and the Unified Modeling Language (Rumbaugh, Jacobson, & Booch, 1999) with the collection, coding, and interrelationship of grounded theory, a unique new methodological approach was developed. Here, the researcher can view an abstract presentation of the data that has been collected and can see the relationships as they emerge. By creating a hierarchy of models, the researcher can ascend to a higher perspective to view the interrelations between large ideas and can then focus in on more distinct details, as the situation warrants. Further, the construction of models and relationships that are somewhat separated from the supporting details allows different observers to approach the model from their own perspective. In doing so, each of them can interpret the model through the prism of their own experience and can uncover unique and meaningful variety.

5.5.3. Practical Contributions

- **Governance**

  One potent practical contribution for this research is in the domain of system governance. In order to properly determine a course of action, a system is well served in knowing its alternatives and understanding their strengths and weaknesses. By evaluating his or her own system against the different archetypes, a system owner may be able to identify which archetypical capabilities exist within the organization and how they might be employed. With this knowledge, and an understanding of system and environmental conditions, the governing body can determine a course of action that is more likely to achieve the desired outcome and ensure system longevity and viability.

5.6. Future Research

In examining the results that have emerged from this study, there are a number of interesting possibilities for future research, which come in a variety of forms. First, there are those research opportunities that revolve around further exploration of the archetypes and their inter-relationships. Secondly, there are opportunities to explore system archetypes that may emerge along other perspectives and evaluate their impact, influence, and interdependency on these archetypes. Finally, the archetypes as they are currently defined may be used as a starting point for the development of analytical tools for evaluating systems and organizations. This is not an exhaustive list, but merely a sampling of some of the possibilities that exist. The following narrative discusses several of these opportunities and how they might be exploited in the future.

5.6.1. Development of a Metaphorical Model

While the structure and layout of the system archetypes provides an ordered examination of the behavior of systems as they progress through various responses to variety, it does not currently have a good metaphorical representation. The Six Thinking Hats metaphor espoused by de Bono (1985) is an example of one such approach In it, the color of each hat is linked to a specific way of thinking or perspective. Similarly, figure 22 shows an illustration that Lindy McKeown (2006) has developed to represent the various approaches educators take in adopting technology in the classroom.

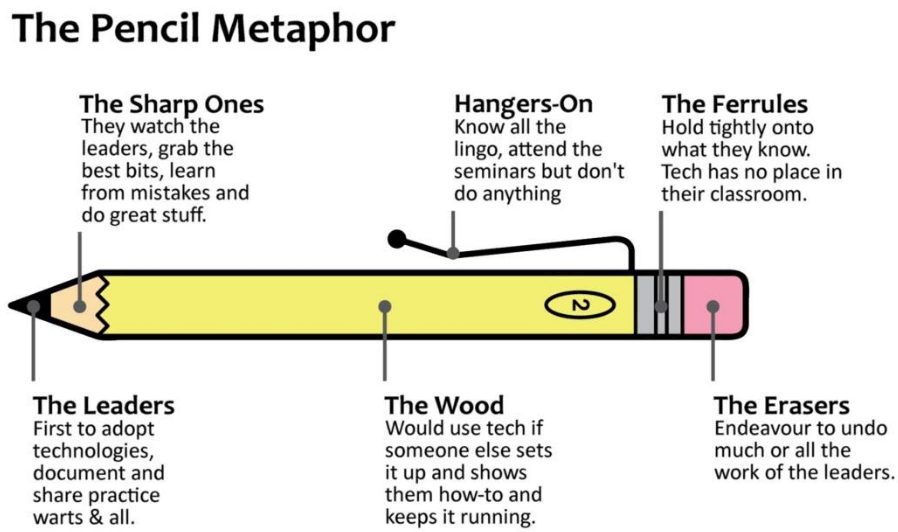

Figure 22. A Model of the Pencil Metaphor (adapted from Lindy McKeown (2006))

It would be beneficial for the system archetypes that were discussed in this study to have a metaphorical representation which allows them to be more quickly understood, adopted, and employed by other researchers. Further, the development of such a metaphorical model could allow the researcher to identify and document other dimensions or continua that are present within the collection of archetypes.

5.6.2. Development of System Analysis Tools

If one recognizes that the manner in which systems respond to approaching variety in the form of change and emergence is one of their key characteristics, then that recognition implies a significant number of vectors by which a system might be analyzed. First, using an introspective approach, the analyst may be able to determine which archetypical characteristics are present within the system. Once these have been identified, further analysis can determine the relative dominance of each characteristic as demonstrated by its frequency of selection and use. An analytical tool that examines the actual behavior of the system is only a first step, however. Further analysis can determine the effectiveness and relative efficiency that the system has experienced in its application of an archetypical approach for addressing variety. In short, has the system historically selected the best approach, or has it merely chosen the one that is best known?

Finally, additional analysis techniques can look beyond the system itself to its surrounding environment. Here, it is possible for tools and techniques to be developed that examine the archetypical capabilities of the system, its current internal condition in terms of stored energy and incurred entropy, and the approaching environmental conditions. Having this information will allow the system to make a better informed decision on how to proceed.

5.6.3. Development of Archetype Based Diagnostics

Within the application of each of these archetypes, there are possibilities for different and distinct pathologies to occur. A quick examination of several of the archetypes provides an illustration of this. Note that the description of pathologies provided below is not proposed to be exhaustive, but is merely an example of some of the pathologies that one might observe during archetypical behavior.

- **Potential Endurant Pathologies**
  1) Failure to collect or convert free energy as required
  2) Inability to store converted energy at the required rate or capacity
  3) Inability to maintain stored energy
  4) Inability to discharge or distribute energy at the required rate or capacity
  5) Inability to use stored energy to maintain the system and reduce entropy

- **Potential Regulator Pathologies**
  1) Dysregulation: regulatory actions that exacerbate the problem or create other problems
  2) Hyporegulation: failure to establish or apply adequate regulatory control to maintain system conditions
  3) Hyperregulation: maintaining tolerances too tightly on a key parameter to the detriment of its subordinates -or- implementation of regulatory rules and hierarchies that are too complex to be operated or maintained

- **Potential Organizer Pathologies**
  1) Disorganization: failure to form a complete and coherent organizational structure
  2) Misorganization: organizing into a form that is inconsistent with the demands of the environment
  3) Failure to adapt
  4) Transformational latency: failing to transform in time
  5) Transformative instability: preferring to change when the current form is adequate

While these are only a few examples of pathologies that are directly related to archetypical behavior, they demonstrate that the system archetypes can be used as a foundation for diagnostics. Future research may extend beyond the development of pathologies specific to each of the archetypes, and should examine the pathologies that occur when a system improperly selects one approach over another. Other pathologies might exist that explain why a system chooses to develop one archetypical capability or fails to recognize that it has other capacities. The development of such diagnostic tools could provide a powerful new perspective for the analyst to use in exploring a system under study.

5.6.4. Environmental Archetypes

As this research has demonstrated, open systems are represented by a collection of archetypical behaviors that dictate how they respond to a potentially antagonistic environment, displace entropy and remain viable. Notably, the behavior of the systems is only one part of the equation. Of equal interest is the nature of the environment that the system is dealing with.

As with the system archetypes, it can be supposed that there are a collection of environmental archetypes that represent the conditions that are present within a system's local environment. Like the complex system archetypes, these archetypes should fall along a spectrum or continuum where different conditions are manifested at different times. If archetypical environments do exist and they can be effectively identified, then it should be possible to develop a correspondence between the individual complex system archetypes and the environment. Such a correspondence would be the foundation of a tool that could allow system owner to assess their environmental conditions and then determine if their archetypical behaviors are consistent with continuity or expansion.

Further, as changing conditions are detected, a continuum of environmental archetypes may allow system owners to reasonably project how the environmental will transform from one type to another. Coupled with an understanding of system capabilities, this foreknowledge would allow a system to preemptively adapt in preparation for an emerging future. Notably, the development of these environmental archetypes would not only complement this research, but could be the basis of other standalone analysis tools that extend the complex system governance toolset.

5.6.5. Summary

In closing, the identification of these system archetypes is merely another step in an ongoing journey to improve our understanding of the world around us. The open systems that we comprise and that we interact with all share a fundamental drive to absorb variety, to collect energy, and to maintain long term viability. By understanding and differentiating the approaches that we take to accomplish that task, we are better prepared to assess our own effectiveness and to evaluate all of our options in the face of a constantly changing world. It is for us, moving forward, to expand these foundational ideas and to employ them in order to make better decisions and to interact more effectively with our environment.

Appendix A: The Referenced Concept Models of Systems Theory

Walt Akers
Old Dominion University, 2015

A-1. Autopoiesis

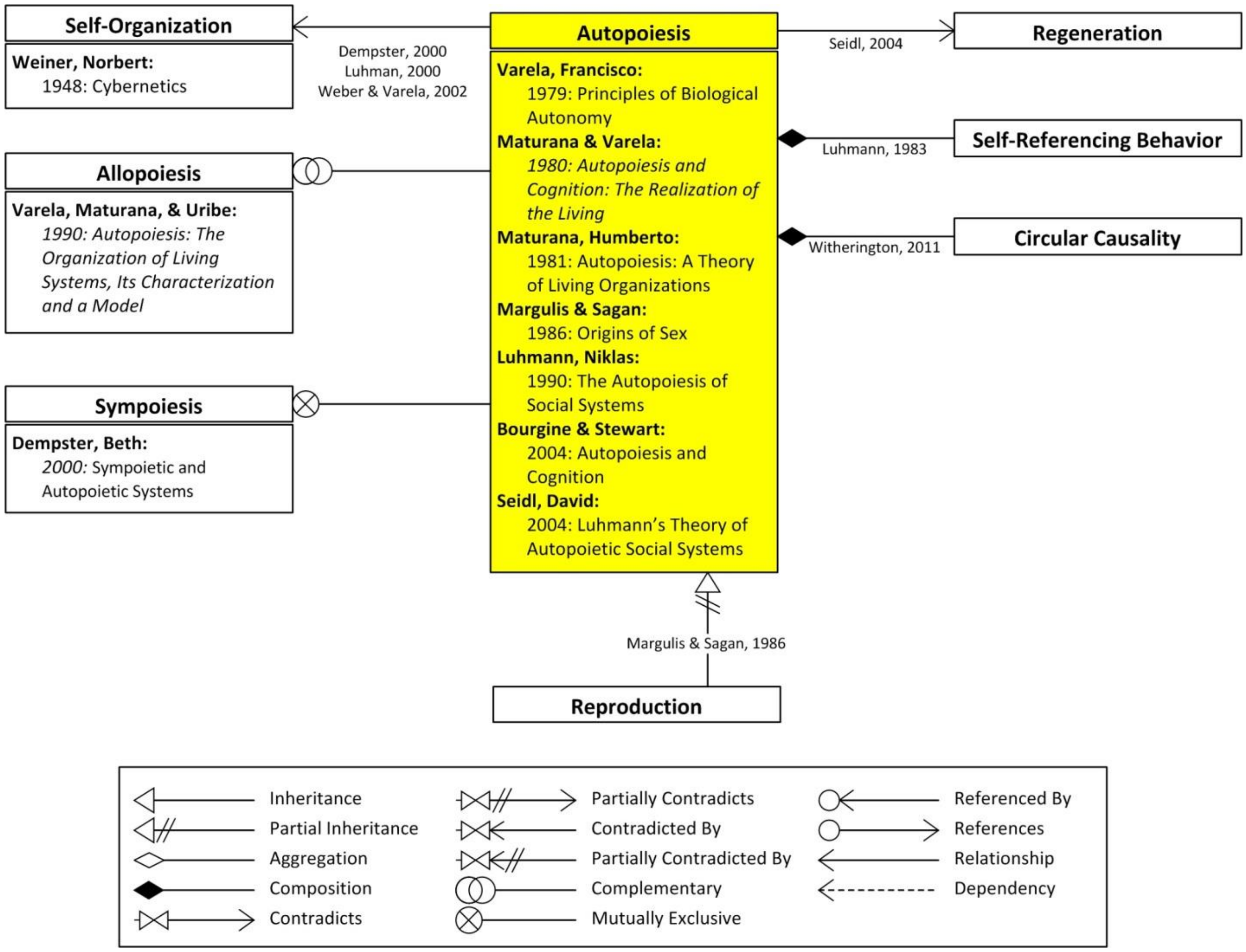

Figure A-1: Conceptual Model of Autopoiesis

■ Definition

Autopoiesis: A system that is capable of producing or regenerating the functional elements within its own system boundaries (Luhmann, 1990)

■ Contributing Scholars

a. Niklas Luhmann (1990)

i. Discussing Autopoeitic Systems

"Autopoietic systems, then, are not only self-organizing systems, they not only produce and eventually change their own structures; their self-reference applies to the production of other components as well. This is the decisive conceptual innovation. [...] Thus, everything that is used as a unit by the system is produced as a unit by the system itself. This applies to

elements, processes, boundaries, and other structures and, last but not least, to the unity of the system itself" (Luhmann, 1990).

ii. As Self-Referential Systems

"The system continuously refers to itself by distinguishing itself from the environment" (Luhmann, 1983).

b. Humberto Maturana (1981) and Francisco Varela (1980)

i. Varela (1979) says

"An autopoietic system is organized (defined as a unity) as a network of processes of production (transformation and destruction) of components that produces the components that

(a) through their interactions and transformations continuously regenerate and realize the network of processes (relations) that produce them and

(b) constitute it (the machine) as a concrete unity in the space in which they exist by specifying the topological domain of its realization as such a network" (Varela, 1979).

ii. Maturana (1981) gives the following definition

Autopoietic *systems "are systems that are defined as unities as networks of productions of components that recursively, through their interactions, generate and realize the network that produces them and constitute, in the space in which they exist, the boundaries of the network as components that participate in the realization of the network"* (Maturana, 1981).

iii. Varela (2000) quoted by Bourgine and Stewart (2004)

"A system is autopoietic if:

(a) it has a semi-permeable boundary,

(b) the boundary is produced from within the system, and

(c) it encompasses reactions that regenerate the components of the system." (Varela, 2000)

iv. Weber and Varela (2002) regarding self-organization

"Thus, autopoiesis is a singularity among self-organizing concepts in that it is on the one hand close to strictly empirical grounds, yet provides the decisive entry point into the origin of individuality and identity, connecting it, through multiple mediation with human lived body and experience, into the phenomenological realm" (Weber & Varela, 2002, p. 116).

c. Paul Bourgine and John Stewart

i. Defining an autopoietic system

"An autopoietic system is a network of processes that produces the components that reproduce the network, and that also regulates the boundary conditions necessary for its ongoing existence as a network" (Bourgine & Stewart, 2004).

d. David Witherington

i. Autopoiesis, Circular Causality, and Stability

Note: Stability is not explicit, but is strongly asserted in the phrase "it metabolically maintains itself as an individual unity, as an invariant organization of patterning, in the face of continuous turnover."

"An autopoietic system produces the very components that give rise to it, establishing its own self-maintaining processes. This is not to suggest that autopoietic systems construct themselves independently from their surround. The autopoietic system exists as thermodynamically open, engaging in incessant exchange of energy and matter with its surround, yet establishes organizational closure in that it metabolically maintains itself as an individual unity, as an invariant organization of patterning, in the face of continuous turnover and renewal of its material and energetic constituents. ***Autopoietic systems thus embody complete circular causality, actively regulating the very external boundary conditions that produce them*** *– by regulating the flow of energy and matter – thereby incorporating external boundary conditions into their own dynamics"* (Witherington, 2011).

e. David Seidl (2004)

i. On Reproduction versus Regeneration

"In order to 'survive' an autopoietic system constantly has to produce further elements. If this (re-)production stops the system disappears; e.g. if a plant stops producing its cells it is considered dead. For this it is irrelevant what concrete cells are produced; whether the plant produces a new leaf, extends its roots or grows a blossom does not matter – as long as any new elements are produced the plant is still alive. The fact of the reproduction as such – independently of the concrete elements reproduced – is referred to as the autopoiesis of the system" (Seidl, 2004).

f. Lynn Margulis and Dorion Sagan (1986)

i. On Autopoiesis versus Reproduction

"Autopoiesis occurs, then, to maintain an organism during its own life, but by itself autopoiesis does not guarantee that an organism will show genetic continuity or that the characteristics of any given organism will persist faithfully though time. The process that ensures genetic continuity is reproduction" (Margulis & Sagan, 1986).

ii. Relationship between Autopoiesis and Reproduction

"Reproduction depends on autopoiesis, but autopoiesis in turn cannot take place without the eventual replication of DNA" (Margulis & Sagan, 1986).

g. Beth Dempster (2000)

i. Relationship to Sympoiesis

"I propose a new concept based on an interpretation of ecosystems: sympoietic systems. These are complex, self-organizing but collectively producing, boundaryless systems. A subsequent distinction between sympoietic and autopoietic systems is discussed. This distinction arises from defining a difference between three key system characteristics: 1) autopoietic systems have self-defined boundaries, sympoietic systems do not; 2) autopoietic systems are self-produced, sympoietic systems are collectively produced; and, 3) autopoietic systems are organizationally closed, sympoietic systems are organizationally ajar" (Dempster, 2000).

A-2. Basins of Stability

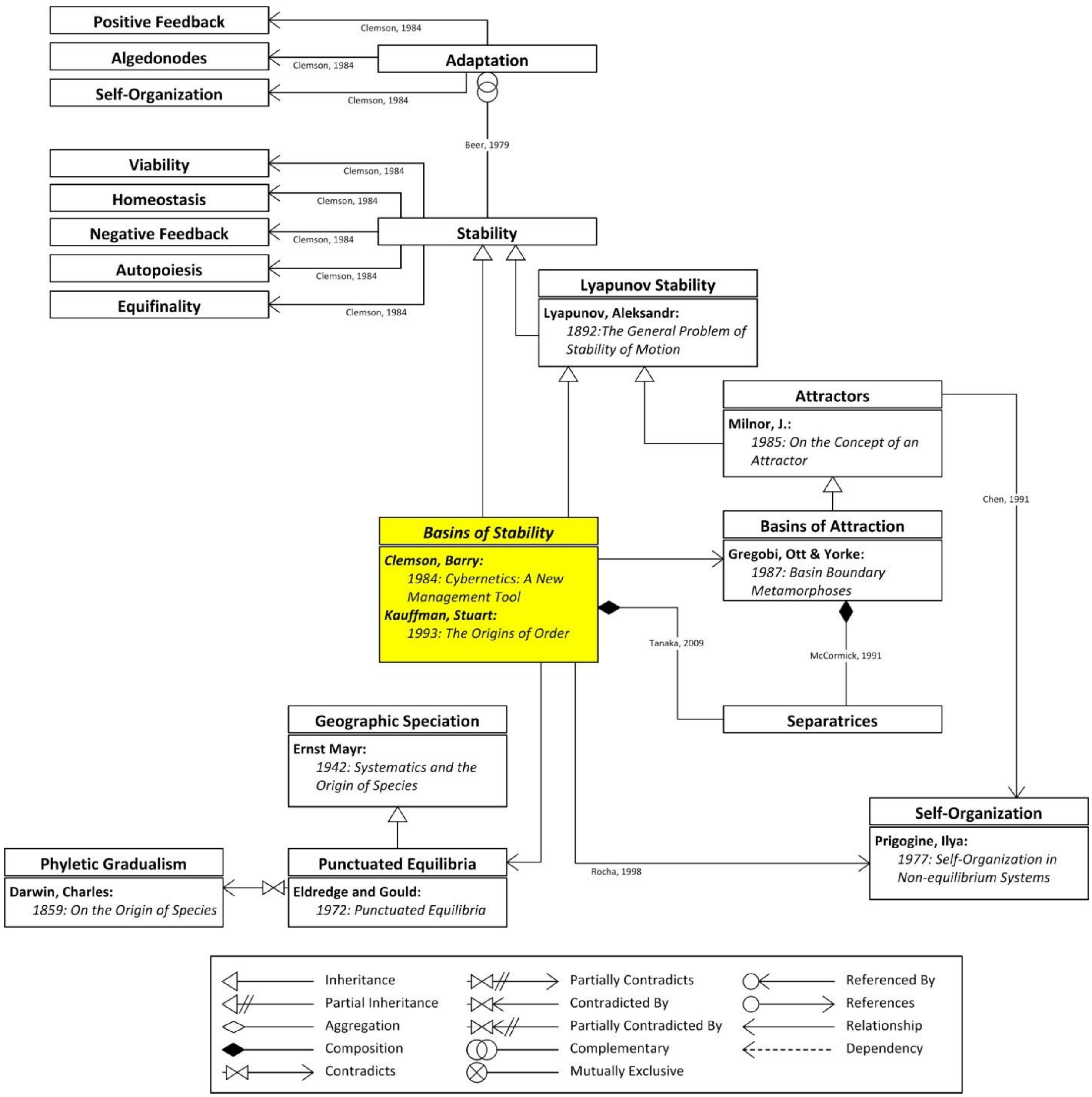

Figure A-2: Concept Model of Basins of Stability

■ Definition

Basins of Stability: Regions of stability within a volume of space that are physically bounded by regions of instability (Clemson, 1984)

■ Commentary

The nature of basins of stability, where systems remain within a fixed domain until circumstances or forces compel them to move to another, is highly consistent with the concept of punctuated equilibria, although the two are not coupled in a specific reference.

In examining Kauffman's attractors, it is also clear that he suggests that the path that a system is likely to take when leaving a basin of stability is highly restricted. Unless interfered with, it will follow a connected *'river'* when leaving the *'lake',* rather than going over a mountain to another river. This suggests that basins of attraction may also have a partially complementary relationship with the basins of stability.

Lyapunov Stability is included as a predecessor because it establishes the concept that mathematical solutions become increasingly stable as they approach a point of equilibrium. Basins of stability are a systemic manifestation of this concept.

■ Contributing Scholars

a. Barry Clemson

i. Definition of Basins of Stability

"Complex systems have basins of stability separated by thresholds of instability. A system 'parked' on a ridge will 'roll downhill'" (Clemson, 1984, p. 220).

ii. Implications for Management

"Organizations have a limited number of stable configurations. An organization that is shifted out of a stable configuration will, seemingly by itself, gravitate toward one of the stable configurations" (Clemson, 1984, p. 220).

iii. On Moving Between Basins

"Basins of stability are separated by ridges that represent changes in energy potential. Thus, moving from one basin of stability to another requires work, even when the new basin is at a lower potential than the old. The ridges separating basins represent thresholds. Thus, while it may be very difficult to push a system 'up' a ridge, the moment it crosses the threshold it will continue without further external effort" (Clemson, 1984, p. 220).

iv. On the Relationship of Stability and Change

"The notion of 'stability' and 'change' complement each other: a firm grasp of one illuminates the other. Stability is discussed as meaning that some variable of interest has not meaningful difference over time. Change, then, has the corresponding meaning that some

variable of interest shows a difference over time. Thus, whether we perceive 'change' or 'stability' depends entirely on our selection of variables to observe and our ability to detect differences in those variables over time" (Clemson, 1984, p. 229).

b. Stuart Kauffman

i. Definition of an Attractor

"The general definition of an attractor is a set of points or states in state space to which trajectories within some volume of state space converge asymptotically over time" (Kauffman, 1993, p. 177).

ii. Basins of Attraction

"The idea of basins of attraction and steady-state point attractors is essentially the same as the idea of a mountainous region with hills, ridges, valleys, lakes and a water drainage system. Just as a mountainous region may have many lakes and drainage basins, so may a dynamical system have many attractors, each draining its own basin" (Kauffman, 1993, p. 177).

iii. On Attractors as Basins of Stability

"Note also that, since attractors are typically much smaller than the volume of states in their basins, the system becomes boxed into an attractor unless perturbed by an outside force" (Kauffman, 1993, p. 177).

c. *L.M.* Rocha

i. On the Relationship of Attractors to Self-Organization

"Self-organization is seen as the process by which systems of many components tend to reach a particular state, a set of cycling states, or a small volume of their state space (attractor basins), with no external interference" (Rocha, 1998).

d. Kevin Adams & Charles Keating

i. Stability as a Relationship Between System and Environment

"If we limit our view of stability to that of the system then we can certainly define the system boundary narrowly-enough to transfer disturbances that cause system instability to the environment. Only the duality of system and environment can be used to properly define stability. To do otherwise may cause us to shift our focus to the stability in the system and

miss the more important relationship between the system and the surrounding environment" (Adams & Keating, 2012).

e. Chen, Ping:

i. Establishing the Relationship to Self-Organization

"Indeed, the mechanism of evolution, one of the central issues in biology and the social sciences, has raised the most fundamental challenge to classical physics. The time arrow of the second law of classical thermodynamics is from order to disorder, while Darwin's theory indicates a general trend of evolution from simplicity to complexity. The attempts to resolve this contradiction, led to the birth of nonequilibrium thermodynamics and the theory of self-organization pioneered by Ilya Prigogine" (Chen, 1991).

f. G. Nicolis & Ilya Prigogine[1]

Noted for the development of the principle of self-organization as associated with non-linear systems.

[1] (Clemson, 1984, p. 220)

A-3. Circular Causality

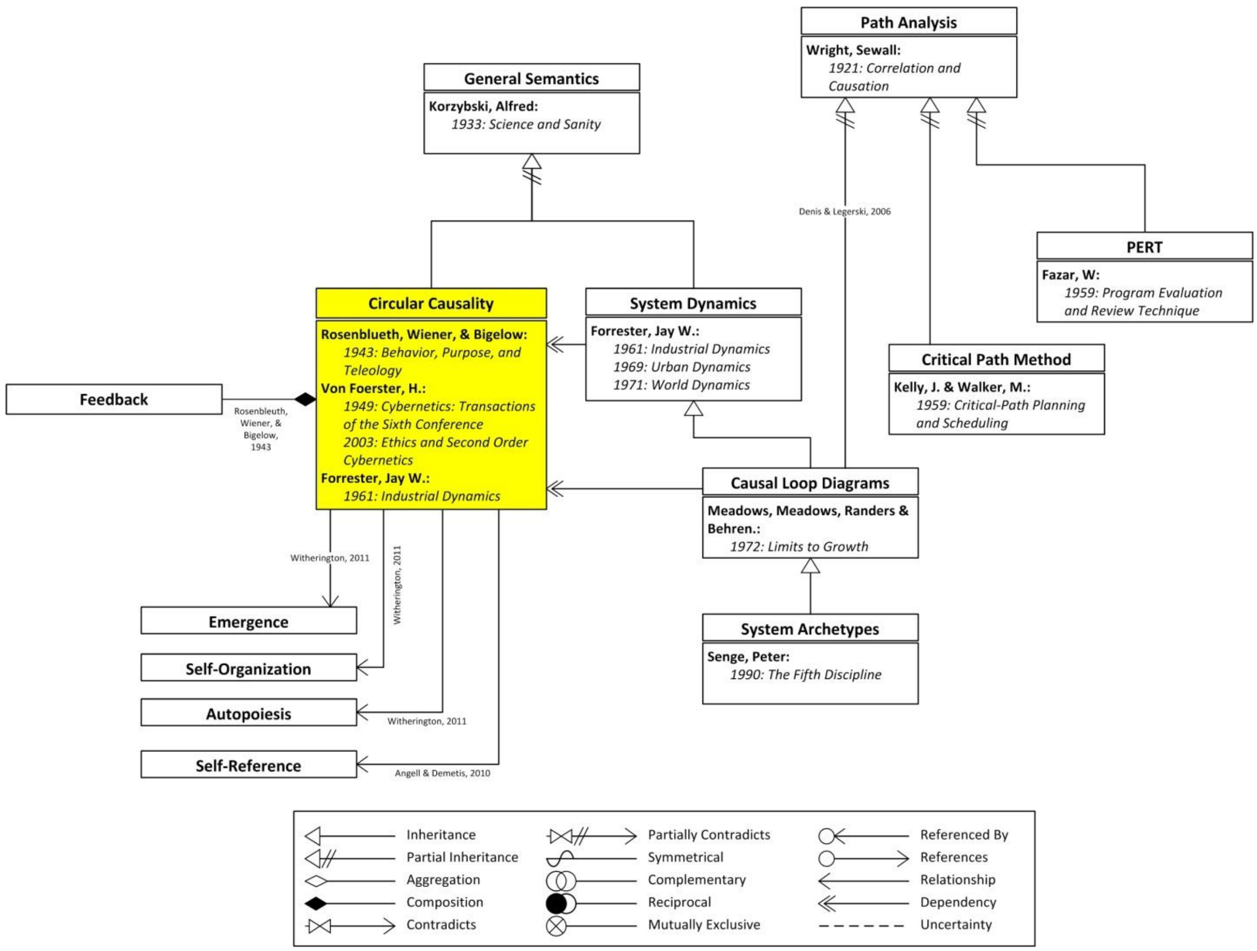

Figure A-3: Concept Model of Circular Causality

■ Definition

Circular Causality: The presence of causal loops that perpetually create emergence within a system through their simultaneous top-down and bottom-up interactions (Witherington, 2011)

■ Commentary

In examining the circular causality, the term is rarely (if ever) used by the originators of the concept or in the literature where it is presented. On the contrary, the formal examination of multi-causality begins with geneticist Sewall Wright, who developed Path Analysis as a mechanism for evaluating genetic contributions. The modeling approach that he developed would eventually be the basis for both the Critical Path Method (Kelley & Walker, 1959) and the Program Evaluation and Review Technique (Fazar, 1959). These early predecessors would contribute to the development of the Causal Loop Model (Meadows, Meadows, Randers, & Behren III, 1973), in which circular causality is manifested.

The direct concept of circular causality seems to begin with Alfred Korzybski (Korzybski, 1933), who discussed the topic as it related to language and to general semantics. Heinz Von Foerster would later participate, and eventually lead, a series of Macy Conferences that focused on circular causation and other system topics. It was here that Arturo Rosenblueth (Rosenblueth, Wiener, & Bigelow, 1943), in conjunction with Norbert Wiener and Julien Bigelow, would introduce the concept of circular causality (Lee, Kirlik, & Dainoff, 2013, p. 19).

Circular causality, however, did not truly gain momentum until it was integrated into the System Dynamics movement by Jay Forrester of MIT. His long term studies into industrial dynamics, urban dynamics, and world dynamics demonstrated the implications of circular causality in social systems. A student of his, Dennis Meadows, would eventually expand the system dynamics concepts into causal loop diagrams. These diagrams would provide clear representations of circular causality and would be popularized in Meadows' "Limits to Growth" (1971) and in Peter Senge's system archetypes (Senge, 1990).

Circular Causality was described as a fundamental component of complex system by David Witherington (2011), who also established its relationship to autopoiesis. Angell and Demetis (2010) identify circular causality as a key element in self-referencing systems.

■ Contributing Scholars

a. Sewall Wright

i. On the Creation of Path Analysis[2]

"The ideal method of science is the study of the direct influence of one condition on another in experiments in which all other possible causes of variation are eliminated. Unfortunately, causes of variation often seem to be beyond control. . . . The degree of correlation between two variables can be calculated by well-known methods, but when it is found it gives merely the resultant of all connecting paths of influence. . . . The present paper is an attempt to present a method of measuring the direct influence along each separate path in such a system and thus of finding the degree to which variation of a given effect is determined by each particular cause. The method depends on the combination of knowledge as may be possessed of the causal relations [emphasis added]. In cases in which the causal relations

[2] From "Causal Modeling and the Origins of Path Analysis" (Denis & Legerski, 2006)

are uncertain the method can be used to find the logical consequences of any particular hypothesis in regard to them" (Wright, 1921).

ii. Contributed to the Development of the Critical Path Method

James Kelly and Morgan Walker (Kelley & Walker, 1959)

iii. Contributed to the Development of the Program Evaluation and Review Technique

Willard Fazar (Fazar, 1959)

b. Alfred Korzybski

i. Initial Discussion in General Semantics

Language is a "uniquely circular structure, where an 'effect' becomes a causative factor for future effects, influencing them in a manner particularly subtle, variable, flexible, and of an endless number of possibilities" (Korzybski, 1933).

ii. On Models and Systems

"The map is not the territory" (Korzybski, 1933).

c. Heinz Von Foerster

i. On The Origins of Circular Causality

"It seems that cybernetics is many different things to many different people . . . . However, all of those perspectives arise from one central theme, and that is that of circularity. ... When, perhaps a half century ago, the fecundity of this concept was seen, it was sheer euphoria to philosophize, epistemologize, and theorize about its consequences, its ramification into various fields, and its unifying power " (Von Foerster, 2003).

d. Jay Wright Forrester

i. From Urban Dynamics (1969)

"In complex systems cause and effect are often not closely related in either time or space. The structure of a complex system is not a simple feedback loop where one system state dominates the behavior. The complex system has a multiplicity of interacting feedback loops. Its internal rates of flow are controlled by nonlinear relationships. The complex system is of high order, meaning that there are many system states (or levels). It usually contains positive-feedback loops describing growth processes as well as negative, goal-seeking loops. In the complex system the cause of a difficulty may lie far back in time from the symptoms, or in a completely different and remote part of the system. In fact, causes are

usually found, not in prior events, but in the structure and policies of the system" (Forrester, 1969).

e. Dennis Meadows

i. The Causal Loop Diagram as an Emergent Product of System Dynamics

"*With the publication of World Dynamics, Professor Jay W. Forrester challenged the world's scientists and decision makers to extend their time horizons and to examine in holistic fashion the long-term causes and consequences of growth in the world's population and material output. To contribute to analysis and understanding of global problems Forrester proposed a formal model of the interactions among population, capital, and several factors that influence their growth: food, resources, and pollution"* (Meadows, Meadows, Randers, & Behren III, 1973).

f. David Witherington

i. As a Fundamental Component of Complex Systems

"As a fundamental feature of complex systems, circular causality involves a perpetual and simultaneous bottom-up and top-down rendering of emergence through self-organization, or in Thompson's [2007] words, both 'local-to-global determination (the formation of macrolevel patterns through microlevel interactions) and global-to-local determination (the constraining of microlevel interactions by macrolevel patterns)' (p. 336)" (Witherington, 2011).

ii. As Related to Autopoietic Systems

"Autopoietic systems thus embody complete circular causality, actively regulating the very external boundary conditions that produce them – by regulating the flow of energy and matter – thereby incorporating external boundary conditions into their own dynamics" (Witherington, 2011).

g. John D. Lee, Alex Kirlik, M. J. Dainoff

i. Origination of the Term Circular Causality

"In 1942, at a conference sponsored by the Macey Foundation to promote interdisciplinary discussions about neuroscience, Arturo Rosenblueth introduced a radical challenge to classical ideas of cause and effect. He introduced the construct of 'circular causality.' This new construct was motivated by collaborations with Norbert Wiener and Julian Bigelow to understand stability in feedback control systems" (Lee, Kirlik, & Dainoff, 2013, p. 19).

h. Patrick Hester and Kevin Adams

i. On the Foundations of Circular Causality and Causal Loop Diagrams

"Jay Forrester of MIT developed a technique (system dynamics) for modeling complex systems which operationalizes the concepts of cybernetics. The feedback principle is the foundation for system dynamics which uses causal loop diagrams that contain information feedback and circular causality to model the dynamic interplay in the real work system under consideration" (Hester & Adams, 2014).

i. Kevin Adams and Charles Keating

i. On the Utility of Circular Causality

"The utility of the principle of causality arises from the fact that systems must be treated carefully and that a range of disturbances and events, no matter how seemingly trivial they seem, may directly impact one another" (Adams & Keating, 2012).

j. Ian Angell and Dionysios Demetis

i. As Direct Relationship to Self-Reference

In Science's First Mistake: Delusions in Pursuit of Theory, page 115 (Angell & Demetis, 2010)

A-4. Complexity

- **Definition**

Complexity: the presence of conditions, processes or activities within a system that defy absolute determination, prediction or control from the perspective of an observer (Akers, 2015)

- **Commentary**

Complexity is not one of the principles that was detailed in the Adams/Keating model; however, it does appear increasingly in literature regarding systems theory. As a result, it was explored and modeled as a normal concept.

Upon examining the literature on complexity, it appears that it is entirely too vast to address as an individual concept and that it is worthy as a discipline unto itself. The question that continues to arise when considering complexity is, "what are the implications of complexity specific to systems and their governance?" Without going into tremendous detail, I assert that in addressing complexity (and all of its variations), we should limit our discussion to the three fundamental ways in which complexity impacts our relationships with systems.

1) ***Determination***: This is complexity's effect on limiting our ability to understand (a) where we are and/or (b) how we got here. This complexity is seen in geomorphological research, where an existing landscape is examined with the objective of understanding how it originated and what forces contributed to its development. *It can be argued that determination is a special case of backward prediction, but maintaining a forward linear timeline makes the description more accessible.*

2) ***Prediction***: This is the impact that complexity has on our ability to predict where a system will be at some point in the future.

3) ***Control***: These are the unpredictable, emergent effects that occur when we attempt to guide a system toward a desired outcome, or away from an undesirable one.

Endless theories may be advanced regarding the type, nature, and differentiation of complexity, but for the purposes of systems governance, examining complexity within the context of these three categories is likely to be the most fruitful approach.

■ Contributing Scholars

a. Henri Poincaré, 1890

i. Discovery of Chaos in 3-Body Experiment

"A tenth of a degree more or less at any given point, and the cyclone will burst here and not there" (Poincare, 1890).

b. Herbert Simon

i. Complexity and Holism

"Roughly, by a complex system I mean one made up of a large number of parts that interact in a nonsimple way. In such systems, the whole is more than the sum of the parts, not in an ultimate, metaphysical sense, but in the important pragmatic sense that, given the properties of the parts and the laws of their interaction, it is not a trivial matter to infer the properties of the whole" (Simon, 1962).

ii. Complexity and Hierarchy

"Thus, the central theme that runs through my remarks is that complexity frequently takes the form of hierarchy, and that hierarchic systems have some common properties that are independent of their specific content. Hierarchy, I shall argue, is one of the central structural schemes that the architect of complexity uses" (Simon, 1962).

c. Mary Douglas

i. Pattern Entrainment: Perspective as a Mechanism for Order

"As perceivers we select from all the stimuli falling on our senses only those which interest us, and our interests are governed by a pattern-making tendency, sometimes called a schema. In a chaos of shifting impressions each of us constructs a stable world in which objects have recognisable shapes, are located in depth and have permanence" (Douglas, 1966).

d. Edward Lorenz

i. The Butterfly Effect

"If a single flap of a butterfly's wing can be instrumental in generating a tornado, so all the previous and subsequent flaps of its wings, as can the flaps of the wings of the millions of other butterflies, not to mention the activities of innumerable more powerful creatures, including our own species" (Lorenz, 1972).

"If a flap of a butterfly's wing can be instrumental in generating a tornado, it can equally well be instrumental in preventing a tornado" (Lorenz, 1972).

e. Paul Cilliers

i. Complex Systems as Open Systems

"Complex systems are open systems – systems that interact with their environment, not only in terms of energy, but also in terms of information" (Cilliers, 1998).

ii. Features of Complex Systems

(1) *"Complex systems consist of a large number of elements"* (Cilliers, 1998, p. 120).

(2) *"These elements interact dynamically"* (Cilliers, 1998, p. 120).

(3) *"The level of interaction is fairly rich. Human individuals interact with many others in a vast array of different capacities. In postmodern society the level of interaction is growing continuously"* (Cilliers, 1998, p. 121).

(4) *"Interactions are non-linear. Non-linearity is a precondition for complexity, especially where self-organisation, dynamic adaptation and evolution are at stake"* (Cilliers, 1998, p. 121).

(5) *"The interactions have a fairly short range. The elements in a complex network usually interact primarily with those around them"* (Cilliers, 1998, p. 121).

(6) *"There are loops in the interconnections. Feedback is an essential aspect of complex systems. Not feedback as understood simply in terms of control theory, but as intricately interlinked loops in a large network"* (Cilliers, 1998, p. 121).

(7) *"Complex systems are open systems"* (Cilliers, 1998, p. 122).

(8) *"Complex systems operate under conditions far from equilibrium. Complex systems need a constant flow of energy to change, evolve and survive as complex entities. Equilibrium, symmetry and complete stability mean death. Just as the flow, of energy is necessary to fight entropy and maintain the complex structure of the system, society can only survive as a process. It is defined not by its origins or its goals, but by what it is doing"* (Cilliers, 1998, p. 122).

(9) *"Complex systems have histories. The importance of history has been emphasised over and over again. One point bears repetition: the history of a complex system is not an objectively given state; it is a collection of traces distributed over the system, and is always open to multiple interpretations"* (Cilliers, 1998, p. 122).

(10) *"Individual elements are ignorant of the behavior of the whole system in which they are embedded"* (Cilliers, 1998, p. 122).

f. Cynthia Kurtz and David Snowden

i. On Contextual Complexity

(1) *"Humans are not limited to one identity"* (Kurtz & Snowden, 2003).

(2) *"Humans are not limited to acting in accordance with predetermined rules"* (Kurtz & Snowden, 2003).

(3) *"Humans are not limited to acting on local patterns"* (Kurtz & Snowden, 2003).

ii. Pattern Entrainment

"Humans use patterns to order the world and make sense of things in complex situations. Give a child a pile of blocks, and he will build patterns out of them. Give an adult a daily commute, and she will build patterns within it. Patterns are something we actively, not passively, create…" (Kurtz & Snowden, 2003).

iii. System's Relative Complexity

Systems can be

(1) *Known [or Simple (Snowden & Boone, 2007)]: "Here cause and effect relationships are generally linear, empirical in nature and not open to dispute"* (Kurtz & Snowden, 2003).

(2) *Knowable [or Complicated (Snowden & Boone, 2007)]: "While stable cause and effect relationships exist in this domain, they may not be fully known, or they may be known only by a limited group. In general, relationships are separated over time and space in chains that are difficult to fully understand. Everything in this domain is capable of movement to the known domain"* (Kurtz & Snowden, 2003).

(3) *Complex: "There are cause and effect relationships between the agents, but both the number of agents and the number of relationships defy categorization or analytic techniques. Emergent patterns can be perceived but not predicted; we call this phenomenon* ***retrospective coherence****"* (Kurtz & Snowden, 2003).

(4) *Chaotic: "In the first three domains we have described, there are visible relationships between cause and effect. In the chaotic domain there are no such perceivable relations and the system is turbulent"* (Kurtz & Snowden, 2003).

g. Steve Maguire, Bill McKelvey, Laurent Mirabeau, and Nail Oztas

i. On Bounding Complex Systems

"Ultimately, delimiting the boundary of a complex system is an analytic choice, determined by the position, perspective and purpose of those who seek to describe it" (Maguire, McKelvey, Mirabeau, & Oztas, 2006, p. 166).

ii. Complex Systems are Emergent and Unpredictable

"Complexity arises when emergent system-level phenomena are characterized by patterns in time or a given state space that have neither too much nor too little form. Neither in stasis nor changing randomly, these emergent phenomena are interesting, due to the coupling of individual and global behaviours as well as the difficulties they pose for prediction. Broad patterns of system behaviour may be predictable, but the system's specific path through a space of possible states is not" (Maguire, McKelvey, Mirabeau, & Oztas, 2006, p. 167).

h. Max Boisot and John Child

i. Relational Complexity

"Relational complexity is a product of the density of interaction among agents as well as of the number of participating agents, it will be reduced both by keeping cognitive complexity down-i.e., establishing codified and abstract rules of interaction among agents-as well as by limiting the number of agents that can interact" (Boisot & Child, 1999).

ii. Cognitive Complexity

"Cognitive complexity is an attribute of the content of information flows among agents within a system. It presents the challenge of knowing and understanding what is going on in the environment" (Child & Rodriques, 2012).

i. Warren Weaver

i. Disorganized Complexity

Disorganized complexity *"is a problem in which the number of variables is very large, and one in which each of the many variables has a behavior which is individually erratic, or perhaps totally unknown. However, in spite of this helter-skelter, or unknown, behavior of all the individual variables, the system as a whole possesses certain orderly and analyzable average properties"* (Weaver, 1948, p. 538).

ii. Organized Complexity

Organized complexity is *"not problems of disorganized complexity, to which statistical methods hold the key. They are all problems which involve dealing simultaneously with a sizable number of factors which are interrelated into an organic whole. They are all, in the language here proposed, problems of organized complexity "* (Weaver, 1948, p. 539).

j. Murray Gell-Mann

i. Effective Complexity

"Effective complexity can be high only in a region intermediate between total order and complete disorder" (Gell-Mann, 1995).

ii. Effective Complexity vs. Logical Depth

"In contemplating natural phenomena, we frequently have to distinguish between effective complexity and logical depth. For example, the apparently complicated pattern of energy levels of atomic nuclei might easily be misattributed to some complex law at the fundamental level, but it is now believed to follow from a simple underlying theory of quarks, gluons, and photons, although lengthy calculations would be required to deduce the detailed pattern from the basic equations. Thus the pattern has a good deal of logical depth and very little effective complexity" (Gell-Mann, 1995, p. 18).

iii. Complex Systems as Parents of Complex Systems

"Complex adaptive systems have a tendency to give rise to other complex adaptive systems" (Gell-Mann, 1995, p. 17).

iv. Crude Complexity

Crude complexity is *'the length of the shortest message that will describe a system, at a given level of coarse graining, to someone at a distance, employing language, knowledge, and understanding that both parties share (and know they share) beforehand"* (Gell-Mann, 1994, p. 34).

k. Yaneer Bar-Yam

i. Definition of Complexity

"A dictionary definition of the word "complex" is: "consisting of interconnected or interwoven parts" (Bar-Yamm, 1997, p. 1).

ii. Complexity as Measured by Descriptive Requirements

"Loosely speaking, the complexity of a system is the amount of information needed in order to describe it. The complexity depends on the level of detail required in the description. A more formal definition can be understood in a simple way. If we have a system that could have many possible states, but we would like to specify which state it is actually in, then the number of binary digits (bits) we need to specify this particular state is related to the number of states that are possible" (Bar-Yamm, 1997, p. 12).

iii. Complexity Driven by Hierarchical Depth

"When the behavior of the system depends on the behavior of the parts, the complexity of the whole must involve a description of the parts, thus it is large. The smaller the parts that must be described to describe the behavior of the whole, the larger the complexity of the entire system" (Bar-Yamm, 1997, p. 14).

iv. Complexity through Emergence

"A complex system is a system formed out of many components whose behavior is emergent, that is, the behavior of the system cannot be simply inferred from the behavior of its components" (Bar-Yamm, 1997, p. 10).

l. R. Badii and A. Politi

i. Definition of Complexity

"A complex object is an arrangement of parts, so intricate as to be hard to understand or deal with (Webster, 1986)" (Badii & Politi, 1997).

m. Jochen Fromm

i. Complexity as a Property of Perspective

"Complexity is the characteristic property of complicated systems we don't understand immediately. It is the amount of difficulties we face while trying to understand it. In this sense, complexity resides largely in the eye of the beholder - someone who is familiar with s.th. often sees less complexity than someone who is less familiar with it" (Fromm, 2004, p. 187).

ii. Complexity Through Self-Organization

a) "The basic concept of complexity theory is that systems show patterns of organization without organizer (autonomous or self-organization). Simple local interactions of many *mutually interacting parts can lead to emergence of complex global structures"* (Fromm, 2004, p. 188).

b) "Complexity originates from the tendency of large dynamical systems to organize themselves into a critical state, with avalanches or "punctuations" of all sizes. In the critical state, events which would otherwise be uncoupled became correlated" (Fromm, 2004, p. 188).

iii. Complexity Through Evolution

"A complex system is created by evolutionary processes. There are multiple pathways by which a system can evolve. Many complex systems are similar, but each instance of a system is unique" (Fromm, 2004, p. 188).

n. Bruce Edmonds

i. Complexity from the Perspective of Modeling

"Complexity is that property of a model which makes it difficult to formulate its overall behaviour in a given language, even when given reasonably complete information about its atomic components and their inter-relations" (Edmonds, 1999).

A-5. Control

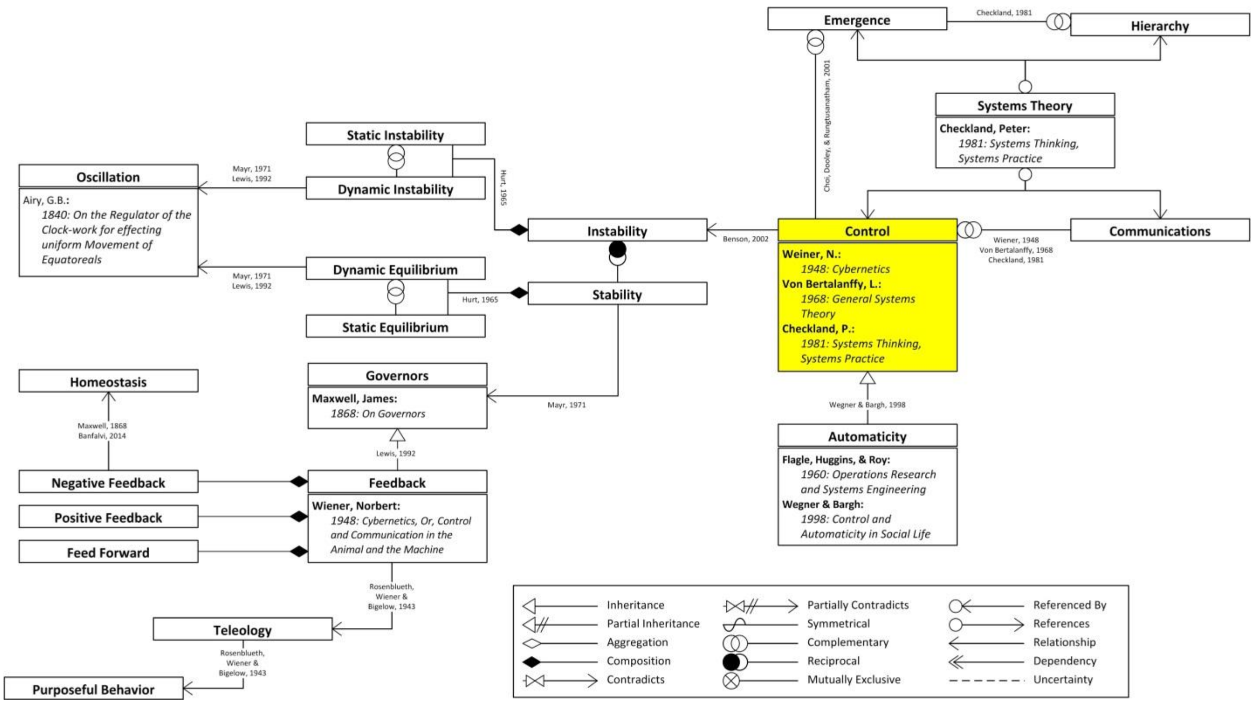

Figure A-4: Concept Model of Control

■ Definition

Control: The mechanisms that are used to move a system between two equilibrium states or into a non-equilibrium state (Benson, 2002)

■ Contributing Scholars

a. H.H. Hurt

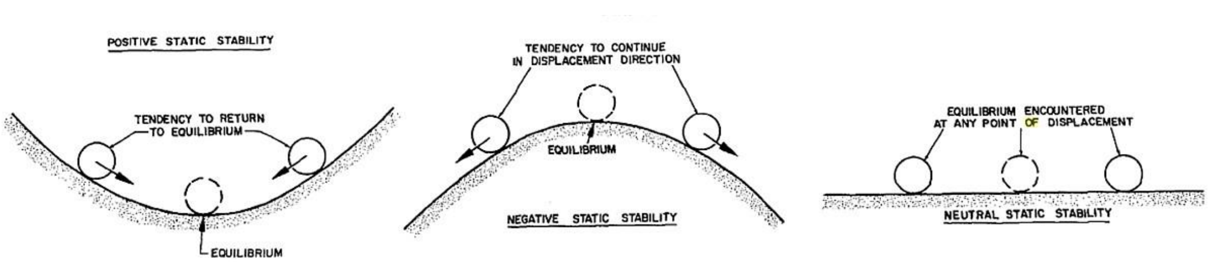

Figure A-5: Types of Static Stability (Hurt, 1965)

i. Static Stability

"The static stability of a system is defined by the initial tendency to return to equilibrium conditions following some disturbance from equilibrium" (Hurt, 1965, p. 245).

Demonstrated by a ball in a trough. If it is set in motion, it will return to the bottom of the trough.

ii. Static Instability

"If the object has a tendency to continue in the direction of disturbance, negative static stability or static instability exists (Hurt, 1965).

Demonstrated by a ball on a hilltop. If it is set in motion, it will roll to the bottom of the hill.

iii. Neutral Static Stability

"If the object subject to disturbance has neither the tendency to return nor the tendency to continue in the displacement direction, neutral static stability exists" (Hurt, 1965).

Demonstrated by a ball on a level surface. If set in motion, it will roll briefly and then stop.

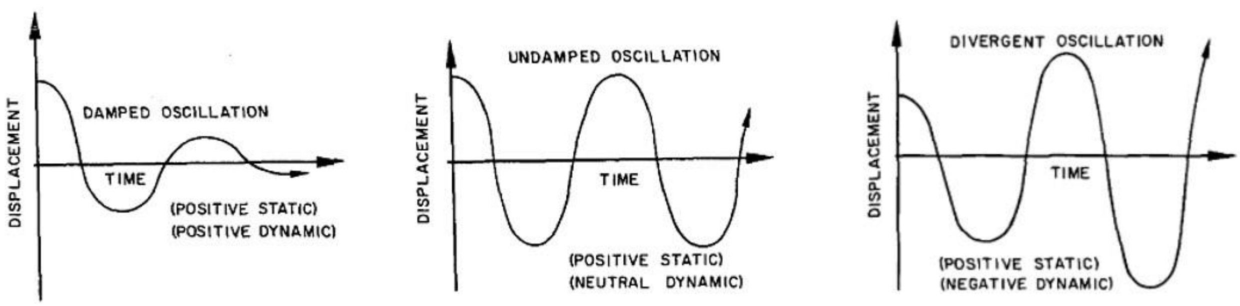

Figure A-6: Types of Oscillation (Hurt, 1965)

iv. Dynamic Stability

"While static stability is concerned with the tendency of a displaced body to return to equilibrium, dynamic stability is concerned with the resulting motion with time. If an object is disturbed from equilibrium, the time history of the resulting motion indicates the dynamic stability of the system. In general, the system will demonstrate positive dynamic stability if the amplitude of the motion decreases with time" (Hurt, 1965, p. 245).

v. Dynamic Instability

This is illustrated by "divergence by a non-cyclic increase of amplitude with time. The initial tendency to continue in the displacement direction is evidence of static instability and the increasing amplitude is proof of dynamic instability" (Hurt, 1965).

vi. Neutral Dynamic Instability

"If the original disturbance creates a displacement that remains constant thereafter, the lack of tendency for motion and the constant amplitude indicate neutral static and neutral dynamic instability" (Hurt, 1965).

b. Tom Benson

i. Stability and Control

"There are two modes of aircraft control: one moves the aircraft between equilibrium states, the other takes the aircraft into a non-equilibrium (accelerating) state. Control is directly opposed to stability" (Benson, 2002).

c. Choi, Dooley and Rungtusanatham

i. Control vs. Emergence

"Imposing too much control detracts from innovation and flexibility; conversely, allowing too much emergence can undermine managerial predictability and work routines" (Choi, Dooley, & Rungtusanatham, 2001).

d. Flagle, Huggins and Roy

i. On the Automatic Nature of Systems

"The last, and most important, characteristic of systems is that they are automatic. Although the degree of automaticity may vary over a wide spectrum, there are no systems in which human beings perform all control functions; conversely, there will probably never be systems in which no human beings are involved" (Flagle, Huggins, & Roy, 1960) quoted in (Adams & Keating, 2012).

e. George Biddell Airy:

i. Oscillation

"Whenever the equilibrium of forces requires that a free body be brought to a determinate position, either absolute or relative to the other parts of the mechanism with which it may be connected, we must not expect that the body will remain steadily in that position of equilibrium, but that it will oscillate on both sides of that position, and that (so far as the action of these forces affect it) it will have no tendency to settle itself in the position of equilibrium: and we must take account of this possible oscillation in planning any

mechanism which depends upon assuming the position of equilibrium to be nearly preserved" (Airy, 1840).

f. Otto Mayr

i. Instability as Described by G.B. Airy

"The first mathematical investigation had been published in 1840 by the Astronomer Royal George Biddell Airy (1801-1892), who had encountered instability on the friction governors regulating the weight drives of equatorial telescopes" (Mayr, 1971).

ii. Instability and Oscillation

Instability was defined by Maxwell as "a governor's response to disturbances: a governor is unstable if its output (the controlled speed) instead of returning to equilibrium will either increase continuously or enter into an oscillation of growing amplitude" (Mayr, 1971).

g. C. E. Thorn and M. R. Welford

i. Equilibrium

"In dynamics, equilibrium is founded on Newton's laws of motion and, thereby, embraces the concept of force, where [F]orce is defined as mass times acceleration (that is the change in motion [velocity] of an object) and is expressed in terms of [M]ass, [L]ength, and [T]ime (F = MLT-2). This relationship leads, in turn, to a definition of equilibrium: "when the velocity of an object is constant, or if the object is at rest, it is said to be in equilibrium" (Serway and Faughn 1992:75)" (Thorn & Welford, 1994).

h. Grove Karl Gibert

i. Dynamic Equilibrium

"Erosion is most rapid where the resistance is least, and hence as the soft rocks are worn away the hard are left prominent. The differentiation continues until an equilibrium is reached through the law of declivities. When the ratio of erosive action as dependent on declivities becomes equal to the ratio of resistances as dependent on rock character, there is equality of action" (Gilbert, 1877).

i. Norbert Weiner

i. On Maxwell as the Father of Automatic Control

"We have decided to call the entire field of control and communication theory, whether in the machine or in the animal, by the name Cybernetics, which we form from the Greek [word

for] or steersman. In choosing this term, we wish to recognize that the first significant paper on feedback mechanisms is an article on governors, which was published by Clerk Maxwell in 1868, and that governor is derived from a Latin corruption…" (Wiener, 1948).

j. Arturo Rosenbleuth, Norbert Wiener and Juan Bigelow

i. Feedback and Teleology

"Purposeful active behavior may be subdivided into two classes: feed-back (or teleological) and non-feed-back (or non-teleological)" (Rosenbleuth, Wiener, & Bigelow, 1943).

ii. Teleology and Purposeful Behavior

"*In classifying behavior, the term teleology was used as synonymous with purpose controlled by feed-back… Since we consider purposefulness a concept necessary for the understanding of certain modes of behavior we suggest that a teleological study is useful if it avoids problems of causality and concerns itself merely with an investigation of purpose*" (Rosenbleuth, Wiener, & Bigelow, 1943).

k. Maxwell, James Clerk[3] [4]

i. Governors as Mechanism for Homeostasis

"A GOVERNOR is a part of a machine by means of which the velocity of the machine is kept nearly uniform, notwithstanding variations in the driving-power or the resistance" (Maxwell, 1868).

ii. Governors as Feedback Systems

"But if the part acted on by centrifugal force, instead of acting directly on the machine, sets in motion a contrivance which continually increases the resistance as long as the velocity is above its normal value, and reverses its action when the velocity is below that value, the governor will bring the velocity to the same normal value whatever variation (within the working limits of the machine) be made in the driving-power or the resistance" (Maxwell, 1868).

---

[3] Referenced from *A Brief History of Feedback Control* (Lewis, 1992)

[4] Referenced from Cybernetics (Weiner, 1948)

l. Daniel Wegner & John Bargh

i. Automaticity

"People have always understood that there are functions of their bodies that they can't control, even if they want to. The beating of the heart, workings of the intestines, functioning of the internal organs, and breathing all go on whether we want them to or not. If we try to exert control, such as by holding our breath, the bodily function eventually wins out over our attempt, even if it has to knock us unconscious to do so" (Wegner & Bargh, 1998).

ii. Control and Automaticity Together

"1. Multitasking: Control and Automatic Processes Can Run in Parallel …

2. Delegation: A Control Process Can Launch an Automatic Process …

3. Orienting: An Automatic Process Can Launch a Control Process …

4. Intrusion: An Automatic Process Can Override a Control Process …

5. Regulation: A Control Process Can Override an Automatic Process …

6. Automation: A Control Process Can Be Transformed into an Automatic Process …

7. Disruption: An Automatic Process Can Be Transformed into a Control Process …" (Wegner & Bargh, 1998).

m. Martin Leonard Pops

i. On the First Feedback Device

"The first feedback device of the modern world was the thermostat, invented before 1624 by the Dutchman Cornelis Drebbel who equipped an alchemical furnace with one in order to maintain the constant temperature he thought necessary for transmuting metals" (Pops, 1977).

n. F.L. Lewis

i. Windmill Fantail

"1745, E. Lee, fantail pointed windmill into wind" (Lewis, 1992)

ii. Fly-Ball Governor

"1788, James Watt patented the fly-ball governor" (Lewis, 1992)

iii. Instability of Closed Loop Systems

"In 1840, the British Astronomer Royal at Greenwich, G.B. Airy, developed a feedback device for pointing a telescope. His device was a speed control system which turned the telescope automatically to compensate for the earth's rotation, affording the ability to study a given star for an extended time.

Unfortunately, Airy discovered that by improper design of the feedback control loop, wild oscillations were introduced into the system. He was the first to discuss the instability of closed-loop systems, and the first to use differential equations in their analysis" (Lewis, 1992).

o. Ludwig von Bertalanffy

i. Feedback and Control

"A second central concept of the theory of communication and control is that of feedback. Feedback arrangements are widely used in modern technology for the stabilization of a certain action, as in thermostats or in radio receivers; or for the direction of actions towards a goal where the aberration from that goal is fed back, as information, till the goal or target is reached" (Von Bertalanffy, 1968).

p. Peter Checkland

i. Control and Hierarchy

"Control is always associated with the imposition of constraints, and an account of a control process necessarily requires our taking into account at least two hierarchical levels. At a given level, it is often possible to describe the level by writing dynamical equations, on the assumption that one particle is representative of the collection and that the forces at other levels do not interfere. But, any description of a control process entails an upper level imposing constraints upon the lower. The upper level is a source of an alternative (simpler) description of the lower level in terms of specific functions that are emergent as a result of the imposition of constraints" (Checkland, 1981).

***q.* Gaspar Banfalvi**

***i.* Negative Feedback and Homeostasis**

"In negative feedback regulation the organism has set points to which different parameters (temperature, volume, pressure, etc.) have to be adapted to maintain the normal state and stability of the body. The momentary value refers to the values at the time the parameters

have been measured. When a parameter changes it has to be turned back to its set point. Oscillations are characteristic to negative feedback regulation…" (Banfalvi, 2014).

r. Meinhardt (1995)

i. Positive Feedback

"An essential element of dynamics systems is a positive feedback that self-enhances the initial deviation from the mean. The avalanche is proverbial. Cities grow since they attract more people, and in the universe, a local accumulation of dust may attract more dust, eventually leading to the birth of a star. Earlier or later, self-enhancing processes evoke an antagonistic reaction. A collapsing stock market stimulates the purchase of shares at a low price, thereby stabilizing the market. The increasing noise, dirt, crime and traffic jams may discourage people from moving into a big city" (Meinhardt, 1995).

s. Warren Johnson

i. First Electric Thermostat (Johnson, 1883)

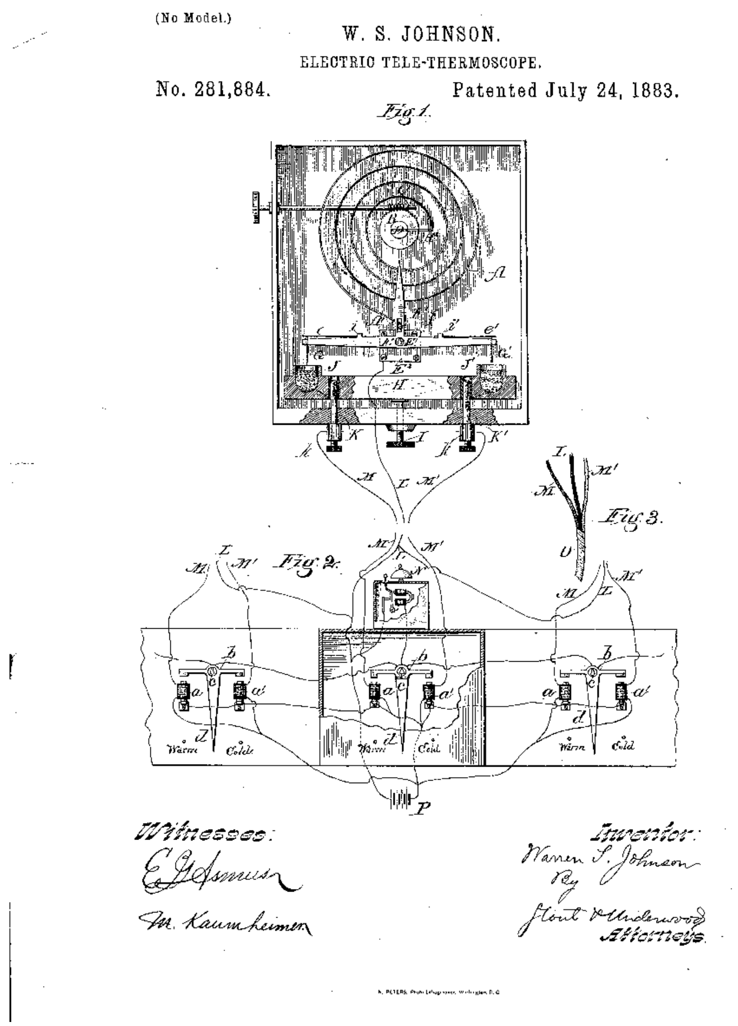

Figure A-7: Electric Thermostat Diagram (Johnson, 1883)

A-6. System Darkness

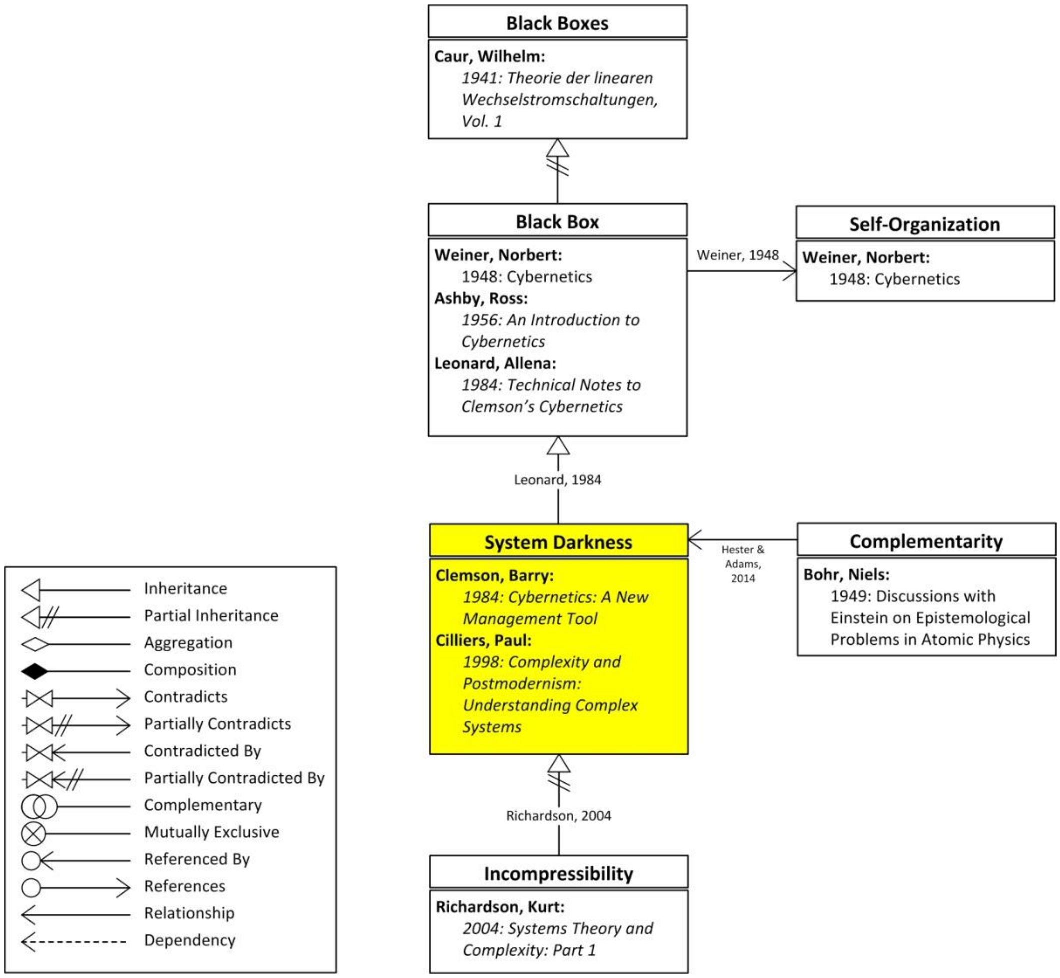

Figure A-8: Concept Model of System Darkness

■ **Definition:**

System Darkness: No system can be known completely (Clemson, 1984)

■ **Commentary**

The concept of system darkness emerged from the Black Box principles of Caur, and was later integrated into cybernetics and general systems theory by Wiener and Ashby.

■ Contributing Scholars

a. Willhelm Caur (Cauer W. , 1941)(Cauer, Mathis, & Pauli, 2000)

i. Conceptual Black Box

His *"way of studying differential equations indirectly through transfer functions of black-boxes and their input-output pairs became characteristic of modern linear system theory"* (Cauer, Mathis, & Pauli, 2000).

b. Ross Ashby (1956)

i. Black Box

"At first we are apt to think, for instance, that a bicycle is not a Black Box, for we can see every connecting link. We delude ourselves, however. The ultimate links between pedal and wheel are those interatomic forces that hold the particles of metal together; of these we see nothing, and the child who learns to ride can become competent merely with the knowledge that pressure on the pedals makes the wheels go round" (Ashby, 1956).

c. Norbert Weiner (1948)

i. Black Box Related to Self-Organization

"We thus see that a non-linear interaction causing the attraction of frequency can generate a self-organization system, as it does, for example, in the case of the brain waves we have discussed and in the case of the a-c network. This possibility of self-organization is by no means limited to the very low frequency of these two phenomena. Consider self-organizing systems at the frequency level, say, of infra-red light or radar spectra" (Weiner, 1948).

d. Allena Leonard (1984)

i. Black Box

"A black box is a model of a system whose inner workings are not open to examination. The workings of a black box may be studied or inferred by varying the inputs and analyzing the outputs... they cannot be taken apart for study and retain their identity as wholes" (Leonard, 1984).

e. Kurt Richardson (2004)

i. Regarding Incompressibility

"In complexity thinking the darkness principle is covered by the concept of incompressibility… The concept of ***incompressibility*** *suggests that the best representation*

of a complex system is the system itself and that any representation other than the system itself will necessarily misrepresent certain aspects of the original system" (Richardson, 2004).

f. Paul Cilliers (1998)

i. Regarding knowledge among elements

"Each element in the system is ignorant of the behavior of the system as a whole, it responds only to information that is available to it locally. This point is vitally important. If each element 'knew' what was happening to the system as a whole, all of the complexity would have to be present in that element" (Cilliers, 1998).

g. Barry Clemson (1984)

"No system can be known completely" (Clemson, 1984).

h. Ern Reynolds (2002)

"No system can be known completely" (Reynolds, 2002).

i. Patrick Hester and Kevin Adams

i. Relating System Darkness and Complementarity

"System meaning is informed by the circumstances and factors that surround the system. The contextual axiom's propositions are those which bound the system by providing guidance that enables an investigator to understand the set of external circumstances or factors that enable or constrain a particular system.

The contextual axiom has three principles: (1) holism, (2) darkness, and (3) complementarity" (Hester & Adams, 2014).

A-7. Dynamic Equilibrium

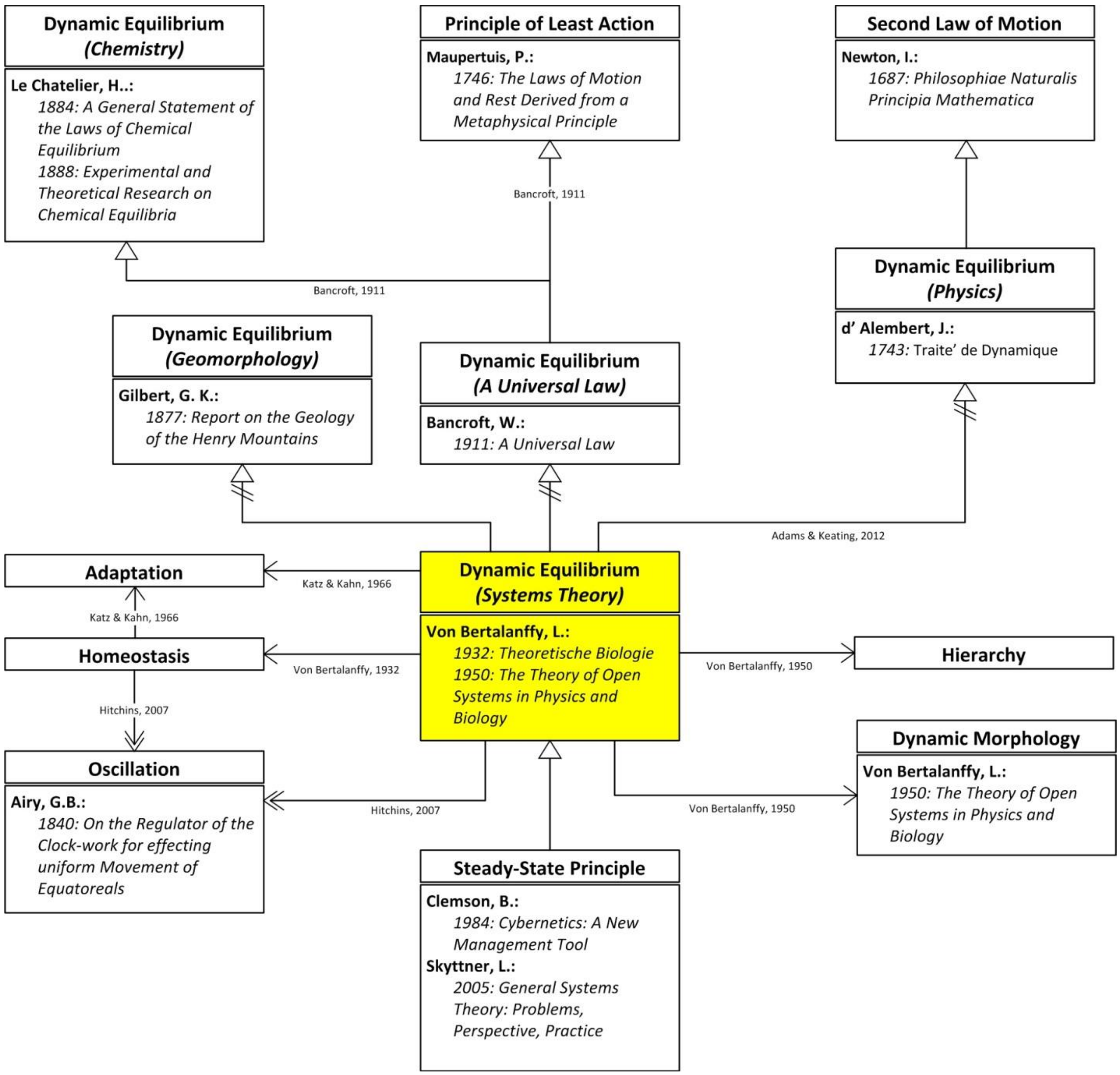

Figure A-9: Concept Model of Dynamic Equilibrium

■ Definition

Dynamic Equilibrium: The maintenance of stability in a complex system by altering its internal equilibrium points in response to internally or externally generated disturbances (Skyttner, 2005)

Commentary

This is a particularly challenging topic to address, because the (recent) literature is divided on what Dynamic Equilibrium is, and what constitutes the Steady-State Principle. For this research, the determination is that Dynamic Equilibrium speaks to the nature of a system to adjust itself to reach a new equilibrium point after system conditions have been altered, either internally or externally. Steady-State refers to the principle that asserts *"If a system is in a state of equilibrium (a steady state), then all sub-systems must be in equilibrium. If all sub-systems are in a state of equilibrium, then the system must be in equilibrium"* (Clemson, 1984).

Experience, however, suggests that this principle may not be true. A particular example is that of a system that can effectively contain a sub-system which is in a non-equilibrium state, such that its chaotic oscillations do not unduly influence the rest of the system. This containment may not necessarily be complete isolation, but rather may provide a dampening barrier that prevents the unstable sub-system from creating perturbations that cannot be absorbed into the normal dynamic equilibrium of the system. Such a relationship is demonstrated by the prison system. Prisons are directly related to society and are part of our social system. Individuals who cannot conduct themselves in a manner that is consistent with the laws of the system (criminals) are confined in the prison, where they are still criminals, but they are no longer able to effect damage on the larger society. Perhaps a better example is the lunatic asylum, where dangerous psychotics are separated from society for the protection of both parties. Within the confines of their own mental recesses, these individuals continue to have psychotic machinations that are clear manifestations of instability and non-equilibrium. The actions that would result from these thoughts, though, are constrained, in order to maintain the stability of the larger system. Clearly, in this case, the system is able to reach a state of equilibrium, although one of its components (the madman) remains highly unstable.

Contributing Scholars

a. Pierre Louis Maupertuis

i. Principle of Least Action

"Nature is thrifty in all its actions." (Maupertuis, 1744)

ii. Principle of Least Action

"The laws of movement and of rest deduced from this principle being precisely the same as those observed in nature, we can admire the application of it to all phenomena. The movement of animals, the vegetative growth of plants ... are only its consequences; and the

spectacle of the universe becomes so much the grander, so much more beautiful, the worthier of its Author, when one knows that a small number of laws, most wisely established, suffice for all movements" (Maupertuis, 1746).

b. Morris Kline

i. The Principle of Least Action as Related to Fermat, Descartes and Newton

"Pierre-Louis Moreau de Maupertuis (1698-1759), while working with the theory of light in 1744, propounded his famous Principle of Least Action in a paper entitled "Accord de différentes lois de la nature qui avaient jusqu'ici paru incompatibles." He started from Fermat's Principle, but in view of disagreements at the time as to whether the velocity of light was proportional to the index of refraction as Descrates and Newton believed, or inversely proportional as Fermat believed, Maupertuis abandoned least time. In fact he did not believe it was always correct" (Kline, 1972).

Note: Pierre de Fermat: Fermat's Principle is the Principle of Least Time which states that the path taken between two points by a ray of light is the one that can be traversed in the least amount of time. Postulated in a letter dated January 1, 1662. (Mahoney, 1994)

Note: Rene Descartes: Law of Refraction. Descartes presented his theory of light-refraction in the Dioptrique (Descartes, 1637), which resulted in a proof of the sine-law but also presented a collection of "vexing logical inconsistencies" (Smith, 1987).

Quote: "Isaac Newton read Descartes work and after analyzing the refraction of light rays through media of differing densities with his newly developed laws of motion, Isaac Newton (1730) concluded that when light struck an interface between two media of different densities, the corpuscles of light were accelerated by the high density media such that the component of the velocity perpendicular to the interface, but not the component parallel to the interface, increased" (Wayne, 2009).

Newton's Theory of Light and Colours was published in 1672 (Newton, 1672).

c. Jean d'Alembert

i. Dynamic Equilibrium in Physics

D'Alembert restructured a dynamic equation to allow it to be treated as a static equation in Traite' de Dynamique (1743). Directly relates to Newton's Second Law as published in Principia (Newton, 1687).

Connection established in Adams and Keating (2012).

d. Henri Louis Le Chatelier

i. Dynamic Equilibrium in Chemistry

"Any system in stable chemical equilibrium, subjected to the influence of an external cause tends to change either its temperature or its condensation (pressure, concentration, number of molecules in unit volume), either as a whole or in some of its parts, can only undergo such internal modifications as would, if produced alone, bring about a change of temperature or of condensation of opposite sign to that resulting from the external cause" (Le Chatelier, 1884).

ii. Dynamic Equilibrium in Chemistry (Restated)

"Every change of one of the factors of an equilibrium occasions a rearrangement of the system in such a direction that the factor in question experiences a change in a sense opposite to the original change" (Le Chatelier, 1888).

e. Wilder Bancroft

i. Dynamic Equilibrium as a Universal Law

"I wish to call your attention to-night to what I believe to be another universal law, a qualitative one and not a quantitative one. The chemists call it the theorem of Le Chatelier. The physicists call it the theorem of De Maupertuis or the principle of least action. By the biologists it is known as the law of the survival of the fittest, while the business man speaks of the law of supply and demand. The broadest definition of it is that a system tends to change so as to minimize an external disturbance" (Bancroft, 1911).

f. Bruce West

i. Dynamic Equilibrium in Chemistry

"Le Chatelier's principle was discovered in chemistry independently by Henri Louis Le Chatelier (1888) and Karl Ferdinand Braun and states that when a system in a dynamic equilibrium is acted on by external stress, it will adjust in such a way as to relieve the stress and establish a new equilibrium" (West, 2013).

g. Ludwing Von Bertalanffy

i. Dynamic Equilibrium and Hierarchy

"Every organic form is the expression of a flux of processes. It persists only in a continuous change of its components. Every organic system appears stationary if considered from a

certain point of view; but if we go a step deeper, we find that this maintenance involves continuous change of the systems of next lower order: of chemical compounds in the cell, of cells in multicellular organisms, of individuals in superindividual life units. It was said, in this sense (von Bertalanffy 1932, p. 248) that every organic system is essentially a ***hierarchical order*** *of processes standing in dynamic equilibrium. ... We may consider, therefore, organic forms as the expression of a pattern of processes of an ordered system of forces. This point of view can be called dynamic morphology"* (Von Bertalanffy, 1950).

ii. Dynamic Equilibrium and the Steady State *(Homeostasis)*

"True equilibria can occur only in closed systems and that, in open systems, disequilibria called 'steady states', or 'flow equilibria' are the predominant and characteristic feature. According to the second law of thermodynamics a closed system must eventually attain a time-independent equilibrium state, with maximum entropy and minimum free energy. An open system may, under certain conditions, attain a time-independent state where the system remains constant as a whole and in its phases, though there is a continuous flow of component materials. This is called a steady state. Steady states are irreversible as a whole… A closed system in equilibrium does not need energy for its preservation, nor can energy be obtained from it. In order to perform work, a system must be in disequilibrium, tending toward equilibrium and maintaining a steady state, Therefore the character of an open system is the necessary condition for the continuous working capacity of the organism" (Von Bertalanffy, 1932).

h. Barry Clemson

i. Steady State Principle

"If a system is in a state of equilibrium (a steady state), then all sub-systems must be in equilibrium. If all sub-systems are in a state of equilibrium, then the system must be in equilibrium" (Clemson, 1984).

i. **Lars Skyttner**

i. **Dynamic Equilibrium and Homeostasis**

"When defining living systems, the term dynamic equilibrium is essential. It does not imply something which is steady or stable. On the contrary, it is a floating state characterized by invisible movements and preparedness for change. To be in dynamic equilibrium is adapting adjustment to balance. Homeostasis stands for the sum of all control functions creating the

state of dynamic equilibrium in a healthy organism. It is the ability of the body to maintain a narrow range of internal conditions in spite of environmental changes" (Skyttner, 2005)**.**

ii. Steady-State Principle

"For a system to be in a state of equilibrium, all subsystems must be in equilibrium. All subsystems being in a state of equilibrium, the system must be in equilibrium" (Skyttner, 2005).

Note: This appears to be taken without attribution from the 1984 work of Barry Clemson.

j. Derek Hitchins

i. Dynamic Equilibrium is Homeostasis related to Oscillation

In discussing the balance between fox and rabbit populations, *"There is, then, no single solution to the question of population size; instead, there is an infinite set of solutions. This oscillating behavior is characteristics of much social, biological and physical behavior; such behavior might be viewed as a form of homeostasis, or dynamic equilibrium of, in this instance, the overall system of fox-rabbit interactions"* (Hitchins, 2007).

k. Mohammad Jamshidi

i. Dynamic Equilibrium Defined

"Dynamic stability holds that a system remains stable as long as it can continue to produce required performance during environmental turbulence and changing conditions. Maintenance of stability, or dynamic equilibrium (Skyttner, 1996), in complex systems is achieved through adjustments to shifts and disturbances (internally or externally generated) that impact system performance" (Jamshidi, 2011).

l. Katz and Kahn

i. Dynamic Equilibrium and Adaptation

Referenced from Skyttner (2005), who identifies one of their requirements of open systems as *"Equilibrium and dynamic homeostasis including adaptation"* (Katz & Kahn, 1966).

m. Grove Karl Gilbert

i. Dynamic Equilibrium in Geomorphology

"Erosion is most rapid where the resistance is least, and hence as the soft rocks are worn away the hard are left prominent. The differentiation continues until an equilibrium is

reached through the law of declivities. When the ratio of erosive action as dependent on declivities becomes equal to the ratio of resistances as dependent on rock character, there is equality of action" (Gilbert, 1877).

A-8. Emergence

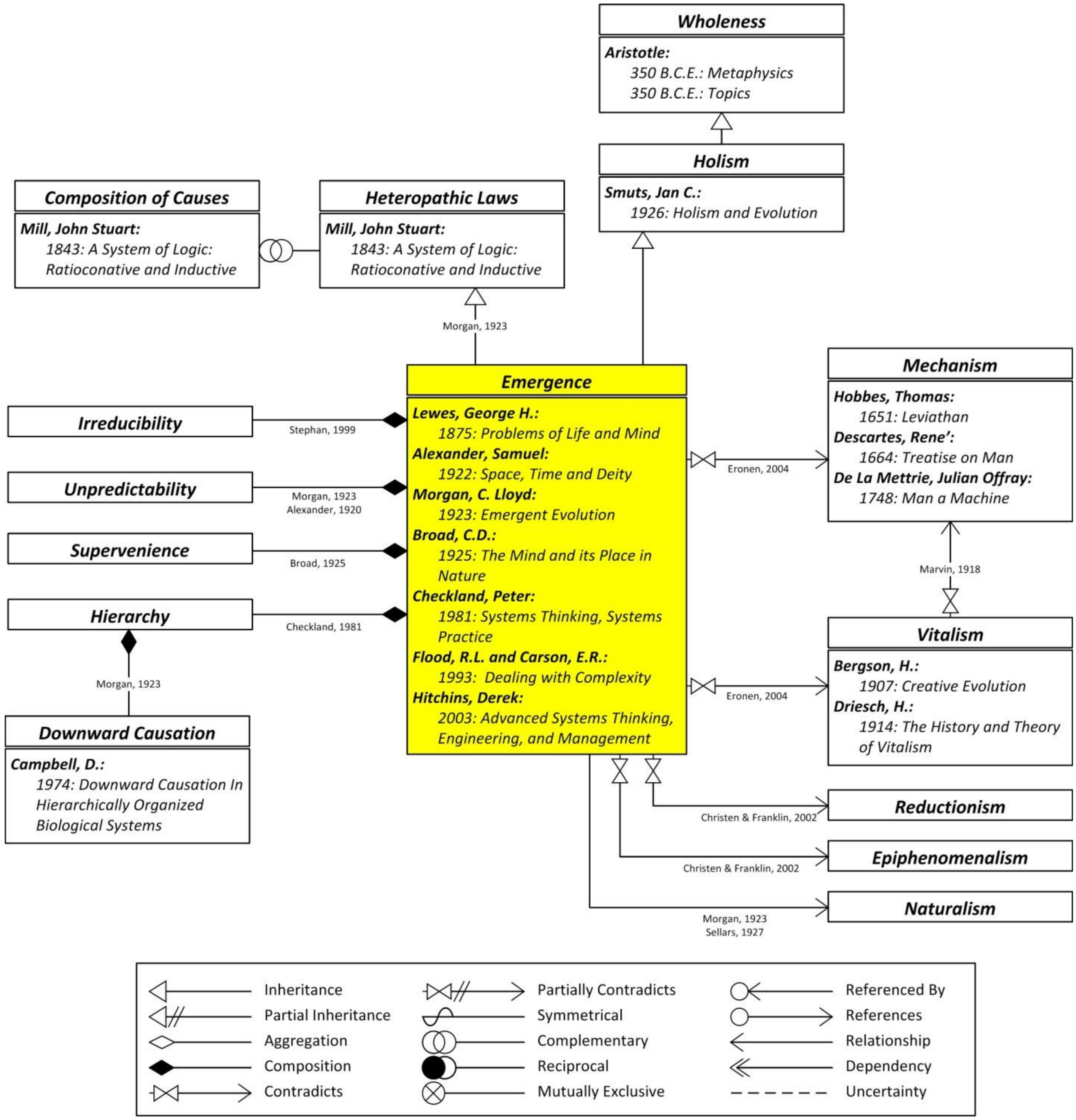

Figure A-10: Concept Model of Emergence

■ Definition

Emergence: Qualities or characteristics that arise in the higher levels of a system that are dependent upon, but not present in, the lower levels (Alexander, 1922)

■ Commentary

The sources of emergence here are drawn largely from the research of Markus Eronen who, in turn, made significant reference to Achim Stephan. All quotations (in English) were traced to their original source and verified. Translated quotations from Stephan's German manuscript were accepted verbatim from Eronen's work.

■ Contributing Scholars

a. Eronen, Markus

i. Emergence vs. Vitalism vs. Mechanism

"It is important to remember that the context in which the theories of Alexander, Lloyd Morgan and Broad were formed was the controversy between mechanism and vitalism that was at its fiercest at the end of the 19th and the beginning of the 20th century. According to vitalism, organic phenomena could not be explained without appealing to nonphysical factors that make living beings what they are. The most prominent defenders of vitalism were Hans Driesch (1867-1941) and Henri Bergson (1859-1941). The former postulated "entelechies", nonphysical elements necessary for the explanation of organic processes, the latter appealed to "élan vital", a driving force responsible for the creation of new forms of life. According to mechanism, everything could be explained mechanically, even organic phenomena. The emergentists rejected both mechanism and vitalism and offered a third alternative. According to emergentism, all beings and structures, whether living or nonliving, are composed of the same basic elements, but there are nonetheless relevant differences between physical, biological and mental phenomena, and different kinds of explanations must be applied to them" (Eronen, 2004).

Note: The conflict between Mechanism and Vitalism is detailed by Walter Marvin in The Philosophical Review (Marvin, 1918).

ii. Emergence and Downward Causation

"According to Lloyd Morgan, an emergent quality (or "a new kind of relatedness", as he sometimes puts it) makes a difference to the way things "run their course" at lower levels. In other words, the manner in which lower-level events happen "depends on" the new kind of relatedness. This must be accepted with Alexander's "natural piety". (Pp. 1518). Therefore, in contrast to Alexander, Lloyd Morgan is clearly and strongly committed to downward causation" (Eronen, 2004).

Note: In 1974 Donald Campbell coined the phrase "downward causation" and Campbell is widely cited in the current literature as the main source of the idea. Downward causation is in contradiction to reductionism. To quote Campbell, "all processes at the lower levels of a hierarchy are restrained by and act in conformity to the laws of the higher levels" (Campbell, 1974).

iii. Emergence and Irreducibility

"Irreducibility. Systemic properties are irreducible, (a.) if they are not behaviourally analyzable, or (b.) if the behaviour of the components over which they supervene is irreducible. In both cases the systemic properties cannot be deduced from the behaviour and properties that the components show in isolation or in simpler systems" (Eronen, 2004).

iv. Emergence and Hierarchy

"Another typical feature of theories of emergence is the layered view of nature. On this view, all things in nature belong to a certain level of existence, each according to its characteristic properties. These levels of existence constitute a hierarchy of increasing complexity that also corresponds to their order of appearance in the course of evolution" (Eronen, 2004).

v. Weak Emergentism

"Weak emergentism has the following defining characteristics (Stephan 1999, 66-67):

(i.) Physical monism. This is a form of naturalism: all entities in the world are composed of physical elements. Therefore, also emergent properties are instantiated by systems that are completely composed of physical elements.

(ii.) Systemic properties. There are systemic properties. A property of a system is systemic if none of the components of the system has it.

(iii.) Synchronic determinism. The properties and behavioural dispositions of a system are nomologically dependent on its microstructure. There can be no difference in the systemic properties without there being a difference in microstructure" (Eronen, 2004).

vi. Synchronic Emergentism

"Synchronic emergentism is weak emergentism supplemented with the characteristic irreducibility (Stephan 1999, 68)" (Eronen, 2004).

vii. Diachronic Emergentism

"Diachronic emergentism is weak emergentism supplemented with the characteristics novelty and unpredictability (Stephan 1999, 69)" (Eronen, 2004).

viii. Eronen's Model of Emergentism

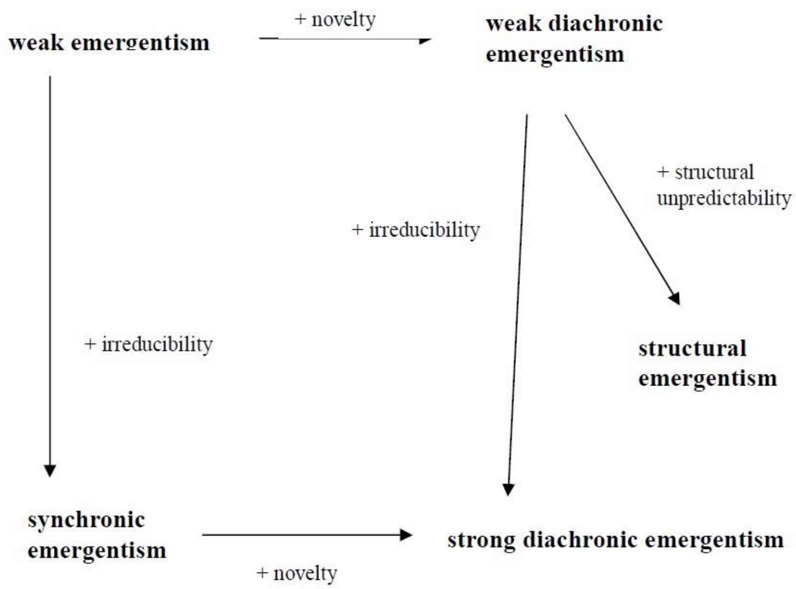

Figure A-11: Eronen's Model of Emergentism (2004)

b. Achim Stephan

i. Emergence Is Irreducible

"Irreducibility. A systemic property is irreducible, if (i) it is not behaviourally analyzable, or (ii) if the specific behaviour of the system components, over which the systemic property supervenes, does not follow from the behaviour of these components in isolation or in simpler systems" (Stephan, 1999).

ii. Emergence is Unpredictable

"A systemic property is in principle unpredictable before its first appearance (i.) if it is irreducible or (ii.) if the structure that instantiates it is unpredictable before its first appearance" (Stephan, 1999).

c. John Stuart Mill

i. Composition of Causes as the Opposite of Emergence

"If a body is propelled in two directions by two forces, one tending to drive it to the north and the other to the east, it is caused to move in a given time exactly as far in both directions as the two forces would separately have carried it; and is left precisely where it would have arrived if it had been acted upon first by one of the two forces, and afterwards by the other. This law of nature is called, in dynamics, the principle of the Composition of Forces: and in

imitation of that well-chosen expression, I shall give the name of the Composition of Causes to the principle which is exemplified in all cases in which the joint effect of several causes is identical with the sum of their separate effects" (Mill, 1843).

ii. Heteropathic Laws as Synonymous with Emergence [*Inheritance*]

"The component parts of a vegetable or animal substance do not lose their mechanical and chemical properties as separate agents, when, by a peculiar mode of juxtaposition, they, as an aggregate whole, acquire physiological or vital properties in addition. Those bodies continue, as before, to obey mechanical and chemical laws, in so far as the operation of those laws is not counteracted by the new laws which govern them as organized beings. […] Though there are laws which, like those of chemistry and physiology, owe their existence to a breach of the principle of Composition of Causes, it does not follow that these peculiar, or, as they might be termed, heteropathic laws, are not capable of composition with one another" (Mill, 1843).

d. C. Lloyd Morgan

i. On John Stuart Mill as the Originator of Emergence

"The concept of emergence was dealt with (to go no further back) by J.S. Mill in his Logic (Bk. III. ch. vi. §2) under the discussion of "heteropathic laws" in causation. The word "emergent", as contrasted with "resultant", was suggested by G. H. Lewes in his Problems of Life and Mind (Vol. II. Prob. V. ch. iii. p. 412)" (Morgan, 1923).

ii. Emergence in Chemistry

"When carbon having certain properties combines with sulphur having other properties there is formed, not a mere mixture but a new compound, some of the properties of which are quite different from those of either component" (Morgan, 1923).

iii. Unpredictability of Emergence

"Let there be three successive levels of natural events, A, B, and C. Let there be in B a kind of relation which is not present in A; and in C a kind of relation, not yet present in B or in A. If then one lived and gained experience on the B-level, one could not predict the emergent characters of the C-level, because the relations, of which they are the expression, are not yet in being. Nor if one lived on the A-level could one predict the emergent character of b-events, because ex hypothesi, there are no such events as yet in existence. What, it is claimed, one cannot predict, then, is the emergent expression of some new kind of relatedness among

preexistent events. One could not foretell the emergent character of vital events from the fullest possible knowledge of physicochemical events only" (Morgan, 1923).

iv. On Downward Causality

"The go of physico-chemical events at the level of life is not the same as that which obtains at the level of materiality only; the go of organic events at the level of effective consciousness is not the same as that which obtains at the level of vitality only. I speak of this alteration in the manner of go at any given level as "dependent on" the new and emergent kind of relatedness which there supervenes in the course of emergent evolution. So long as the words are used in a purely naturalistic sense, one may say that the higher kinds of relatedness guide or control the go of lower-level events" (Morgan, 1923).

v. Relationship to Naturalism

"The naturalistic contention is that, on the evidence, not only atoms and molecules, but organisms and minds are susceptible of treatment by scientific methods fundamentally of like kind; that all belong to one tissue of events; and that all exemplify one foundational plan" (Morgan, 1923).

e. Samuel Alexander

i. Emergence Cannot be Predicted

"The higher quality emerges from the lower level of existence and has its roots therein, but it emerges therefrom, and it does not belong to that lower level, but constitutes its possessor a new order of existent with its special laws of behaviour. The existence of emergent qualities thus described is something to be noted, as some would say, under the compulsion of brute empirical fact, or, as I should prefer to say in less harsh terms, to be accepted with the "natural piety" of the investigator. It admits no explanation" (Alexander, 1922).

f. C. D. Broad

i. If It Can Be Deduced from the Parts, It Is NOT Emergence

"Take any ordinary statement, such as we find in chemistry books; e.g., 'Nitrogen and Hydrogen combine when an electric discharge is passed through a mixture of the two. The resulting compound contains three atoms of Hydrogen to one of Nitrogen; it is a gas readily soluble in water, and possessed of a pungent and characteristic smell.' If the mechanistic theory be true the archangel could deduce from his knowledge of the microscopic structure of atoms all these facts but the last. He would know exactly what the microscopic structure

of ammonia must be; but he would be totally unable to predict that a substance with this structure must smell as ammonia does when it gets into the human nose. The utmost that he could predict on this subject would be that certain changes would take place in the mucous membrane, the olfactory nerves and so on. But he could not possibly know that these changes would be accompanied by the appearance of a smell in general or of the peculiar smell of ammonia in particular, unless someone told him so or he had smelled it for himself. If the existence of the so-called 'secondary qualities,' or the fact of their appearance, depends on the microscopic movements and arrangements of material particles which do not have these qualities themselves, then the laws of this dependence are certainly of the emergent type" (Broad, 1925).

ii. Synchronic Determinism or Supervenience

"Put in abstract terms the emergent theory asserts that there are certain wholes, composed (say) of constituents A, B, and C in a relation R to each other; that all wholes composed of constituents of the same kind as A, B, and C in relations of the same kind as R have certain characteristic properties [...]" (Broad, 1925).

g. Roy Wood Sellars

i. Associating Emergence with Naturalism

In a system of quotes, too long to include here, Sellars states that emergence is a property of naturalism (Sellars, 1927).

h. George Lewes

i. Emergence

"Still greater is the difficulty in psychological research. Here observation is always that of resultants, never of components. Real analysis, such as that of the chemist, is impossible. The components have no observable existence : they are only inferred. I mean, that a feeling cannot be taken to pieces like a salt, these pieces separately studied, first isolated, next in combination. All the stages of a process must be completed before the feeling emerges. In no one stage is it a feeling. The separation, therefore, of the stages, the analysis of the feeling into its elements, is ideal only. Moreover, each of these ideal elements has a history. The elements of an inorganic object, the moments of a dynamic process, are unchangeable that is to say, the oxygen torn from rust, from water, or from an animal tissue, reappears with unaltered and unalterable characters after every fresh combination. Not so the elements of

a feeling ; the very tissues which are its physical basis are in incessant change" (Lewes, 1875).

i. Aristotle

i. The Whole as a Unity

"To return to the difficulty which has been stated with respect both to definitions and to numbers, what is the cause of their unity? In the case of all things which have several parts and in which the totality is not, as it were, a mere heap, but the whole is something beside the parts, there is a cause; for even in bodies contact is the cause of unity in some cases, and in others viscosity or some other such quality" (Aristotle, 350 B.C.E).

ii. The Part and the Whole

"In general, too, all the ways of showing that the whole is not the same as the sum of its parts are useful in meeting the type just described; for a man who defines in this way seems to assert that the parts are the same as the whole. The arguments are particularly appropriate in cases where the process of putting the parts together is obvious, as in a house and other things of that sort: for there, clearly, you may have the parts and yet not have the whole, so that parts and whole cannot be the same" (Aristotle, 350 B.C.E.).

j. Ludwig Von Bertalanffy

i. Emergence as an Alternative to Darwinian Evolution

"From the standpoint of science... the history of life does not appear to be the result of an accumulation of changes at random but subject to laws. This does not imply mysterious controlling factors that in an anthropomorphic way strive towards progressive adaptation, fitness, or perfection. Rather there are principles of which we already know something at present, and of which we can hope to learn more in the future. Nature is a creative artist; but art is not accident or arbitrariness, but the fulfilment of great laws" (Von Bertalanffy, 1952).

k. Markus Christen and Laura Franklin

i. Emergence vs. Reductionism

"The concept of emergence – at least in the philosophical tradition – is opposed to reductionism" (Christen & Franklin, 2002).

ii. Emergence vs. Epiphenomenalism

"The concept of emergence also opposes epiphenomenalism, which claims that there might be phenomena on the systems level lacking any causal or explanatory power" (Christen & Franklin, 2002).

l. Peter Checkland

i. On Emergence

"The principle that whole entities exhibit properties which are meaningful only when attributed to the whole, not to its parts – e.g. the smell of ammonia. Every model of human activity system exhibits properties as a whole entity which derive from it component activities and their structure, but cannot be reduced to them" (Checkland, 1981).

ii. Emergence and Hierarchy

Hierarchy is *"the principle according to which entities meaningfully treated as wholes are built up of smaller entities which are themselves wholes… and so on. In hierarchy, emergent properties denote the levels"* (Checkland, 1981).

A-9. Equifinality

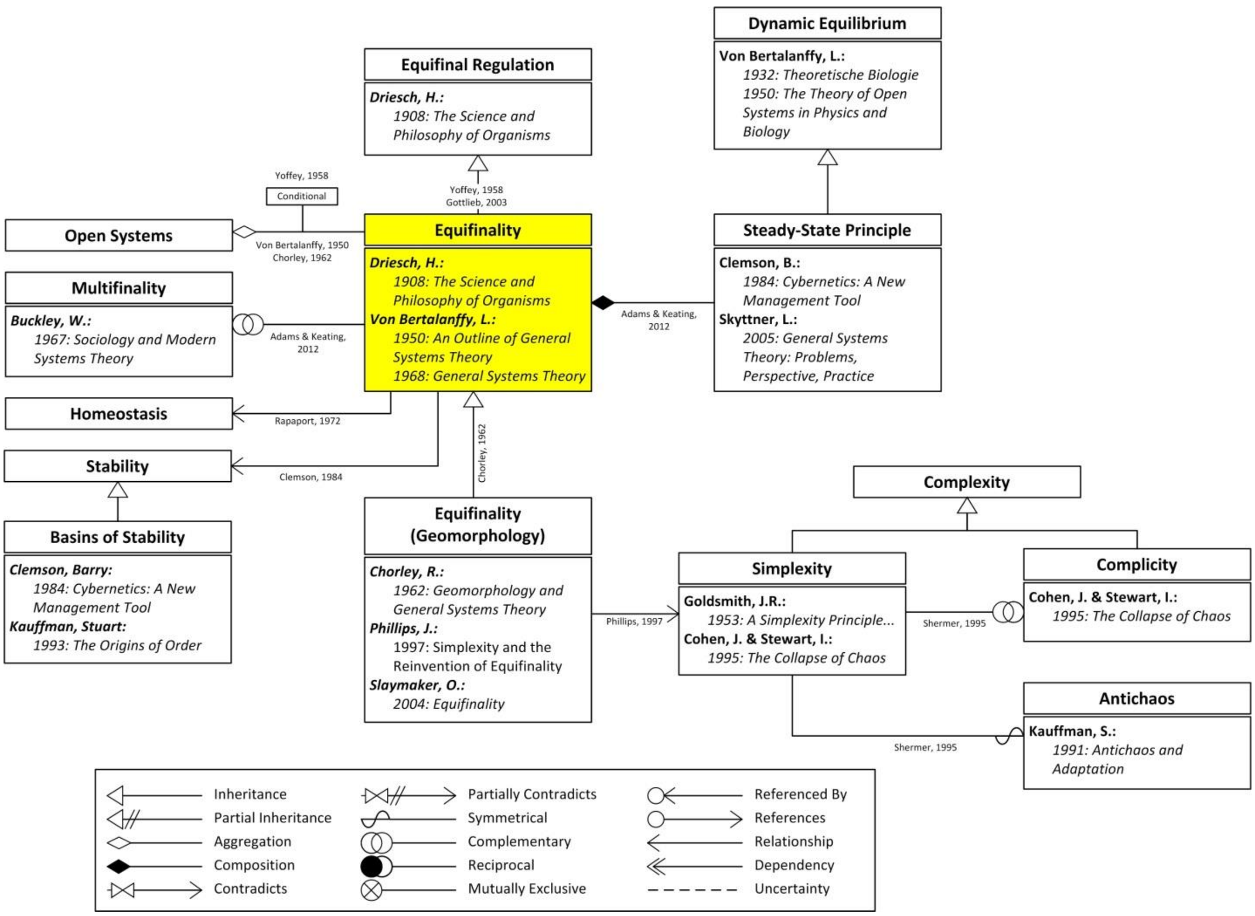

Figure A-12: Concept Model of Equifinality

■ Definition

Equifinality: The ability of an open system to reach the same final state from different initial conditions and in different ways (Von Bertalanffy, 1968)

■ Contributing Scholars

a. Kevin Adams & Charles Keating

i. Principle of Equifinality

"Principle of Equifinality: If a steady state is reached in an open system, it is independent of the initial conditions, and determined only by the system parameters, i.e. rates of reaction and transport" (Adams & Keating, 2012).

ii. Complementary to Multifinality

"Walter Buckley [1922-2006], in his discussion of morphogenetic processes in socio-cultural systems suggests a principle opposite to Bertalanffy"s Principle of Equifinality (Gharajedaghi, 1999). Buckley (1967) calls this multifinality where similar initial conditions may lead to dissimilar end states" (Adams & Keating, 2012).

b. Ludwig Von Bertalanffy

i. Definition by Contrast

"In most physical systems, the final state is determined by the initial conditions. Take, for instance, the motion in a planetary system where the positions at a time t are determined by those of a time t0, or a chemical equilibrium where the final concentrations depend on the initial ones. If there is a change in either the initial conditions or the process, the final state is changed" (Von Bertalanffy, 1950).

ii. Equifinality

"The first is the principle of equifinality. In any closed system, the final state is unequivocally determined by the initial conditions: e.g., the motion in a planetary system where the positions of the planets at a time t are unequivocally determined by their positions at a time t_0. Or in a chemical equilibrium, the final concentrations of the reactants naturally depend on the initial concentrations. If either the initial conditions or the process is altered, the final state will also be changed. This is not so in open systems. Here, the same final state may be reached from different initial conditions and in different ways" (Von Bertalanffy, 1968).

iii. Equifinality as a Property of Open Systems

"Analysis shows that closed systems cannot behave equifinally. This is the reason why equifinality is found in inanimate nature only in exceptional cases. However, in open systems, which are exchanging materials with the environment, in so far as they attain a steady state, the latter is independent of the initial conditions, or is equifinal" (Von Bertalanffy, 1950).

iv. Equifinality Implies Equilibrium

"Steady state systems show equifinality, in sharp contrast to closed systems in equilibrium where the final state depends on the components given at the beginning of the process" (Von Bertalanffy, 1950).

c. Richard J. Chorley

i. Equifinality and Open Systems in Geomorphology

"A last important characteristic of open systems is that they are capable of behaving "equifinally" in other words, different initial conditions can lead to similar end results (Von Bertalanffy, 1950, p. 25; and 1952, p. 143). Davisian (closed system) thinking is instinctively opposed to this view, and the immediate and facile assumption, for example, that most breaks of stream slope are only referable to a polycyclic mechanism is an illustration of the one cause-one effect mentality. The concept of equifinality accentuates the multivariate nature of most geomorphic processes and militates against the unidirectional inevitability of the closed system cyclic approach of Davis" (Chorley, 1962).

d. Olav Slaymaker

i. Equifinality in Geomorphology

"Equifinality is the principle which states that morphology alone cannot be used to reconstruct the mode of origin of a landform on the grounds that identical landforms can be produced by a number of alternative processes, process assemblages or process histories. Different processes may lead to an apparent similarity in the forms produced. For example, sea-level change, tectonic uplift, climatic change, change in source of sediment or water or change in storage may all lead to river incision and a convergence of form. The usage of the term in this way stems from Chorley (1962) but the related concept of converging landforms was developed earlier by Mortensen (1948), who pointed out that there are many convergences in the landforms of arid and polar regions even though their climates (and therefore by implication their geomorphic process assemblages) are so different" (Slaymaker, 2004).

e. Jonathan Phillips

i. Equifinality in Geomorphology

"Particular landforms or surface morphologies may be generated, in some cases, by several different processes, sets of environmental controls, or developmental histories. This convergence to similar forms despite variations in processes and controls is called equifinality" (Phillips, 1997).

ii. Simplexity as a Bridge Between Chaos and Equifinality

"I have not attempted to argue that instability and chaos is the only, or even the predominant, source of simplexity in geomorphic systems. While I believe instability and chaos are quite common in earth surface systems, I have not attempted to argue that here. The point is that if and when geomorphic systems exhibit deterministic chaos, simplexity is likely at some level, and therefore chaos does not necessarily preclude, and may indeed promote, equifinality in the form of simplexity" (Phillips, 1997).

A Note on the Origins of Simplexity in Geology

GOLDSMITH, J. R., (1953)*, A "simplexity principle" and its relation to "ease" of crystallization. Journal of Geology, Vol. 61, p. 439-451.*

A Note on Simplexity/Complicity/Antichaos from Michael Shermer

"What Kauffman calls antichaos Cohen and Stewart call simplexity, or "the emergence of large-scale simplicities as a direct consequences of rules, "or laws of nature. These predictable laws interact with unpredictable contingencies to occasionally trigger the "collapse of chaos." After the collapse simple rules "emerge from underlying disorder and complexity, "again as described in Corollaries 1 and 4. The antonym of Cohen's and Stewart's simplexity is complicity, "the tendency of interacting systems to coevolve in a manner that changes both, leading to a growth of complexity from simple beginnings – complexity that is unpredictable in detail, but whose general course is comprehensible and foreseeable." Complicity is a restatement of the model of contingent-necessity, especially Corollary 3" (Shermer, 1995).

f. Anatol Rapaport

i. Equifinality and Homestasis

"Open systems, in contrast to closed systems, exhibit a principle of equifinality, that is, a tendency to achieve a final state independent of initial conditions. In other words, open systems tend to 'resist' perturbations that take them away from some steady state. They can exhibit homeostasis" (Rapaport, 1972).

g. Barry Clemson

i. Relationships Between Stability and Equifinality

"Every system of whatever size must maintain its own structure and must deal with a dynamic environment, i.e., the system must strike a proper balance between stability and change. The cybernetic mechanisms for stability (i.e., homeostasis, negative feedback,

autopoiesis, equifinality) and change (i.e., positive feedback, algedonodes, self-organization) are found in all viable systems" (Clemson, 1984).

h. Gilbert Gottlieb

i. Driesch as the Originator of the Term Equifinality

(1) "While Roux found that killing one cell and allowing the second cleavage cell to survive resulted in a half embryo in frogs, Driesch (1908) found that detaching the first two cells in a sea urchin resulted in two fully formed sea urchins, albeit diminished in size" (Gottlieb, 2003).

(2) "Because Driesch had found that a single cell could lead to the creation of a fully formed individual, he gathered, quite correctly, that each cell must have the same prospective potency, as he called it, and could in principle become any pan of the body. He thought of these cells as harmonious-equipotential systems. For Driesch, the vitalistic feature of these harmonious-equipotential systems is their ability to reach the same outcome or endpoint by different routes, a process that he labeled equifinality?" (Gottlieb, 2003)

i. J.M. Yoffey

i. Driesch as the Originator of Equifinality

"Driesch made a great to-do about this "principle' when he demonstrated that a very young sea urchin embryo, when split in two, developed into two complete sea urchins instead of two halves of one as it presumably would have done under the influence of "blind mechanical forces" (Yoffey, 1958).

ii. Equifinality is not in ALL Open Systems

"Two qualifications of this observation are in order, First, it is by no means true that every "open system" is able to exhibit equifinality. "Equifinality" as a property of all open systems has never been rigorously defined. If one assumes a rigorous definition in terms of a unique steady state, then, of course, this is realizable only on paper…" (Yoffey, 1958).

j. Sato, et. al.

i. As a Basis for Historically Structured Sampling

"Historically Structured Sampling (HSS) is a method of sampling individual cases based on their previous (up-to-now) knowable life course histories analyzed as a series of bifurcation points. It makes it possible to contrast individuals who have arrived at the present state

(equifinality point) through vastly different life course trajectories. The notion of HSS relies heavily upon the notion of equifinality that originated in the general systems theory (GST) of von Bertalanffy (1968) and is rooted in the early work of Hans Driesch (1908)" (Sato, Yasuda, Kido, Arakawa, Mizoguchi, & Valsiner, 2007).

k. Hans Driesch

i. Origination of Equifinal Regulations

"Of course, we must be careful about what has to be "known" and "judged " and "willed." This problem seems rather easy to answer in the light of morphological restitutions Here the end to be attained is the normal organisation ; that "means" towards this end are known and found may seem very strange, but it is a fact; and it in a fact also, in the case of what we have called "equifinal regulations,' that different means leading to one and the same final state may be known and adopted" (Driesch, 1908).

A-10. Feedback

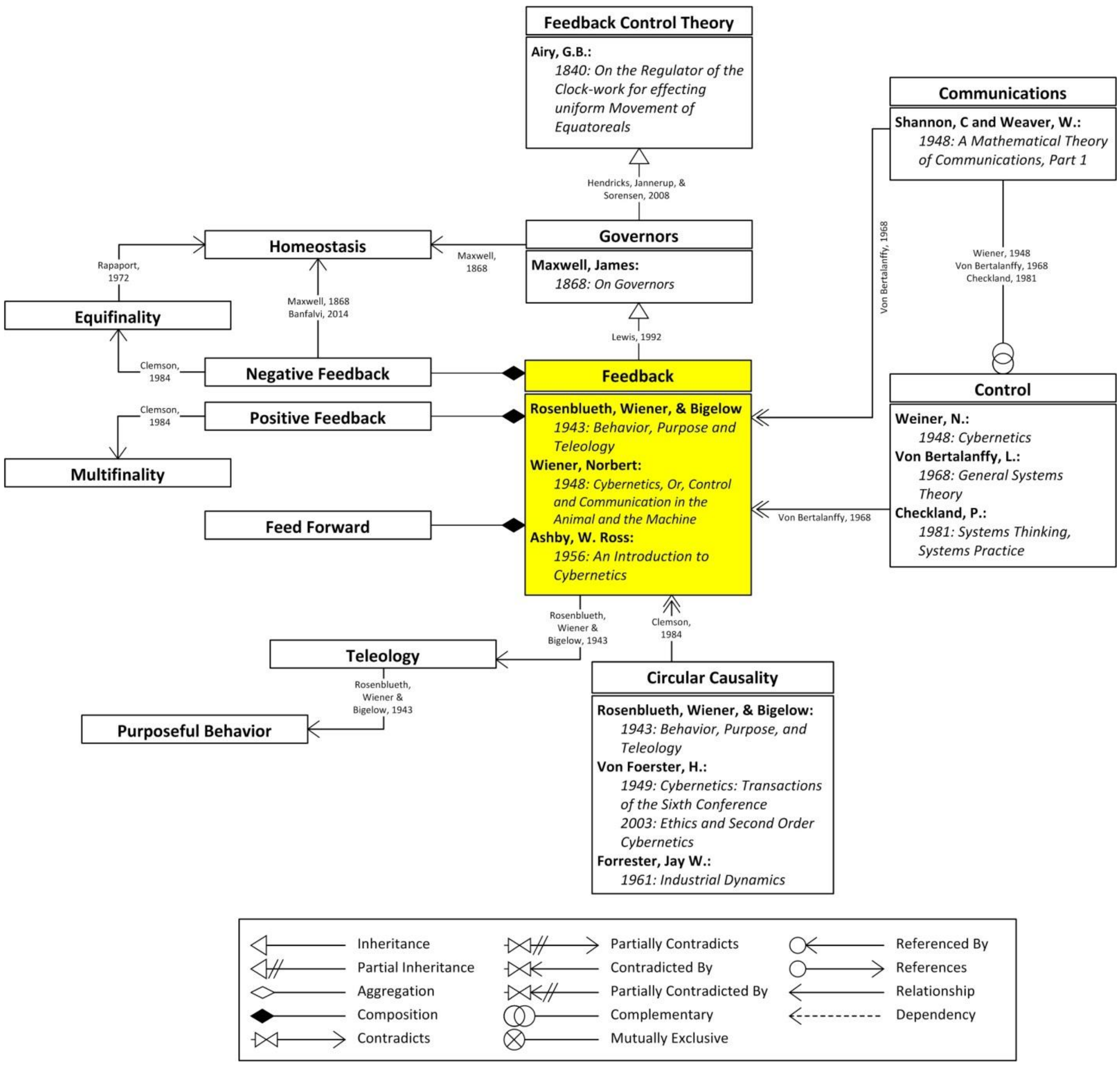

Figure A-13: Concept Model of Feedback

■ Definition

Feedback: A control mechanism that detects the system state using a receptor and then transmits signals to an effector to facilitate changes based on the new conditions (Von Bertalanffy, 1968)

■ Commentary

In the topics of both communications, circular causality and control, the issue of feedback has arisen several times. In beginning the exploration of feedback as an independent topic, the data collected in those sources will first be integrated here, and then extended information will be sought.

■ Contributing Scholars

a. Maxwell, James Clerk[5] [6]

i. Governors as Mechanism for Homeostasis

"A GOVERNOR is a part of a machine by means of which the velocity of the machine is kept nearly uniform, notwithstanding variations in the driving-power or the resistance" (Maxwell, 1868).

ii. Governors as Feedback Systems

"But if the part acted on by centrifugal force, instead of acting directly on the machine, sets in motion a contrivance which continually increases the resistance as long as the velocity is above its normal value, and reverses its action when the velocity is below that value, the governor will bring the velocity to the same normal value whatever variation (within the working limits of the machine) be made in the driving-power or the resistance" (Maxwell, 1868).

b. Norbert Wiener

i. Feedback

"When feed-back is possible and stable, its advantage, as we have already said, is to make performance less dependent on the load.[…] Thus feed-back serves to diminish the dependence of the system on the characteristics of the motor, and serves to stabilize it, for all frequencies [supported by the feedback formula] " (Weiner, 1948).

ii. Feedback and Oscillations

"We have now come to the end of an elementary discussion of linear oscillations, studied from the point of view of feed-back. A linear oscillating system has certain very special properties which characterize its oscillations" (Weiner, 1948, p. 128).

---

[5] Referenced from *A Brief History of Feedback Control* (Lewis, 1992)

[6] Referenced from Cybernetics (Weiner, 1948)

iii. Feedback and Homeostasis

"We must not forget another important physiological application of the principle of feed-back. A great group of cases in which some sort of feed-back is not only exemplified in physiological phenomena, but is absolutely essential for continuation of life, is found in what is known as homeostasis. [...] In short, our inner economy must contain an assembly of thermostats, automatic hydrogen-ion-concentration controls, governors, and the like, which would be adequate for a great chemical plant. These are what we know collectively as our homeostatic mechanism" (Wiener, 1948, p. 135).

iv. On Maxwell as the Originator of Feedback Mechanism Literature

"We have decided to call the entire field of control and communication theory, whether in the machine or in the animal, by the name Cybernetics, which we form from the Greek [word for] or steersman. In choosing this term, we wish to recognize that the first significant paper on feedback mechanisms is an article on governors, which was published by Clerk Maxwell in 1868, and that governor is derived from a Latin corruption…" (Wiener, 1948).

c. Arturo Rosenbleuth, Norbert Wiener and Juan Bigelow

i. Feedback and Teleology

"Purposeful active behavior may be subdivided into two classes: feed-back (or teleological) and non-feed-back (or non-teleological)" (Rosenbleuth, Wiener, & Bigelow, 1943).

ii. Teleology and Purposeful Behavior

"In classifying behavior, the term teleology was used as synonymous with purpose controlled by feed-back… Since we consider purposefulness a concept necessary for the understanding of certain modes of behavior we suggest that a teleological study is useful if it avoids problems of causality and concerns itself merely with an investigation of purpose" (Rosenbleuth, Wiener, & Bigelow, 1943).

d. Ludwig Von Bertalanffy

i. Feedback and Control

"Feedback arrangements are widely used in modern technology for the stabilization of a certain action, as in thermostats or in radio receivers; or for the direction of actions towards a goal where the aberration from that goal is fed back, as information, till the goal or target is reached" (Von Bertalanffy, 1968).

ii. Feedback and Communications, Self-Regulation and Stability

"A second central concept of the theory of communication and control is that of feedback. A simple scheme for feedback is the following. The system comprises, first, a receptor or "sense organ," be it a photoelectric cell, a radar screen, a thermometer, or a sense organ in the biological meaning. The message may be, in technological devices, a weak current, or, in a living organism, represented by nerve conduction, etc. Then there is a center recombining the incoming messages and transmitting them to an effector, consisting of a machine like an electromotor, a heating coil or solenoid, or of a muscle which responds to the incoming message in such a way that there is power output of high energy. Finally, the functioning of the effector is monitored back to the receptor, and this makes the system self-regulating, i.e., guarantees stabilization or direction of action" (Von Bertalanffy, 1968).

e. Ross Ashby

i. Feedback and Complexity

"In fact, there need be no dispute, for the exact definition of "feedback" is nowhere important. The fact is that the concept of "feedback", so simple and natural in certain elementary cases, becomes artificial and of little use when the interconnexions between the parts become more complex. When there are only two parts joined so that each affects the other, the properties of the feedback give important and useful information about the properties of the whole. But when the parts rise to even as few as four, if every one affects the other three, then twenty circuits can be traced through them; and knowing the properties of all the twenty circuits does not give complete information about the system. Such complex systems cannot be treated as an interlaced set of more or less independent feedback circuits, but only as a whole" (Ashby, 1956, p. 54).

f. Barry Clemson

i. Feedback and Circular Causality

(1) "*Feedback: Perhaps the key notion in cybernetics is that of circular causality*" (Clemson, 1984, p. 22).

(2) *"Circular causal processes are generally called feedback. There is a language problem here because 'feedback' in popular usage has come to mean one person's response to another person's action or performance, ie. an instructor provides 'feedback' to the student on the student's performance. This popular usage of 'feedback' is a severe distortion of the term's technical meaning. In a technical sense, feedback should be*

applied only to those situations in which A affects B and B affects A and there are numerous repetitions around the loop" (Clemson, 1984, p. 23).

ii. Positive Feedback and Multifinality

"Given initial conditions may give different final conditions (with a positive feedback loop)" (Clemson, 1984, p. 23).

iii. Negative Feedback and Equifinality

"Different initial conditions may give the same result (with a negative feedback loop)" (Clemson, 1984, p. 23).

iv. Negative Feedback and Stability / Positive Feedback and Adaptation (Change)

"Every system of whatever size must maintain its own structure and must deal with a dynamic environment, i.e., the system must strike a proper balance between stability and change. The cybernetic mechanisms for stability (i.e., homeostasis, negative feedback, autopoiesis, equifinality) and change (i.e., positive feedback, algedonodes, self-organization) are found in all viable system." (Clemson, 1984).

g. James March

i. Feedback and Adaptation

"Contemporary theories that emphasize reacting to feedback include theories of:

Experiential learning. A process by which the propensities to use certain procedures (or to have certain attributes) depend on the history of outcomes associated with previous uses in such a way that successes associated with a procedure in the past increase the propensity to use that procedure in the present (Cohen and Sproull, 1996; Lomi, Larsen, and Ginsberg, 1997; Greve, 2003).

Learning from others (diffusion, imitation). A process by which procedures or attributes of one unit are reproduced in another, and the likelihood of reproducing a particular procedure depends (positively) on the successes of the units using it (Abrahamson, 1991; Mezias and Lant, 1994; Miner and Haunschild, 1995; Strang and Soule, 1998; Miner and Raghavan, 1999).

Variation/selection. A process by which the procedures used by particular units are unchanging but more successful units are more likely to survive, grow, and reproduce than are less successful ones (Nelson and Winter, 1982; Hannan and Freeman, 1989; Aldrich, 1999).

Each of these is a theory of feedback-based change over time. They posit that procedures or attributes associated with successes are more likely to survive and to replicate at a more rapid rate than procedures or attributes associated with failures" (March, 2006)

h. Elbert Hendricks, Ole Jannerup, & Paul Sorensen

i. Beginning of Feedback Control Theory

"Unfortunately in some cases use of the governor lead to speed instability and to solve this problem it was necessary to create a theory to explain why this could occur. The first analysis of speed governors was carried out by George Airy (Astronomer Royal at Greenwich from 1835). Clockwork mechanisms were used to control the movement of large telescopes to compensate for the rotation of the earth and these were fitted with speed governors in an attempt to improve their accuracy. Using energy and angular momentum considerations, Airy set up a simplified nonlinear differential equation for the system in about 1840. Considering the linearized form of this equation, it was possible to show that in some circumstances small oscillations could build up exponentially and thus account for the instability observed" (Hendricks, Jannerup, & Sorensen, 2008).

i. John D. Lee, Alex Kirlik, M. J. Dainoff

i. Feedback and Circular Causality

"In 1942, at a conference sponsored by the Macey Foundation to promote interdisciplinary discussions about neuroscience, Arturo Rosenblueth introduced a radical challenge to classical ideas of cause and effect. He introduced the construct of 'circular causality.' This new construct was motivated by collaborations with Norbert Wiener and Julian Bigelow to understand stability in feedback control systems" (Lee, Kirlik, & Dainoff, 2013, p. 19).

j. Patrick Hester and Kevin Adams

i. Feedback and Circular Causality

"Circular causality refers to a complex of events that reinforce themselves through series of feedback loops (e.g., causal loops). There are labels that may be used for these two highly specialized loops:

1. Virtuous Circles: 'What is a vicious circle for one party, then, is a virtuous circle for another' [54, pp. 30-31]. A virtuous circle has favorable results.

2. Vicious Circles: 'A deviation amplifying loop (i.e., actions loops) with counterproductive results" [54, p. 16]. A vicious circle has detrimental results" (Hester & Adams, 2014).

k. Martin Leonard Pops

i. On the First Feedback Device

"The first feedback device of the modern world was the thermostat, invented before 1624 by the Dutchman Cornelis Drebbel who equipped an alchemical furnace with one in order to maintain the constant temperature he thought necessary for transmuting metals" (Pops, 1977).

l. F.L. Lewis

i. Windmill Fantail

"1745, E. Lee, fantail pointed windmill into wind" (Lewis, 1992).

ii. Fly-Ball Governor

"1788, James Watt patented the fly-ball governor" (Lewis, 1992).

iii. Instability of Closed Loop Systems

"In 1840, the British Astronomer Royal at Greenwich, G.B. Airy, developed a feedback device for pointing a telescope. His device was a speed control system which turned the telescope automatically to compensate for the earth's rotation, affording the ability to study a given star for an extended time.

Unfortunately, Airy discovered that by improper design of the feedback control loop, wild oscillations were introduced into the system. He was the first to discuss the instability of closed-loop systems, and the first to use differential equations in their analysis" (Lewis, 1992).

m. Warren Johnson

i. First Electric Thermostat (Johnson, 1883)

Warren Johnson filed patent number 281,884 for the first electric thermostat on July 24th, 1883.

***n.* Gaspar Banfalvi**

i. Negative Feedback and Homeostasis

"In negative feedback regulation the organism has set points to which different parameters (temperature, volume, pressure, etc.) have to be adapted to maintain the normal state and stability of the body. The momentary value refers to the values at the time the parameters

have been measured. When a parameter changes it has to be turned back to its set point. Oscillations are characteristic to negative feedback regulation…" (Banfalvi, 2014).

o. Meinhardt (1995)

i. Positive Feedback

"An essential element of dynamics systems is a positive feedback that self-enhances the initial deviation from the mean. The avalanche is proverbial. Cities grow since they attract more people, and in the universe, a local accumulation of dust may attract more dust, eventually leading to the birth of a star. Earlier or later, self-enhancing processes evoke an antagonistic reaction. A collapsing stock market stimulates the purchase of shares at a low price, thereby stabilizing the market. The increasing noise, dirt, crime and traffic jams may discourage people from moving into a big city" (Meinhardt, 1995).

A-11. Heterostasis

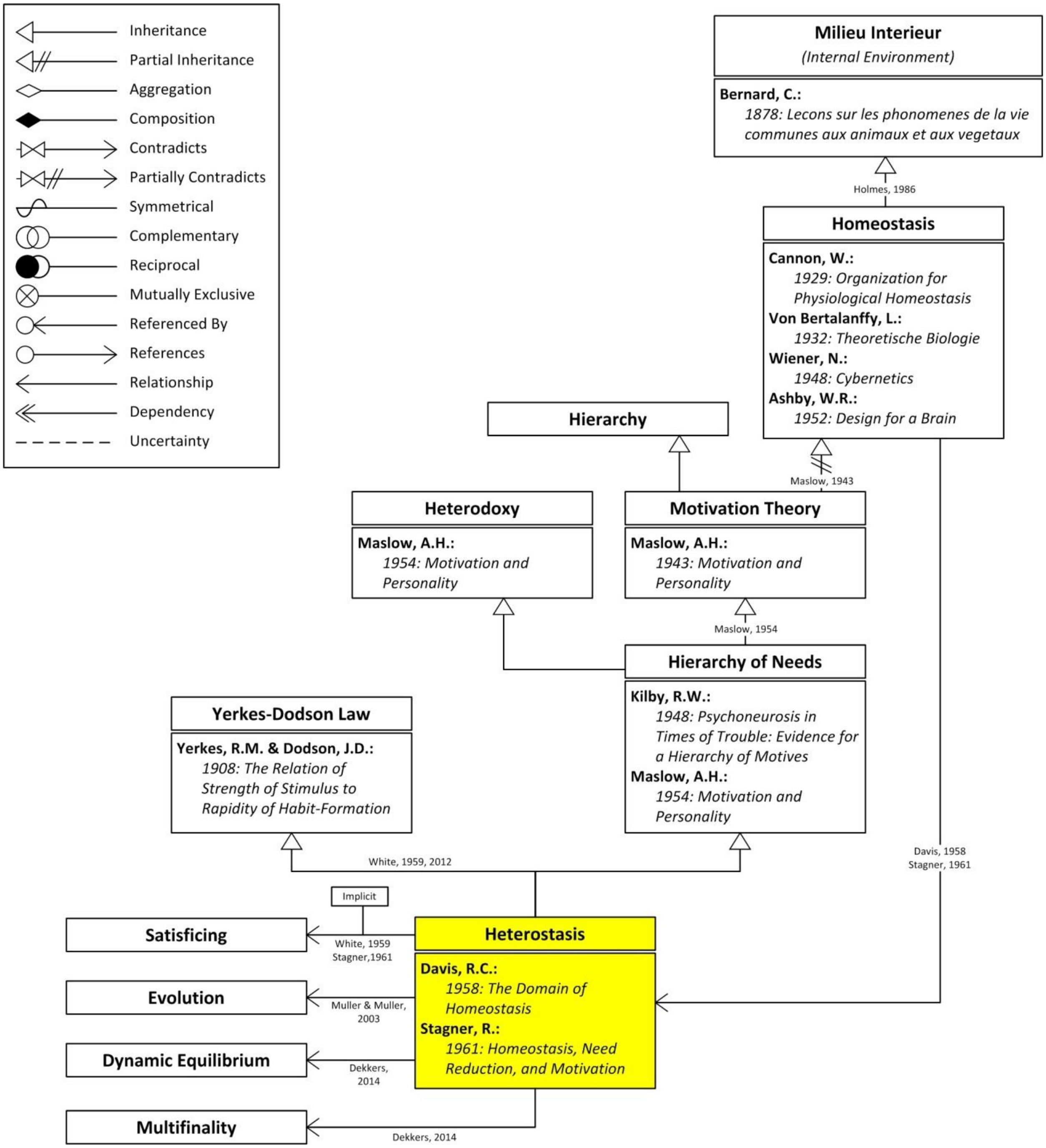

Figure A-14: Concept Model of Heterostasis

■ Definition

Heterostasis: The process by which a system maintains the steady-state of a homeostatic variable by altering or adjusting another, heterostatic variable (Davis R. , 1958)

■ Commentary

The principle of heterostasis emerged during an examination of homeostasis. While it was not included in the Adams/Keating, Clemson, Skyttner, or Leonard catalogs, it is still a meaningful principle and worthy of exploration.

■ Contributing Scholars

a. Abraham Maslow

i. Hierarchy of Prepotency (Motivation Theory)

"At once other (and 'higher') needs emerge and these, rather than physiological hungers, dominate the organism. And when these in turn are satisfied, again new (and still 'higher') needs emerge and so on. This is what we mean by saying that the basic human needs are organized into a hierarchy of relative prepotency" (Maslow, 1943).

ii. Motivation Theory Related to Homeostasis

"Homeostasis refers to the body's automatic efforts to maintain a constant, normal state of the blood stream. Cannon (2) has described this process for (i) the water content of the blood, (2) salt content, (3) sugar content, (4) protein content, (5) fat content, (6) calcium content, (7) oxygen content, (8) constant hydrogen-ion level (acid-base balance) and (9) constant temperature of the blood. Obviously this list can be extended to include other minerals, the hormones, vitamins, etc." (Maslow, 1943).

References:

(1) Cannon, W. B. (1932), Wisdom of the body. New York: Norton

(2) Maslow, A.H., *(*1943*)*, A preface to motivation theory. Psychosomatic Med., 1943, 5, 85-92.

iii. On Heterodoxy

(1) *"Means centering tends inevitably lo bring into being a scientific orthodoxy, which in turn creates a heterodoxy. Questions and problems in science can rarely be formulated, classified, or put into a filing system. The questions of the past are no longer questions, but answers. The questions of the future have not yet come into existence. But it is possible to formulate and classify the methods and techniques of the past. These then are termed the "laws of scientific method." Canonized, crusted about with tradition, loyalty, and history, they tend to become binding upon the present day (rather than merely suggestive or helpful). In the hands of the less creative, the timid, the*

conventional, these "laws" become virtually a demand that we solve our present problems only as our forefathers solved theirs" (Maslow, 1954).

(2) "Ordinarily, the advance of science is a collaborative product. How else could limited individuals make important, even great, discoveries? When there is no collaboration, the advance is apt to stop dead until there shows up some giant who needs no help. Orthodoxy means the denial of help to the heterodox. Since few (of the heterodox, as well as of the orthodox) are geniuses, this implies continuous, smooth advance only for orthodox science. We may expect heterodox ideas to be held tip for long periods of weary neglect or opposition, to break through rather suddenly (if they are correct), and then to become in turn orthodox" (Maslow, 1954).

iv. Hierarchy of Needs

"The hierarchy of needs and metaneeds has been helpful to me in another way. I find that it serves as a kind of smorgasbord table from which people can choose in accordance with their own tastes and appetites. That is to say, that in any judging of the motivations for a person's behavior, the character of the judge also has to be taken into account. He chooses the motivations to which he will attribute the behavior, for instance, in accord with his generalized optimism or pessimism. I find the latter choice to be made far more frequently today, so frequently that I find it useful to name the phenomenon 'downlevelling of the motivations'" (Maslow, 1954).

b. Richard W. Kilby

i. On Hierarchy of Motives

"Briefly stated (and oversimplified) Maslow postulates that most human needs or motives can be arranged in the following five groups: (1) physiological needs, (2) safety needs, (3) love needs, (4) esteem needs, and (5) need for self-actualization. These needs form a hierarchy with the physiological needs being most basic, the others following in importance in the order listed, with the self-actualization need being least basic and least psychologically important. Maslow postulates that because of this hierarchial nature of motives the person who is in physical want—of food when starving, of water, of warmth when cold, etc.—will have his behavior dominated by these physiological needs, and as long as the physiological needs are dominant the other less basic needs (safety, love, esteem, self-actualization) will be nonexistent or, more correctly stated, latent" (Kilby, 1948).

c. R.C. Davis

i. Heterostasis

"In general, the organism, let us say, is acted upon by a force of a certain energy. The displacement produced by that force cannot be neutralized without the use of further force, inasmuch as the energy of the new state cannot be made to vanish. In the case of homeostasis, it is the organism itself which provides the restoring energy, by increased sweating or shivering, by changes in circulation, changes in digestion, and ultimately changes in fuel consumption. In cases of changed energy relations between the organism and environment, then, homeostasis can be maintained for one variable only at the expense of heterostasis in at least one other" (Davis, 1958).

d. Ross Stagner

i. Origin of Term Heterostasis

"Davis (12) has coined the term heterostasis to refer to the fact that any homeostatic action may disrupt some other stable function. Consider the temperature problem; perspiring may disrupt the water balance or the salt balance. Homeostatic action to keep body temperature down sets off a thirst drive" (Stagner, 1961).

References Davis, R. C. The domain of homeostasis. Psychol. Rev., 1958, 65, 8-13.

ii. Heterostasis, Hierarchy and Satisficing

"Heterostasis implies that the body has a hierarchy of steady states, and that those in the upper ranges are preserved even at the cost of disruption of one or more in the lower levels. Such a concept is of course essential to any theory of motivation, holistic or molecular. Maslow (23) has pro pounded the notion of a hierarchy of needs, one of which dominates behavior until it is satisfied, after which the one next in the hierarchy takes over" (Stagner, 1961).

Note: By implication, this behavior is <u>Satisficing.</u>

e. Hans Selye

i. Heterostasis versus Homeostasis

"When such an abnormal equilibrium must be established to protect against potential pathogens, I propose to speak of heterostasis (heteros = other; stasis = fixity) as the establishment of a new steady state by exogenous (pharmacologic) stimulation of adaptive mechanisms through the development and maintenance of dormant defensive tissue

reactions. In a sense this would be the counterpart of homeostasis (homoios = like) which has been defined as the maintenance of a normal steady state by means of endogenous (physiologic) responses. In heterostasis, as in homeostasis, the fixity of the "milieu intérieur" is not absolute. Both Bernard [1] and Cannon [2] have clearly realized that in order to maintain a state of relative stability the body cannot remain completely inert but must answer each stimulus with an appropriate counter stimulus to maintain equilibrium. However, in homeostasis, this equilibrium is maintained with small fluctuations near the physiologic level, whereas in heterostasis unusual defense reactions are mobilized to permit resistance to unusual aggression. Furthermore, in general, homeostasis, unlike heterostasis, depends upon rapidly developing and vanishing readjustments, although— as in all biologic classifications—transitional types are common" (Selye, 1973).

f. Tibor Muller and Harmond Muller

i. Description of Heterostatic Effect as Related to Evolution

"Obviously homeostasis stops any kind of progress as it is directed towards the preservation of the state of a system. Consequently, there must be completely different processes forcing the evolution of systems. The term heterostasis (Greek heteros and stasis: 'other' and 'states') is used to characterize these agents. According to Cannon (e.g. Cannon 1932) heterostasis leads to the transition from one homeostatic equilibrium to another one under the influence of a stress imposed on the system (Cannon reflex). Other authors (e.g. Antonovsky 1987) regard heterostasis as the basic principle underlying the development of an organism under the influence of the stress imposed upon it by its environment and determining its life from birth to death" (Muller & Muller, 2003).

g. Rob Dekkers

i. Heterostasis and Multiple Points of Equilibrium (Dynamic Equilibrium)

"Another overlooked phenomenon, called heterostasis, makes it possible that systems operate at multiple points of equilibrium, even though a limited number exist in practice (Selye, 1973)" (Dekkers, 2014, p. 53).

ii. Multifinality and Heterostasis

"The principles of equifinality, multifinality, homeostasis and heterostasis have far-stretching implications for the application of deductive reasoning The paradox of equifinality and multifinality means that when observing the behaviour of a system, it might

be moving towards a final state irrespective of the initial state or moving away from an initial state without being able to predict the final outcome” (Dekkers, 2014, p. 54).

h. Robert K. White

i. Yerkes-Dodson Law

“This point was demonstrated half a century ago in some experiments by Yerkes and Dodson (1908). They showed that maximum motivation did not lead to the most rapid solving of problems, especially if the problems were complex. For each problem there was an optimum level of motivation, neither the highest nor the lowest, and the optimum was lower for more complex tasks” (White, 1959).

References:

(1) Yerkes, R. M. and Dodson, J.D. (1908). "The relation of strength of stimulus to rapidity of habit-formation". Journal of Comparative Neurology and Psychology 18: 459–482.

ii. Linkage to Heterostasis, Hierarchy and Satisficing

“Maslow (1954, 1955), too, belongs with the heterodox. He insists that we should take account of growth motivation as well as the deficiency motivation implied in the visceral drives, and he offers the valuable idea of a hierarchy of motives, according to which the satisfaction of "lower" needs makes it possible for "higher" needs to emerge and become regnant in behavior” (White, 1959).

References:

(1) MASLOW, A. H. (1954), Motivation and personality. New York: Harper.

(2) MASLOW, A. H. (1955), Deficiency motivation and growth motivation. In M. R. Jones (Ed.), Nebraska symposium on motivation 1955. Lincoln, Neb.: Univer. Nebraska Press, 1955. Pp. 1-30.

iii. Yerkes-Dodson Law and Heterostasis

“The speed limits at which the nonverbal mind operates can vary depending on the task or situation. Heterostasis is very different from Homeostasis. In homeostasis, there are many regulators all doing one job each, for example regulating the body temperature, the body water, etc. Each regulator operates independently of the other and consciousness is not needed; it is an automated process. It is like a batch-processing machine where the regulators simultaneously each do their own things to maintain some optimal set point for each of the Essential Variables.

In direct contrast, Heterostasis is like a timeshare. There is one regulator working for all the variables so that regulator must be shared. In the case of heterostasis, consciousness is necessary and occurring whenever the organism is awake. Depending on where the organism is on the Y-D curve will determine the level of consciousness. Heterostasis is the wisdom of the mind and is programmed to keep the Essential Variable of the mind in region B of the arousal curve. This knowledge, which makes Heterostasis work normally, works automatically, and if nothing else we should all learn to keep our arousal or signal level at B" (White, 2012).

A-12. Hierarchy

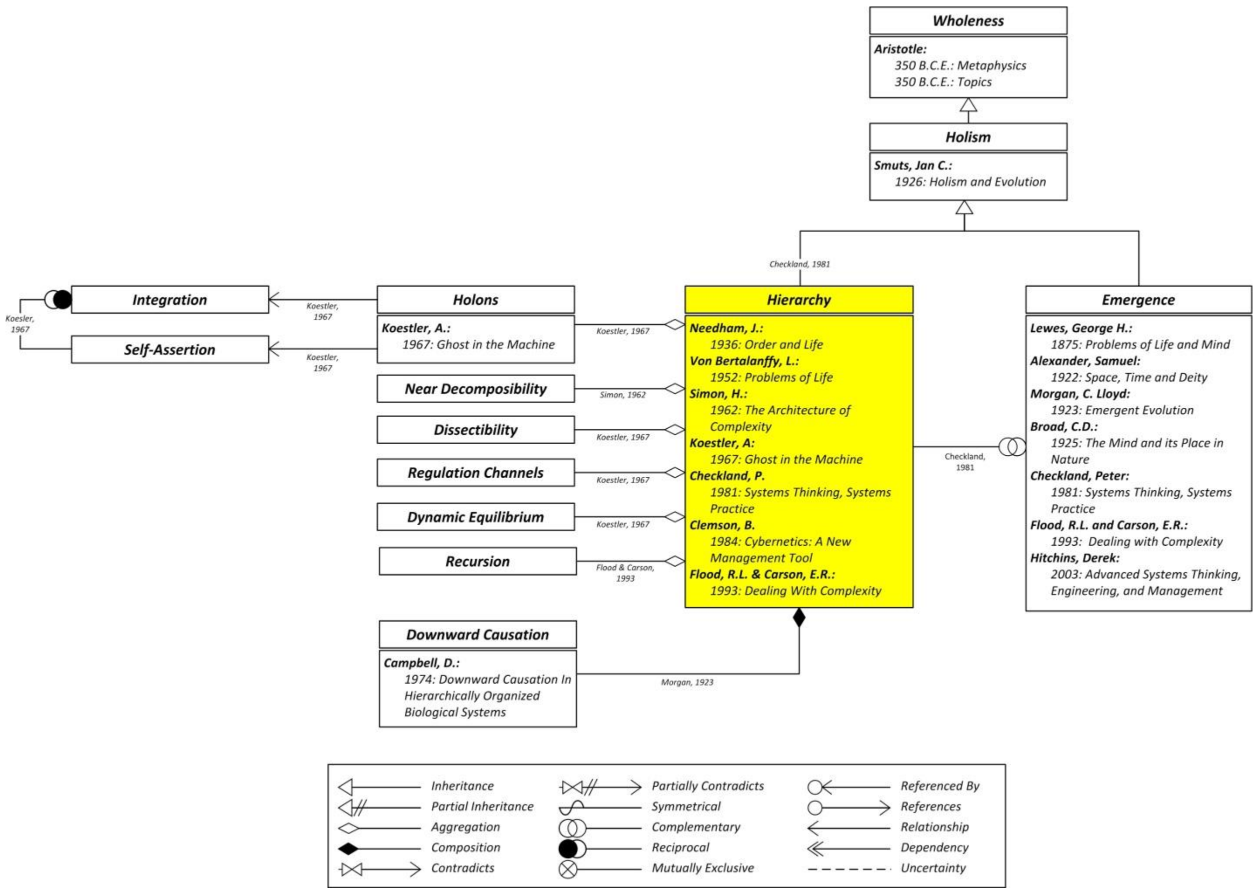

Figure A-15: Concept Model of Hierarchy

- **Definition**

Hierarchy: A system that is composed of interrelated subsystems which are, in turn, hierarchic structures continuing downward until a lowest level of elementary subsystem is reached (Simon, 1962)

- **Commentary**

Hierarchy is related to emergence as a key element of the Centrality Axiom (Adams & Keating, 2012).

■ Contributing Scholars

a. Barry Clemson

i. Structure of Hierarchy

"Hierarchy Principle: Complex natural phenomena are organized in hierarchies with each level made up of several integral systems" (Clemson, 1984).

b. Joseph Needham

i. On The Importance of Hierarchy

"Whatever the nature of organizing relations may be, they form the central problem of biology, and biology will be fruitful in the future only if this is recognized. The hierarchy of relations, from the molecular structure of carbon compounds to the equilibrium of species and ecological wholes, will perhaps be the leading idea of the future" (Needham, 1936).

c. Ludwig Von Bertalanffy

i. Hierarchy as a Fundamental

"Hierarchical organization on the one hand, and the characteristics of open systems on the other, are fundamental principles of living nature, and the advancement of theoretical biology will depend mainly on the development of a theory of these two fundamentals" (Von Bertalanffy, 1952).

d. Herbert Simon

i. Definition of Hierarchy

"By a hierarchic system, or hierarchy, I mean a system that is composed of interrelated subsystems, each of the latter being, in turn, hierarchic in structure until we reach some lowest level of elementary subsystem" (Simon, 1962).

ii. Complexity and Hierarchy

"Thus, the central theme that runs through my remarks is that complexity frequently takes the form of hierarchy, and that hierarchic systems have some common properties that are independent of their specific content. Hierarchy, I shall argue, is one of the central structural schemes that the architect of complexity uses" (Simon, 1962).

iii. Hierarchies Have Time to Evolve

"Complex systems will evolve from simple systems much more rapidly if there are stable intermediate forms than if there are not. The resulting complex forms in the former case will be hierarchic. We have only to turn the argument around to explain the observed predominance of hierarchies among the complex systems Nature presents to us. Among possible complex forms, hierarchies are the ones that have the time to evolve" (Simon, 1962).

iv. Near Decomposability

"We have seen that hierarchies have the property of near-decomposability. Intra-component linkages are generally stronger than intercomponent linkages. This fact has the effect of separating the high-frequency dynamics of a hierarchy-involving the internal structure of the components from the low frequency dynamics-involving interaction among components" (Simon, 1962).

v. Hierarchy and Redundancy

"If a complex structure is completely unredundant- if no aspect of its structure can be inferred from any other-then it is its own simplest description. We can exhibit it, but we cannot describe it by a simpler structure. The hierarchic structures we have been discussing have a high degree of redundancy, hence can often be described in economical terms" (Simon H. A., 1962).

e. Arthur Koestler (Open Hierarchic System)

i. Description of Hierarchical Representation and Origin

"We find such tree diagrams of hierarchic organization applied to the most varied fields: genealogical tables; the classification of animals and plants; the evolutionist's 'tree of life'; charts indicating the branching structures of government departments or industrial enterprises; physiological charts of the nervous system, and of the circulation of the blood. The word 'hierarchy' is of ecclesiastical origin and is often wrongly used to refer merely to order of rank — the rungs on a ladder, so to speak. I shall use it to refer not to a ladder but to the tree-like structure of a system, branching into subsystems, and so on…" (Koestler, 1967).

ii. Semi-Autonomous Holons

"The organism is to be regarded as a multi-levelled hierarchy of semi-autonomous sub-wholes, branching into sub-wholes of a lower order, and so on. Sub-wholes on any level of the hierarchy are referred to as holons" (Koestler, 1967).

iii. The Janus Effect

"Biological holons are self-regulating open systems which display both the autonomous properties of wholes and the dependent properties of parts. This dichotomy is present on every level of every type of hierarchic organization, and is referred to as the Janus Effect or Janus principle" (Koestler, 1967).

iv. Dissectibility

"Hierarchies are 'dissectible' into their constituent branches, on which the holons form the nodes; the branching lines represent the channels of communication and control" (Koestler, 1967).

v. Integration and Self-Assertion

"Every holon has the dual tendency to preserve and assert its individuality as a quasi-autonomous whole; and to function as an integrated part of an (existing or evolving) larger whole." (Koestler, 1967).

vi. Regulation Channels

"The higher echelons in a hierarchy are not normally in direct communication with lowly ones, and vice versa; signals are transmitted through 'regulation channels', one step at a time, up or down" (Koestler, 1967).

vii. Mechanization and Freedom

"Holons on successively higher levels of the hierarchy show increasingly complex, more flexible and less predictable patterns of activity, while on successive lower levels we find increasingly mechanized, stereotyped and predictable patterns" (Koestler, 1967).

viii. Dynamic Equilibrium

"An organism or society is said to be in dynamic equilibrium if the [self-assertive] and [integrative] tendencies of its holons counterbalance each other" (Koestler, 1967).

f. Robert Flood and Ewart Carson

i. Hierarchy, Emergence and Complexity

"Hierarchy and emergence contribute to complexity because new and interesting properties that cannot be found in the parts emerge and add a whole new dimension to understanding" (Flood & Carson, 1993).

ii. Hierarchy and Recursion

"The model is used to explain a systemic hierarchy called recursion. It stresses the need and caters for adaptation, evolution, and survival. It proffers a set of management functions that filter variety (reducing 'the volume' of complexity)" (Flood & Carson, 1993).

g. Peter Checkland

i. Hierarchy as Related to Holism

"The principle according to which entities meaningfully treated as wholes are built up of smaller entities which are themselves wholes … and so on. In a hierarchy, emergent properties denote the levels" (Checkland, 1981).

ii. Hierarchy and Emergence

"There exists a hierarchy of levels of organization, each more complex than the one below, a level being characterized by emergent properties which do not exist at the lower level. Indeed, more than the fact that they 'do not exist' at the lower level, emergent properties are meaningless in the language appropriate to the lower level" (Checkland, 1981).

A-13. Holism

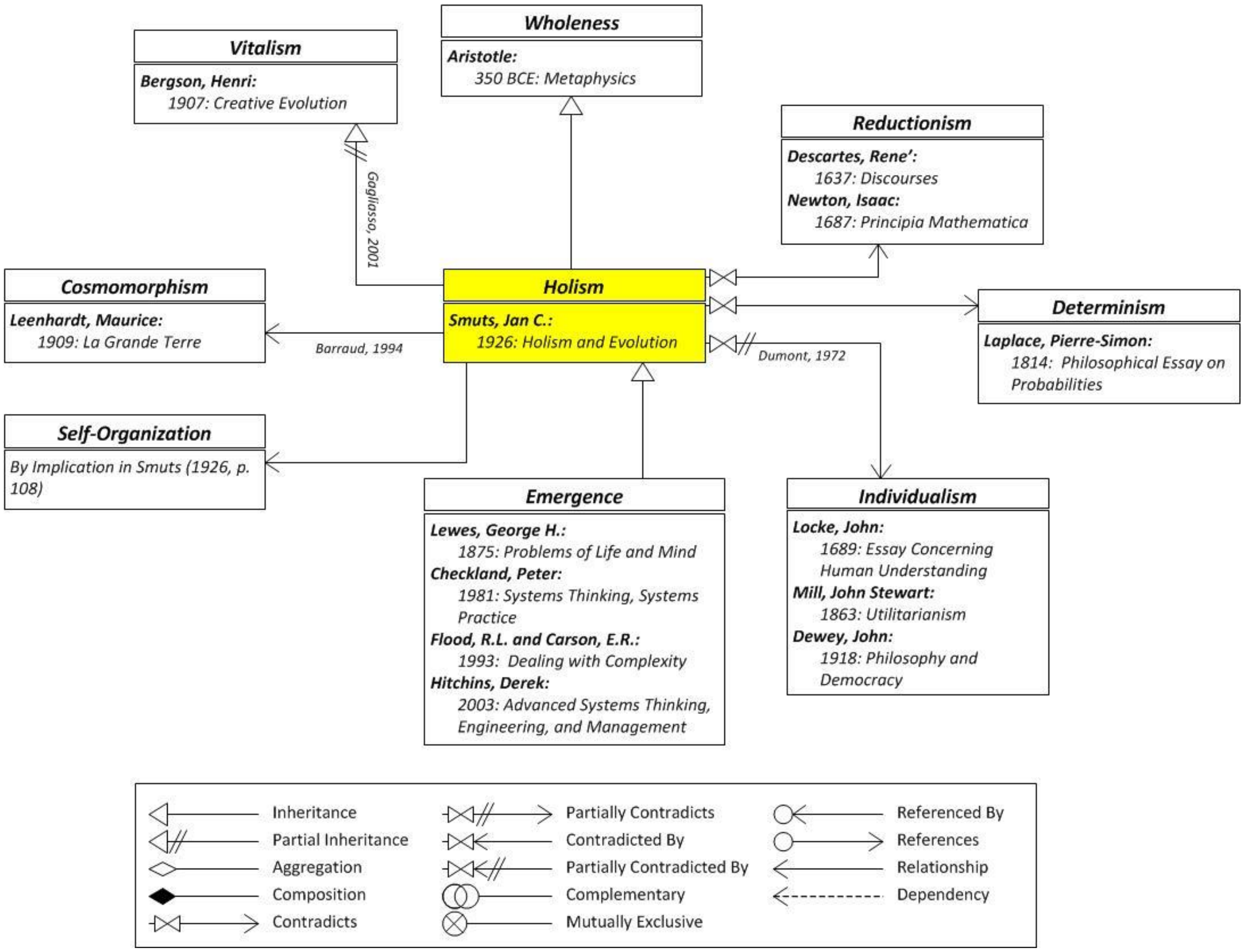

Figure A-16: Concept Model of Holism

- **Definition**

Holism: The principle that whole things differ from parts in that wholes are an arrangement of parts in a definite structural arrangement with mutual activities that constitute a whole (Smuts, 1926)

- **Commentary**

Holism appears to be so well-founded and long-lived that it is accepted as axiomatic with little or no discussion. In brief, it is a restatement of Aristotle's principle of wholeness, which asserts that the whole is greater than the sum of the parts. This characteristic of being "*greater than*" immediately feeds into the concept of emergence, where its manifestations are witnessed.

■ Contributing Scholars

a. Jan Smuts (1926)

i. Holism as a Vehicle for Self-Organization

"Holism in all its endless forms is the principle which works up the raw material or unorganised energy units of the world, utilises, assimilates and organises them, endows them with specific structure and character and individuality, and finally with personality, and creates beauty and truth and value from them" (Smuts, 1926).

ii. Holism and Wholeness

"Both matter and life consist of unit structures whose ordered grouping produces natural wholes which we call bodies or organisms. This character of wholeness meets us everywhere and points to something fundamental in the universe. Holism (from όλος = whole) is the term here coined for this fundamental factor operative towards the creation of wholes in the universe" (Smuts, 1926).

iii. Holism as a Union of Parts, Structure and Function

"It is very important to recognize that the whole is not something additional to the parts: it is the parts in a definite structural arrangement with mutual activities that constitute the whole. The structure and the activities differ in character according to the stage of development of the whole; but the whole is just this specific structure of parts with their appropriate activities and functions" (Smuts, 1926).

b. Aristotle

i. Wholeness

(1) "In the case of all things which have several parts and in which the totality is not, as it were, a mere heap, but the whole is something beside the parts, there is a cause" (Aristotle, 350 B.C.E).

(2) "That which is a whole and has a certain shape and form is one in a still higher degree; and especially if a thing is of this sort by nature, and not by force like the things which are unified by glue or nails or by being tied together, i.e. if it has in itself the cause of its continuity" (Aristotle, 350 B.C.E).

c. Henri Bergson

i. Vitalism

"But the position of vitalism is rendered very difficult by the fact that, in nature, there is neither purely internal finality nor absolutely distinct individuality. The organized elements composing the individual have themselves a certain individuality, and each will claim its vital principle if the individual pretends to have its own. But, on the other hand, the individual itself is not sufficiently independent, not sufficiently cut off from other things, for us to allow it a 'vital principle' of its own" (Bergson, 1907).

d. Elena Gagliasso

i. Holism as Partially Inheriting from Vitalism

"Holism and organicism have often been considered by radical reductionism as nothing but a transformation of vitalism deprived of its transcendent elements" (Gagliasso, 2001).

e. Rene Descartes

i. Reductionism *(Contradicted by Holism)*

"You won't find that at all strange if you know how many kinds of automata or moving machines the skill of man can construct with the use of very few parts, in comparison with the great multitude of bones, muscles, nerves, arteries, veins and all the other parts that are in the body of any animal, and if this knowledge leads you to regard an animal body as a machine.

Having been made by the hands of God, it is incomparably better organised—and capable of movements that are much more wonderful—than any that can be devised by man, but still it is just a machine" (Descartes, 1637).

f. Isaac Newton (1687)

i. Reductionism *(Contradicted by Holism)*

"Following the publication of Isaac Newton's 'Principia Mathematica' in 1687, reductionism and mathematical modeling became the most powerful tools of modern science. The dream that we could know and master the entire physical world through the extension and refinement of mathematical theory became the central feature and principles of scientific knowledge" (Kosciejew, 2014).

g. Pierre-Simon Laplace

i. Determinism *(Contradicted by Holism)*

"All events, even those which on account of their insignificance do not seem to follow the great laws of nature, are a result of it just as necessarily as the revolutions of the sun. In ignorance of the ties which unite such events to the entire system of the universe, they have been made to depend upon final causes or upon hazard, according as they occur and are repeated with regularity, or appear without regard to order; but these imaginary causes have gradually receded with the widening bounds of knowledge and disappear entirely before sound philosophy, which sees in them only the expression of our ignorance of the true causes" (Laplace, 1814).

h. Joseph Agassi

i. Individualism versus Holism

"When the individualist contends that only individuals are responsible actors on the social and historical stage, the holist retorts that society is more than merely a collection of individuals. To this retort the individualist answers that there is no mysterious additional entity which turns a collection of individuals into a society; a collection of individuals is a society if there is strong interaction between them; this interaction is due to the fact that when any one individual acts (rationally) on the basis of his own aims and interests, he takes into account the existence of other individuals with aims and interests. To this the holist retorts that the individualist misses the point; that people's aims do not constitute a society but rather depend on society; so that members of different societies have different aims and interests" (Agassi, 1975).

Note: Individualism is advanced by the following scholars:

(1) John Locke, Essay Concerning Human Understanding (1689)
(2) John Stuart Mill, Utilitarianism (1863)
(3) John Dewey, Philosophy and Democracy (1918)

i. James Clifford (regarding Maurice Leenhardt)

i. Cosmomorphism

"In a cosmomorphic world the human body is not clearly differentiated. A cadaver is part of the earth; the dead are nameless presences indistinct from other natural presences. There are no individualized ancestors, and thus there is no real ancestor worship. The landscape

itself. its mountains, its plant and animal life, is experienced as living, as vivant. The basic rule of cosmomorphic perception is vivant=vivant. The living being enters into relations of identification with other living beings. This participatory mode of life is not haphazard. The 'personage' (Leenhardt reserves the term 'person' for another stage of development) does not spill out chaotically into identification with all life" (Clifford, 1982).

Relates to Maurice Leenhardt, La Grande Terre (1909)

j. Peter Checkland

i. On Emergence and Holism

"The principle that whole entities exhibit properties which are meaningful only when attributed to the whole, not to its parts – e.g. the smell of ammonia. Every model of human activity system exhibits properties as a whole entity which derive from it component activities and their structure, but cannot be reduced to them." (Checkland, 1981)

Note: Emergence is discussed further by:

(1) George H. Lewes, Problems of Life and Mind (1875)

(2) Flood & Carson, Dealing with Complexity (1993)

(3) Derek Hitchins, Advanced Systems Thinking, Engineering, and Management (2003)

A-14. Homeorhesis

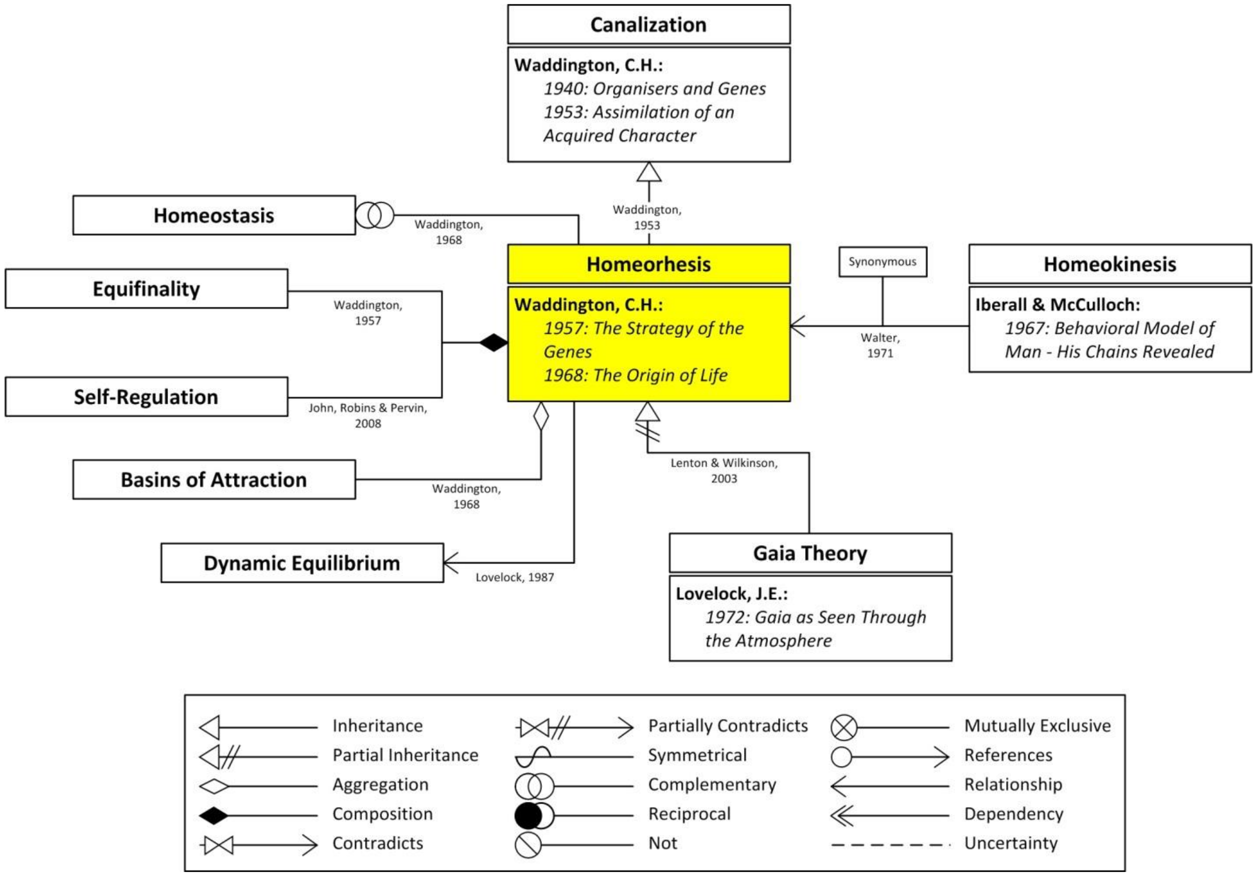

Figure A-17: Concept Model of Homeorhesis

■ Definition

Homeorhesis: A system behavior where the system is not drawn to a point of stability, but rather it tends to return to an invariant trajectory or ensemble of trajectories (Waddington, 1968)

■ Commentary

This principle is a departure from the catalog of Adams and Keating and was suggested by the ongoing research of Polinho Katina into systems pathologies. Because the concept of homeorhesis departs significantly from homeostasis, it seemed a meaningful principle to examine.

■ Contributing Scholars

a. Conrad Hal Waddington

i. Canalization as Synonymous with Homeorhesis

"Under the influence of natural selection, development tends to become canalised so that more or less normal organs and tissues are produced even in the face of slight abnormalities of the genotype or of the external environment (Waddington, 1940)" (Waddington C. , 1953).

References Waddington, C. H. (1940), Organisers and genes, Cambridge Univ. Press.

ii. Homeorhesis and Basins of Attraction

"Homeostasis and homeorhesis. The distinction between homeostasis and homeorhesis is familiar to the technician of differential equations: homeostasis signifies that the point representing the state of the system rests in the neighbourhood of a position of stable equilibrium in the phase space; homeorhesis signifies that the representative point finds itself in the neighbourhood of an invariant ensemble of trajectories K, which is an attractor (or at least a 'centre') for the trajectories of a neighbourhood" (Waddington, 1968).

iii. Homeorhesis and Equifinality

"Another idea about the organization of a creode which has come from breeding experiments is Lerner's recent suggestion that homeorhesis, i.e. the attainment of a relatively invariant end state, is dependent of the level of heterozygosis in the individual, animals with a large number of homozygous factors always being in some way abnormal" (Waddington, 1957).

b. A. Iberall and W.S. McCulloch

i. Origin of Homeokinesis

"The collection of all of these chains forms an extensive system of such non-linear oscillators whose action is controlled mainly by inhibition. It is this collection of oscillators (of active linearly unstable, but non-linearly stable, ever beating networks) that represents life itself.

The scheme of regulation and control which these oscillator systems are modulated through their non-linear stable operating range is best described by the term 'homeokinesis.' This is proposed as a modification of Cannon's concept of homeostasis, to connote that it is the manipulation of kinetic variables of space and time (such as a changing concentration in a *local tissue), by which the processes, predominantly regulatory, take place"* (Iberall & McCulloch, 1968).

c. Donald O. Walter

i. Homeokinesis and Homeorhesis

"This general idea, called homeokinesis by Iberall and McCulloch, or homeorhesis by Waddington [15, page 179], can be well represented by weakly linked systems of differential equations, of the types used by Goodwin or by Dewan" (Walter, 1971).

References

(1) Iberall, A. and McCulloch, W. (1968), Behavioral Model of Man - His Chains Revealed, NASA Contract Rept. NASA CR-858, July, 1967.

(2) Waddington, C. H. ed., (1968), Toward a theoretical biology. Edinburgh Univ. Press, Edinburgh.

d. James Lovelock

i. Homeorhesis and Evolution through Dynamic Equilibrium

"Physical and chemical variables, such as temperature or oxygen concentration, are summed and compared with the operating point of the system. If there is a difference the biota responds by active feedback to oppose it and so keep the system in homeostasis. The system also has the capacity to evolve by moving the operating point to a new steady state value. This form of system evolution is called homeorhesis" (Lovelock, 1987).

e. Timothy Lenton and David Wilkinson

i. Linking Homeorhesis to Gaia Theory

"Kirchner suggests that some Gaia theorists are still arguing for universal or overwhelming negative feedback as a feature of the Gaia system, as if this were a prerequisite for regulation. Confusingly, he labelled this the 'Homeostatic Gaia' hypothesis (Kirchner, 1989). Yet homeostasis often involves a combination of positive and negative feedback. A good example is the Daisyworld model, where the growth of the daisies is intrinsically a positive feedback process (the more daisies there are, the more daisies they can beget) and when the system is establishing, recovering from large perturbations or collapsing, the sign of feedback on temperature is often positive. We do not support a hypothesis of overwhelming negative feedback. Lovelock also has drawn attention to the positive feedback during the recent glacial-interglacial transitions and the dangers of positive feedback on human-

induced global change (Lovelock, 1991; Lovelock and Kump, 1994). Kirchner uses similar evidence to conclude that 'Homeostatic Gaia' is incorrect. Yet many complex systems undergo transitions between states in which positive feedback predominates. 'Homeorhesis' and 'punctuated equilibria' have both been applied to Gaia in an attempt to describe the notion of long intervals of relative stability (predominance of negative feedback) interspersed by shorter transitions (predominance of positive feedback)" (Lenton & Wilkiinson, 2003).

References: Lovelock, J. E. (*1972*)*, 'Gaia as Seen through the Atmosphere', Atmos. Environ. 6, 579–580.*

f. Oliver P. John, Richard W. Robins, and Lawrence A. Pervin

i. Homeorhesis as Self-Regulation

"Waddington considered the tendency for the marble to maintain its initial course in the face of external pressures to be an analogue to a fundamental self-regulatory process in cell development, 'homeorhesis'" (John, Robins, & Pervin, 2008).

g. Robert G. B. Reid

i. Homeorhesis, Heterorhesis, and More

"Aristotle's aphorism that nature is true to type is so consistent that it presents evolutionists with the perennial dilemma of understanding how it works, and how it might be overridden. Although he knew of the existence of abnormalities in human development that survived to maturity, he argued that the soul had a quality called "entelechy" that ensured that cats begat cats. The dilemma was emphasized for materialist Ivan Schmalhausen, because he could see that developmental stabilization became more rigid with the passage of time, as external environmental triggers became internalized in the organism. But he had a good general idea of how to resolve the problem. Entelechy was then re-invented by Waddington (1957) as "homeorhesis," which signifies the stabilized flow of epigenesis. "The thing that is being held constant is not a single parameter but is a time-extended course of change, that is to say, a trajectory," Thus, the organism's development is kept on track by compensations for minor misguiding influences. Waddington distinguished the processes of homeorhesis and physiological homeostasis. He did not, however, completely round the circle by comparing their evolutionary roles. Homeostasis allows the mature organism to persist in its being while exploring new environments, and acquiring habits that might otherwise tend to disequilibrate its internal milieu. It places no obstacle in the way of functional anatomical

change that would complement new behaviors in new environments, quite the opposite. Homeorhesis does, however, obstruct anatomical change 'by conserving the integrity of the original form. Therefore homeorhesis cannot be equated with evolutionary adaptability in the same way as physiological homeostasis. Nevertheless, anatomical changes have occurred, and, as Peter Saunders points out, 'Homeorhesis is a necessary property of an epigenetic system. But a system which possesses this property will also have the capacity for heterorhesis, i.e., for large, organized change'" (Reid, 2007).

h. Tariq Enver, Martin Pera, Carsten Peterson, and Peter W. Andrews

i. Directly Equating Canalization with Basins of Attraction

Note: Because the development of the connection is drawn out, only the pertinent parts of the adjoining paragraphs are provided.

(1) "From a metaphorical perspective, it is intuitive to think of cell states and state-transitions in the context of landscape models. Indeed, Waddington, in his "canalization of development," did precisely that, depicting cells as rolling down different bifurcating channels on a hillside, thereby acquiring divergent and irreversible cell fates (Waddington, 1957)" (Enver, Pera, Peterson, & Andrews, 2009).

(2) "An attractor is a stable solution to the set of mathematical equations that describe a dynamical system: that is, it represents the state of equilibrium to which a dynamical system will tend to move. Dynamical systems often have more than one solution, or attractor. The imagery of a landscape is often used to illustrate the concepts of an attractor, which is envisaged as a depression (bowls or valleys) in the landscape so that, for example, a ball (representing the "system") which is rolling around in the landscape will eventually enter into the depression" (Enver, Pera, Peterson, & Andrews, 2009).

A-15. Homeostasis

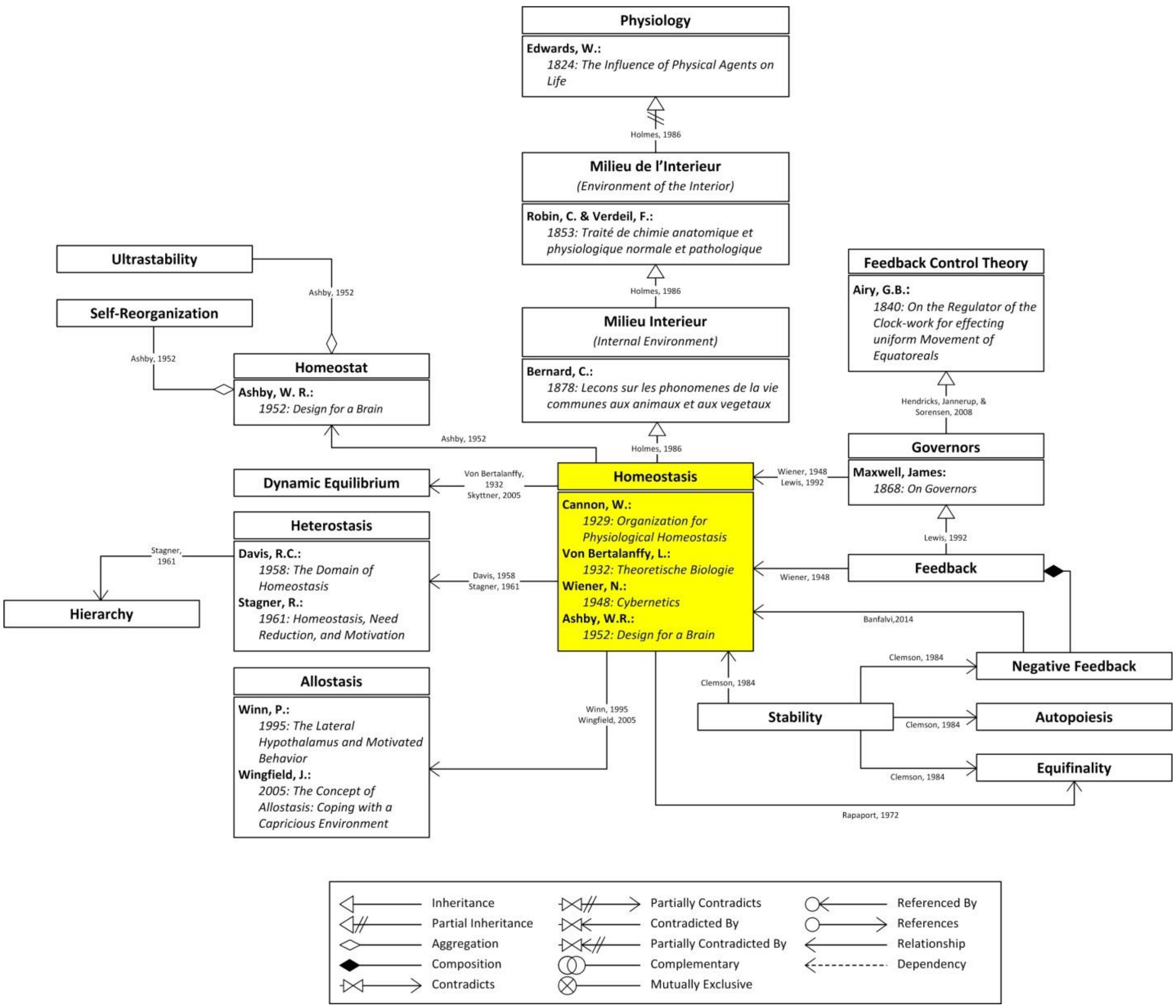

Figure A-18: Concept Model of Homeostasis

■ Definition

Homeostasis: A coordinated system of physiological reactions that maintain the steady-state of key variables within the system (Cannon, 1929).

■ Commentary

There is some commentary relating to homeostasis that discusses its specific relationship to dynamic equilibrium. Specifically, it notes that when the *set-point* of homeostasis is reset or changed to a new equilibrium, the terms *heterostasis* or *allostasis* are employed.

Contributing Scholars

a. Frederic Holmes

i. On the Predecessors to Milieu Interieur

"In a pioneering experimental study of 'the influence of physical agents on life', William Edwards showed in 1824 that changes in temperature, air pressure, humidity, and other factors do effect the physiological functions of young mammals" (Holmes, 1986).

b. Charles Robin

i. Milieu de l'interieur[7]

"It is impossible to conceive of a living organism without an environment from which it draws and into which it discharges; one is the agent, the other furnishes the conditions of activity. The agent is in turn sub-divided into several orders of parts which are also indispensable to each other; on the one hand are the solids, which act; and on the other the fluids which maintain them in a state to act; these fluids comprise the conditions of action, playing with respect to the solids the role which the external environment plays with respect to the entire organism. Finally, they establish the liaison between the interior and the exterior, between the general environment and the organized being. If the general environment disappears or is altered, the agent ceases to act; if the humours (this 'milieu' de l'intérieur) are altered, then all activity ceases in the solids, just as if they had... been destroyed" (Robin & Verdeil, 1853).

c. Claude Bernard

i. Milieu Interieur (Internal Environment)[8]

"The fixity of the internal environment is the condition of free, independent life" (Bernard, 1878).

[7] Relationship established in "The Milieu Interieur" (Holmes, 1986)

[8] Relationship established in A Paper on Changes in the Character of Diseases (Rolleston, 1933)

d. Maxwell, James Clerk[9] [10]

i. Governors as Mechanism for Homeostasis

"A GOVERNOR is a part of a machine by means of which the velocity of the machine is kept nearly uniform, notwithstanding variations in the driving-power or the resistance" (Maxwell, 1868).

e. Walter Cannon

i. Origination of the Term Homeostasis

"The highly developed living being is an open system having many relations to its surroundings. . . changes in the surroundings excite reactions in this system, or affect it directly, so that internal disturbances are produced. . . the coordinated physiological reactions which maintain most of the steady states in the body are so complex, and so peculiar to the living organism, that it is suggested that a specific designation for these states be employed --- homeostasis" (Cannon, 1929).

f. Norbert Wiener

i. Feedback and Homeostasis

"We must not forget another important physiological application of the principle of feed-back. A great group of cases in which some sort of feed-back is not only exemplified in physiological phenomena, but is absolutely essential for continuation of life, is found in what is known as homeostasis. [...] In short, our inner economy must contain an assembly of thermostats, automatic hydrogen-ion-concentration controls, governors, and the like, which would be adequate for a great chemical plant. These are what we know collectively as our homeostatic mechanism" (Wiener, 1948, p. 135).

g. W. Ross Ashby

i. The Homeostat

"It was given the name of ' Homeostat ' for convenience of reference, and the noun seems to be acceptable. The derivatives 'homeostatic' and ' homeostatically ', however, are unfortunate, for they suggest reference to the machine, whereas priority demands that they be used only as derivatives of Cannon's ' homeostasis '" (Ashby, 1952).

---

[9] Referenced from *A Brief History of Feedback Control* (Lewis, 1992)

[10] Referenced from Cybernetics (Weiner, 1948)

ii. The Homeostat and Ultrastability

In comparing an automatic pilot and the homeostat, *"So far they show no difference; but connect the ailerons in reverse and compare them. The automatic pilot would act, after a small disturbance, to increase the roll, and would persist in its wrong action to the very end. The homeostat, however, would persist in its wrong action only until the increasing deviation made the step-functions start changing. On the occurrence of the first suitable new value, the homeostat would act to stabilise instead of to overthrow; it would return the plane to the horizontal, and it would then be ordinarily self-correcting for disturbances. There is therefore some justification for the name 'ultrastable'; for if the main variables are assembled so as to make their field unstable, the ultrastable system will change this field till it is stable"* (Ashby, 1952, pp. 98-99).

iii. The Homeostat and Self-Reorganization

"The nervous system provides many illustrations of such a series of events: first the established reaction, then an alteration made in the environment by the experimenter, and finally a reorganisation within the nervous system, compensating for the experimental alteration. The homeostat can thus show, in elementary form, this power of self-reorganisation" (Ashby, 1952, p. 109).

h. Anatol Rapaport

i. Equifinality and Homeostasis

"Open systems, in contrast to closed systems, exhibit a principle of equifinality, that is, a tendency to achieve a final state independent of initial conditions. In other words, open systems tend to 'resist' perturbations that take them away from some steady state. They can exhibit homeostasis" (Rapaport, 1972).

i. Barry Clemson

i. Relationships Between Stability and Homeostasis

"Every system of whatever size must maintain its own structure and must deal with a dynamic environment, i.e., the system must strike a proper balance between stability and change. The cybernetic mechanisms for stability (i.e., homeostasis, negative feedback, autopoiesis, equifinality) and change (i.e., positive feedback, algedonodes, self-organization) are found in all viable systems" (Clemson, 1984).

j. Gaspar Banfalvi

i. Negative Feedback and Homeostasis

"In negative feedback regulation the organism has set points to which different parameters (temperature, volume, pressure, etc.) have to be adapted to maintain the normal state and stability of the body. The momentary value refers to the values at the time the parameters have been measured. When a parameter changes it has to be turned back to its set point. Oscillations are characteristic to negative feedback regulation…" (Banfalvi, 2014).

k. Ludwig Von Bertalanffy

i. Dynamic Equilibrium and the Steady State *(Homeostasis)*

"True equilibria can occur only in closed systems and that, in open systems, disequilibria called 'steady states', or 'flow equilibria' are the predominant and characteristic feature. According to the second law of thermodynamics a closed system must eventually attain a time-independent equilibrium state, with maximum entropy and minimum free energy. An open system may, under certain conditions, attain a time-independent state where the system remains constant as a whole and in its phases, though there is a continuous flow of component materials. This is called a steady state. Steady states are irreversible as a whole… A closed system in equilibrium does not need energy for its preservation, nor can energy be obtained from it. In order to perform work, a system must be in disequilibrium, tending toward equilibrium and maintaining a steady state, Therefore the character of an open system is the necessary condition for the continuous working capacity of the organism" (Von Bertalanffy, 1932).

ii. Homeostasis Defined

"We may define homeostasis as the field of organic regulations which act so as to maintain the steady state of the organism in outside changes and which are effectuated by regulating mechanisms in such a way that they do not occur necessarily in the same, and often in the opposite direction, to what a corresponding change would cause according to general physical principles" (Von Bertalanffy, 1951).

l. Lars Skyttner

i. Dynamic Equilibrium and Homeostasis

"When defining living systems, the term dynamic equilibrium is essential. It does not imply something which is steady or stable. On the contrary, it is a floating state characterized by

invisible movements and preparedness for change. To be in dynamic equilibrium is adapting adjustment to balance. Homeostasis stands for the sum of all control functions creating the state of dynamic equilibrium in a healthy organism. It is the ability of the body to maintain a narrow range of internal conditions in spite of environmental changes" (Skyttner, 2005)**.**

m. Derek Hitchins

i. Dynamic Equilibrium is Homeostasis related to Oscillation

In discussing the balance between fox and rabbit populations, "There is, then, no single solution to the question of population size; instead, there is an infinite set of solutions. This oscillating behavior is characteristics of much social, biological and physical behavior; such behavior might be viewed as a form of homeostasis, or dynamic equilibrium of, in this instance, the overall system of fox-rabbit interactions" (Hitchins, 2007).

n. Katz and Kahn

i. Homeostasis, Dynamic Equilibrium and Adaptation

Referenced from Skyttner (2005), who identifies one of their requirements of open systems as "Equilibrium and dynamic homeostasis including adaptation" (Katz & Kahn, 1966).

o. R.C. Davis

i. Heterostasis

"In general, the organism, let us say, is acted upon by a force of a certain energy. The displacement produced by that force cannot be neutralized without the use of further force, inasmuch as the energy of the new state cannot be made to vanish. In the case of homeostasis, it is the organism itself which provides the restoring energy, by increased sweating or shivering, by changes in circulation, changes in digestion, and ultimately changes in fuel consumption. In cases of changed energy relations between the organism and environment, then, homeostasis can be maintained for one variable only at the expense of heterostasis in at least one other" (Davis, 1958)*.*

p. Ross Stagner

i. Heterostasis, Homeostasis and Hierarchy

"Heterostasis implies that the body has a hierarchy of steady states, and that those in the upper ranges are preserved even at the cost of disruption of one or more in the lower levels. Such a concept is of course essential to any theory of motivation, holistic or molecular. Maslow (23) has pro pounded the notion of a hierarchy of needs, one of which dominates

behavior until it is satisfied, after which the one next in the hierarchy takes over" (Stagner, 1961).

q. Philip Winn

i. Homeostasis and Allostasis as Complementary

"There is another process, contrasted to homeostasis, called allostasis (meaning "stability through change"). Allostasis emphasizes anticipation, expectation, and the organism's readiness to adapt, physiologically and behaviorally, to changing circumstances. Homeostasis requires systems to have set points that define how much of any particular resource (glucose or water, for instance) there should be. Homeostatic systems are therefore rather rigid, and, although undeniably important, homeostatic processes on their own lack the ability to change dynamically. In contrast, allostasis is adaptive and gives greater weight to the role of learning in determining when and where eating and drinking happen" (Winn, 1995).

r. John Wingfield

i. Allostasis

(1) *"The concept of allostasis, maintaining stability through change, has been introduced as a fundamental process through which organisms actively adjust to both predictable and unpredictable events" (Wingfield, 2005)*.

(2) *"The concept of allostasis, stability through change (McEwen 2000; Schulkin 2003; Sterling and Eyer 1988), is a theoretical framework that can integrate the metabolic demands of normal life-history stages (predictable life cycle) and those caused by perturbations of the environment (unpredictable). Furthermore, allostasis allows for a continuum of responses that includes the ability to anticipate environmental change and assume a life-history stage before the environment changes, whereas classical homeostasis results in adjustments of morphology, physiology, and behavior after the environment has changed or as it changes (acclimation)"* (Wingfield, 2005).

***s.* Stafford Beer**

***i.* Viable Systems Model Homeostats**

"The model of any viable system, V.S.M., was devised from the beginning (the early 'fifties) in terms of sets of interlocking Ashbean homeostats. An industrial operation, for example,

would be depicted as homeostatically balanced with its own management on one side, and with its market on the other" (Beer, 1984).

t. Allenna Leonard

i. Viable Systems Model Homeostat

"Individuals, networks and organizations must maintain a balance between their activities in the present and those oriented toward the future. In knowledge-based fields, this balance is likely to be tilted more toward the future than it is with manufacturing organizations. A homeostat, such as the furnace thermostat, keeps a variable within acceptable limits. In the VSM, the function of the Three/Four homeostat is to maintain the right balance between present and future attention for each situation" (Leonard, 1999).

A-16. Information Channels

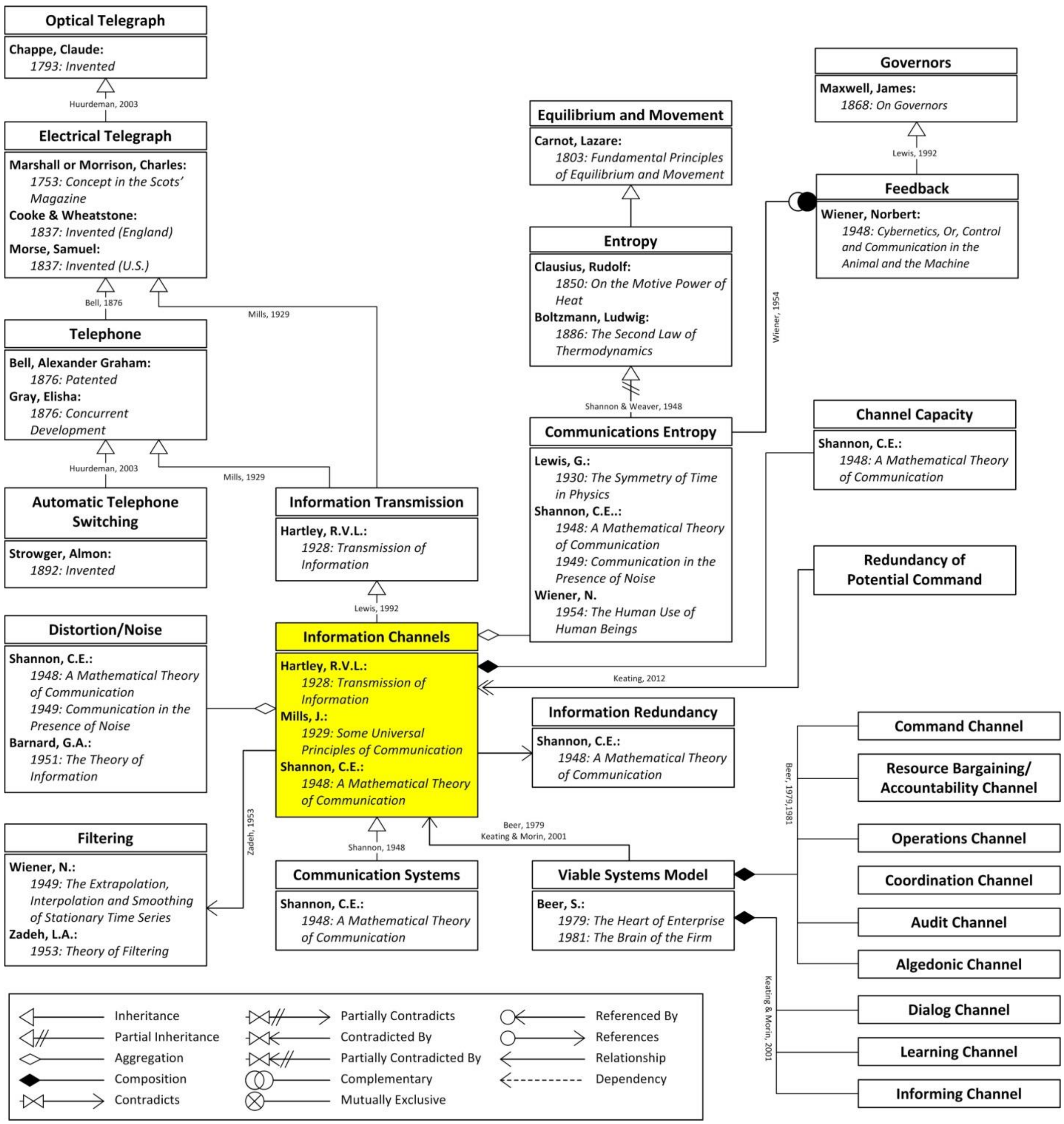

Figure A-19: Concept Model of Information Channels

■ Definition

The distinct communication path or medium through which information is transmitted from a source to a destination (Shannon, 1948)

■ Commentary

While Information Channels are indeed essential to communications within systems, based on this exploration, they may not warrant a place as a distinct and separate *principle*.

■ Contributing Scholars

a. Huurdeman, Anton A.

i. The Optical Telegraph

"The optical telegraph was the first functional telecommunications device to be used successfully until succeeded by a superior solution; the electrical telegraph. This it is that the creator of the optical telegraph, Claude Chappe, deserves to be called the 'father of telecommunications'" (Huurdeman, 2003, p. 17).

ii. Tachygraphe of Claude Chappe

"On August 23, 1793, the Convention Nationale declared the whole of France under a state of siege and decided on a military enlistment en masse. In this dramatic situation, quick dissemination of information and immediate reactions were essential. Fortunately for France, Abbe Claude Chappe (1763-1805) had just started experiments with what he called a tachygraphe (Latin for 'rapid writer')" (Huurdeman, 2003, p. 18).

iii. The Electrical Telegraph

(1) "The history of electrical telegraphy is generally considered to have begun on February 17, 1753, when a remarkable Ietter, signed by a certain C.M. (perhaps standing for Charles Marshall, Renfrew, Scotland; or perhaps for Charles Morrison), was published in the Scots' Magazine. Under the heading 'An Expeditious Method of Conveying Intelligence.' C.M, proposed briefly that 'a set of wires equal in number to the letters of the alphabet, be extended horizontally between two given places, parallel to one another and each of them an inch distant from the next to it.' The letter then explains in detail how the wires are to be connected to the conductor of an electrostatic machine when it is desired to signal a particular letter. On the receiving side, C.M. explains: "Let a ball be suspended from every wire, and about one sixth to one eighth of an inch below the balls, place the letters of the alphabet, marked on bits of paper" (Huurdeman, 2003, p. 48).

(2) *"Almost simultaneously, in 1837, Cooke together with Wheatstone presented an electrical needle telegraph in Great Britain and Morse an electrical writing telegraph in the United States"* (Huurdeman, 2003, p. 33).

iv. Alexander Graham Bell and the Telephone

(1) *Bell's new telephone was first demonstrated in May 1876 at the American Academy of Arts and Sciences at the Massachusetts Institute of Technology (MIT)"* (Huurdeman, 2003, p. 163).

(2) *"Bell's invention of the telephone (1876) marks the beginning of a unique 30-year period with an incomparable wealth of technological innovations that all became major components of our contemporary modern civilization"* (Huurdeman, 2003, p. 90).

v. Automatic Telephone Line Switch

"The accumulation of operational and especially human errors connected with manual switching became so frustrating for funeral director Almon Brown Strowger of Kansas City that he changed his profession and developed the world's first "girl-less, cuss-less, out-of-order-less and wait-less telephone exchange," which began operation in La Porte, Indiana, on November 3, 1892, starting the era of automatic telephone switching" (Huurdeman, 2003, p. 90).

b. Alexander Graham Bell

i. Connection to the Telegraph

"I cannot with any great accuracy fix the date of the conception of the system of Multiple Telegraphy for which I have applied for letters-patent of the United States. I merely know that the idea had been conceived previously to my departure from England in 1870, and that it could not have occurred to me at an earlier date than 1867, in which year I commenced the study of Telegraphy with a friend in the city of Bath" (Bell, 1876).

c. R.V.L. Hartley

i. Earliest Discussion of Information Transmission

Note: The title, "Transmission of Information", contains what may be the earliest use of the term information in regard to communications.

ii. Channels and Multiplexing

"Multiplex operation may then be employed in which the line is used by the various operators in rotation. It is interesting to note that this distributor type of multiplex utilizes the frequency-range of the line as efficiently as would a single printing telegraph channel using the same dotting speed, and more efficiently than does the carrier multiplex method. By the distributor method each operator utilizes the full frequency-range of the line during the time allotted to him and there is no time wasted in separating the channels from each other. In the carrier multiplex, on the other hand, while each operator uses the line for the full time it is available, a part of the frequency-range is wasted in separating the channels because of the departure of physical filters from the ideal" (Hartley, 1928).

d. John Mills

i. Originating from Morse and Bell

"ALL communication involves conventions and understandings as to the meanings of symbols, and it is usually through making symbols audible or visual that intelligence is transferred. When the distance is too great for unaided ear or eye, electrical systems apply. All those in use to-day derive fundamentally from the telegraphy of Morse and the telephony of Bell" (Mills, 1929).

ii. Channels and Control (Zadeh, 1953)

"Any communication system to-day involves apparatus for two distinct purposes: the first is the production of a channel for communication with its related terminal equipment; the second is the control, switching and supervision of the channel" (Mills, 1929).

e. Gilbert Lewis

i. Information and Entropy

"Gain in entropy always means loss of information, and nothing more' (Lewis, 1930).

f. Norbert Wiener

i. Information

"Information is information, not matter or energy" (Weiner, 1948, p. 155).

ii. Information Entropy

"In control and communication we are always fighting nature's tendency to degrade the organized and to destroy the meaningful; the tendency,[...] for entropy to increase" (Wiener, 1954).

iii. Entropy versus Feedback

"It is my thesis that the physical functioning of the living individual and the operation of some of the newer communication machines are precisely parallel in their analogous attempts to control entropy through feedback" (Wiener, 1954).

g. G.A. Barnard

i. Noise

"The other source of statistical ideas is "noise". This is caused by random disturbances (e.g. "atmospherics") which affect the channel of communication in such a way that the received signal is not the same as that sent, and there is no one-to-one correspondence between transmitted and received signals" (Barnard, 1951).

ii. Distortion

"If there is no noise in the channel there may, none the less, be distortion, so that the number sent, x, is not necessarily the same as the number received, y, but there is a definite 1 - 1 functional relationship y = d(x) between x and y" (Barnard, 1951).

h. L.A. Zadeh

i. Theory of Filtering

Referencing Norbert Wiener's (1949). "The extrapolation, interpolation and smoothing of stationary time series", New York: John Wiley & Sons.

"Prior to the advent of Wiener's theory of smoothing and prediction, a filter was generally regarded as an electrical network which would pass freely certain desired bands of frequencies, while highly attenuating the neighboring undesired bands of frequencies.- This narrow view of the filter was greatly broadened by Wiener, who introduced the concept of ensemble of signals into communication theory and placed the theory of filtering on a statistical basis" (Zadeh, 1953).

i. H. Quastler

i. Information Theory

"'Information Theory' is a name remarkably apt to be misunderstood. The theory deals, in a quantitative way, with something called 'information', which, however, has nothing to do with meaning. On the other hand, the 'information' of the theory is related to such diverse activities as arranging, constraining, designing, determining, differentiating, messaging, ordering, organizing, planning, restricting, selecting, specializing, specifying, and systematizing…" (Quastler, 1953).

j. C.E. Shannon

i. Communication

"The fundamental problem of communication is that of reproducing at one point, either exactly or approximately, a message selected at another point" (Shannon, 1948).

ii. Elements of a Communication Systems

A communication system *"consists of essentially five parts:*

1. An information source which produces a message or sequence of messages to be communicated to the receiving terminal […]

2. A transmitter which operates on the message in some way to produce a signal suitable for transmission over the channel […]

3. The channel is merely the medium used to transmit the signal from transmitter to receiver […]

4. The receiver ordinarily performs the inverse operation of that done by the transmitter, reconstructing the message from the signal

5. The destination is the person (or thing) for whom the message is intended" (Shannon, 1948).

iii. Distortion and Noise

"We now consider the case where the signal is perturbed by noise during transmission or at one or the other of the terminals. This means that the received signal is not necessarily the same as that sent out by the transmitter. Two cases may be distinguished. If a particular transmitted signal always produces the same received signal, i.e., the received signal is a definite function of the transmitted signal, then the effect may be called distortion. If this function has an inverse — no two transmitted signals producing the same received signal —

distortion may be corrected, at least in principle, by merely performing the inverse functional operation on the received signal. The case of interest here is that in which the signal does not always undergo the same change in transmission. In this case we may assume the received signal E to be a function of the transmitted signal S and a second variable, the noise N" (Shannon, 1948).

iv. Information Redundancy

"It is clear, however, that by sending the information in a redundant form the probability of errors can be reduced. For example, by repeating the message many times and by a statistical study of the different received versions of the message the probability of errors could be made very small" (Shannon, 1948).

v. Channel Capacity and Bandwidth

"In a continuous channel the input or transmitted signals will be continuous functions of time f (t) belonging to a certain set, and the output or received signals will be perturbed versions of these. We will consider only the case where both transmitted and received signals are limited to a certain band W" (Shannon, 1948).

vi. Entropy

"It is convenient to measure the randomness of an arbitrary type of noise not directly by its entropy, but by comparison with white Gaussian noise. We can calculate the power in a white noise having the same entropy as the given noise" (Shannon, 1949).

k. Shannon and Weaver

i. Noise

"In the process of being transmitted, it is unfortunately characteristic that certain things are added to the signal which were not intended by the original information source. These unwanted additions may be distortions of sound (in telephony, for example) or static (in radio), or distortions in shape or sending of picture (television), or errors in transmission (telegraphy or facsimile), etc. All of these changes in the transmitted signal are called noise" (Shannon & Weaver, 1949).

l. Herb Simon

i. Information Channels

"The organization provides channels of communication running in all directions through which information for decision-making flows. Again, these channels are both formal and

informal. The formal channels are party based on, and partly separate from, the lines of formal authority, and the informal channels are closely related to the informal social organization" (Simon, 1976).

m. Chuck Keating

i. Entropy

(1) *"The entropy rate of a data source means the average number of bits (either a 0 or a 1) per symbol needed to encode it"* (Keating, 2012).

(2) *"Shannon's definition of entropy, when applied to an information source, can determine the minimum channel capacity required to reliably transmit the source as encoded binary digits"* (Keating, 2012).

ii. Information Redundancy

(1) *"Redundancy is actually the amount of wasted "space" used to transmit certain data"* (Keating, 2012).

(2) *"Data compression is a way to reduce or eliminate unwanted redundancy"* (Keating, 2012).

(3) *"Checksums are a way of adding desired redundancy for purposes of error detection when communicating over a noisy channel of limited capacity"* (Keating, 2012).

(4) *"Errors in information transmission can be reduced (to any level desired) by increasing the redundancy of messages"* (Keating, 2012).

iii. Redundancy of Potential Command

(1) *"The redundancy of potential command principle emphasizes the part played by auxiliary information channels"* (Keating, 2012).

(2) *"The auxiliary channel is transmitting, like the primary channel, so it is not really feedback"* (Keating, 2012).

(3) *"Command should pass to the channel with the most important information"* (Keating, 2012).

n. Charles Keating and Mary Morin

i. Communications Channels in a Viable System

Note: Channels 1 - 6 originate from Stafford Beer. Channels 7 - 9 are from Keating and Morin.

(1) *"Command: Provides direction to operational units. Primarily from the System 3 (control) function to the System 1 (operations) function"* (Keating & Morin, 2001).

(2) *"Resource Bargain[ing]/Accountability: Provides/determines the resources (manpower, material, money, information, support) for operational units. Primarily directed between System 3 and System 1. Defines performance levels to which operational units will be held responsible. Determines how operational units will report and be held accountable for performance requirements"* (Keating & Morin, 2001).

(3) *"Operations: Provides for the routine interface between operational units and from System 3 to System 1s. Direct link between System 1s without external interference or monitoring"* (Keating & Morin, 2001).

(4) *"Coordination: Provides for system balance and stability by ensuring that information concerning decisions and actions necessary to prevent disturbances are shared among operational units"* (Keating & Morin, 2001).

(5) *"Audit: Provides routine and sporadic feedback on the performance of selected operational attributes. Reports and investigates areas identified by the System 3 function as problematic. Primarily a System 3* channel for communicating between System 1s and System 3"* (Keating & Morin, 2001).

(6) *"Algedonic: Provides instant alert to crisis or potentially catastrophic situations. Direct from operational units to the policy function bypasses routine communications channels error and structure"* (Keating & Morin, 2001).

(7) *"The dialog channel has the primary purpose of providing examination and interpretation of organizational decisions, actions, and events. This aligns perspectives and creates a shared understanding of organizational decisions and actions in light of system purpose and identity"* (Keating & Morin, 2001).

(8) *"The system learning channel supports the System 4* function. This channel provides detection and correction of system errors, testing of assumptions, and identification of system design deficiencies"* (Keating & Morin, 2001).

(9) *"The informing channel is designed to provide routine transmission of information throughout the system. Thus, information that is not appropriate for other channels is made accessible across the entire system through this channel"* (Keating & Morin, 2001).

o. Jose Perez Rios

i. Communication Channels

"Communication channels are responsible for connecting all those systems or functions, as well as linking the organization with its environment. Particularly relevant are the algedonic channels, whose role is collecting and transmitting to System 5 information critical for the viability of the organization" (Perez Rios, 2010).

p. Kimball and Howard

i. State Information

"In any system undergoing a process of the multistage decision type, certain information is needed at each decision point in order to make that decision... The term state will be used to denote all the information needed to describe the system at any stage. The stage is usually described in terms of the values of the set of variables. In some cases, these variables are discrete, in others they are continuous. As the process we are considering proceeds, the state of the system is ordinarily constantly changing" (Kimball & Howard, 1959).

A-17. Information Redundancy

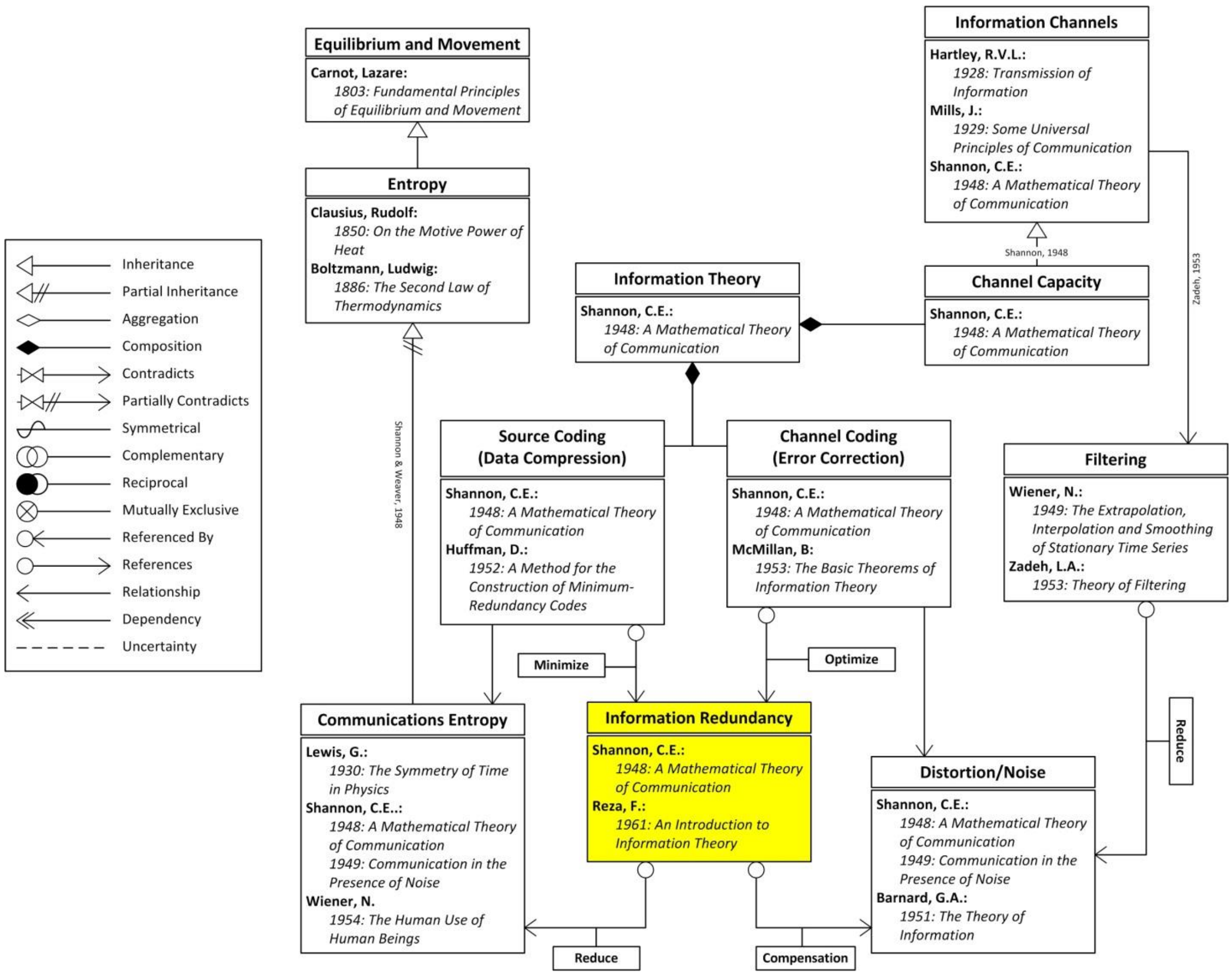

Figure A-20: Concept Model of Information Redundancy

■ Definition

Information Redundancy: The use of additional, redundant data during a communication transaction in order to overcome noise or information entropy (Shannon, 1948)

■ Commentary

In approaching this, it is recognized that the notion of information redundancy is really an adjacent subset of communications. Because it is called out distinctly in the Adams/Keating model, it is explored independently here.

■ Contributing Scholars

a. Claude E. Shannon

Note: Shannon is referred to as the "Father of Information Theory" commonly in periodicals and literature.

i. Information Redundancy

"It is clear, however, that by sending the information in a redundant form the probability of errors can be reduced. For example, by repeating the message many times and by a statistical study of the different received versions of the message the probability of errors could be made very small" (Shannon, 1948).

ii. Entropy and Redundancy

"The ratio of the entropy of a source to the maximum value it could have while still restricted to the same symbols will be called its relative entropy. This is the maximum compression possible when we encode into the same alphabet. One minus the relative entropy is the redundancy. The redundancy of ordinary English, not considering statistical structure over greater distances than about eight letters, is roughly 50%. This means that when we write English half of what we write is determined by the structure of the language and half is chosen freely" (Shannon, 1948).

iii. Redundancy as a Solution for Noise

"The redundancy must be introduced in the proper way to combat the particular noise structure involved. However, any redundancy in the source will usually help if it is utilized at the receiving point. In particular, if the source already has a certain redundancy and no attempt is made to eliminate it in matching to the channel, this redundancy will help combat noise" (Shannon, 1948).

b. Brockway McMillan

i. Information Theory

"For the purposes of this exposition, information theory is the body of statistical mathematics which has developed, largely over the last decade, out of efforts to understand and improve the communications art" (McMillan, 1953).

c. Fazlollah Reza

i. Absolute and Relative Redundancy/Channel Capacity

"The difference between the actual rate of transmission of information and its maximum possible value is defined as the (absolute) redundancy of the communication system. The ratio of absolute redundancy to channel capacity is defined as relative redundancy" (Reza, 1961).

ii. The Benefit of Redundancy

"It should be kept in mind that redundancy is not always undesirable. For example, in the presence of noise redundancy contributes to improvement in the intelligibility of the text" (Reza, 1961).

iii. Referencing Huffman's Minimum-Redundancy Code

"Huffman has suggested a simple method for constructing separable codes with minimum redundancy for a set of discrete messages" (Reza, 1961).

iv. Efficiency as the Inverse of Redundancy

"An increase in transmission efficiency can be obtained by proper encoding of messages, that is, assigning new sequences of symbols to each message so that the statistical distribution of the new symbols reduces the average word length" (Reza, 1961, p. 133).

Note: On page 134, Reza provides the formula that directly correlates efficiency and redundancy.

v. Channel Capacity

"In this section, it is intended to introduce a suitable measure for efficiency of transmission of information by making a comparison between the actual rate and the upper bound of the rate of transmission of information for a given channel. In this respect, Shannon has introduced the significant concept of channel capacity. According to Shannon, in a discrete communication system the channel capacity is the maximum of transinformation" (Reza, 1961).

d. John Anderson and Seshadri Mohan

i. Information and Entropy

"In the view of Shannon information theory an information source is defined in terms of a probability distribution. A simple example is the rolling of a six-sided fair die. Each face has

a probability 1/6 of coming up and we view the information in the outcome as related to this probability distribution. The favored view in information theory is that the information should measure the uncertainty in the outcome, a view with which dice players will sympathize. But only the distribution is important, not the physical fact of the die; any object with six equiprobable outcomes will do" (Anderson & Mohan, 1991).

ii. Source Coding

(1) "In a kind of source coding called noiseless source coding, the purpose is lowering the redundancy in the information" (Anderson & Mohan, 1991).

(2) "Another kind of source coding is rate-distortion coding. Here the object is to remove information and therefore suffer distortion, because the loss is imperceptible or the information is not worth the cost of handling it" (Anderson & Mohan, 1991).

iii. Channel Coding

"The final type of code in this book is the channel coder. Here the object is to correct channel errors, or more generally, to defeat channel noise" (Anderson & Mohan, 1991).

e. David A. Huffman

i. Minimum-Redundancy Codes

(1) The term 'redundancy" has been defined by Shannon as a property of codes. A "minimum-redundancy code" will be defined here as an ensemble code which, for a message ensemble consisting of a finite number of members, N, and for a given number of coding digits, D, yields the lowest possible average message length" (Huffman, 1952).

(2) "The following basic restrictions will be imposed on an ensemble code: (a) No two messages will consist of identical arrangements of coding digits. (b) The message codes will be constructed in such a way that no additional indication is necessary to specify where a message code begins and ends once the starting point of a sequence of messages is known" (Huffman, 1952).

f. John Avery

i. On Shannon Entropy

"*When Shannon had been working on his equations for some time, he happened to visit the mathematician John von Neumann, who asked him how he was getting on with his theory of missing information Shannon replied that the theory was in excellent shape, except that he needed a good name for 'missing information'. 'Why don't you call it entropy?', von*

Neumann suggested? […] Shannon took von Neumann's advice, and used the word 'entropy' in his pioneering paper on information theory. Missing information in general cases has come to be known as 'Shannon entropy' But Shannon's ideas can also be applied to thermodynamics" (Avery, 2012).

g. Kevin Adams and Charles Keating

i. Information Redundancy Principle

"Information redundancy is the number of bits used to transmit a message minus the number of bits of actual information in the message" (Adams & Keating, 2012).

ii. Corollary to Principle of Information Redundancy

"The principle of information redundancy leads to an important Corollary: Errors in information transmission can be reduced (to any level desired) by increasing the redundancy of messages" (Adams & Keating, 2012).

***h.* Charles Keating**

i. Information Redundancy

(1) *"Redundancy is actually the amount of wasted "space" used to transmit certain data"* (Keating, 2012).

(2) *"Data compression is a way to reduce or eliminate unwanted redundancy"* (Keating, 2012).

(3) *"Checksums are a way of adding desired redundancy for purposes of error detection when communicating over a noisy channel of limited capacity"* (Keating, 2012).

(4) *"Errors in information transmission can be reduced (to any level desired) by increasing the redundancy of messages"* (Keating, 2012).

A-18. Minimum Critical Specification

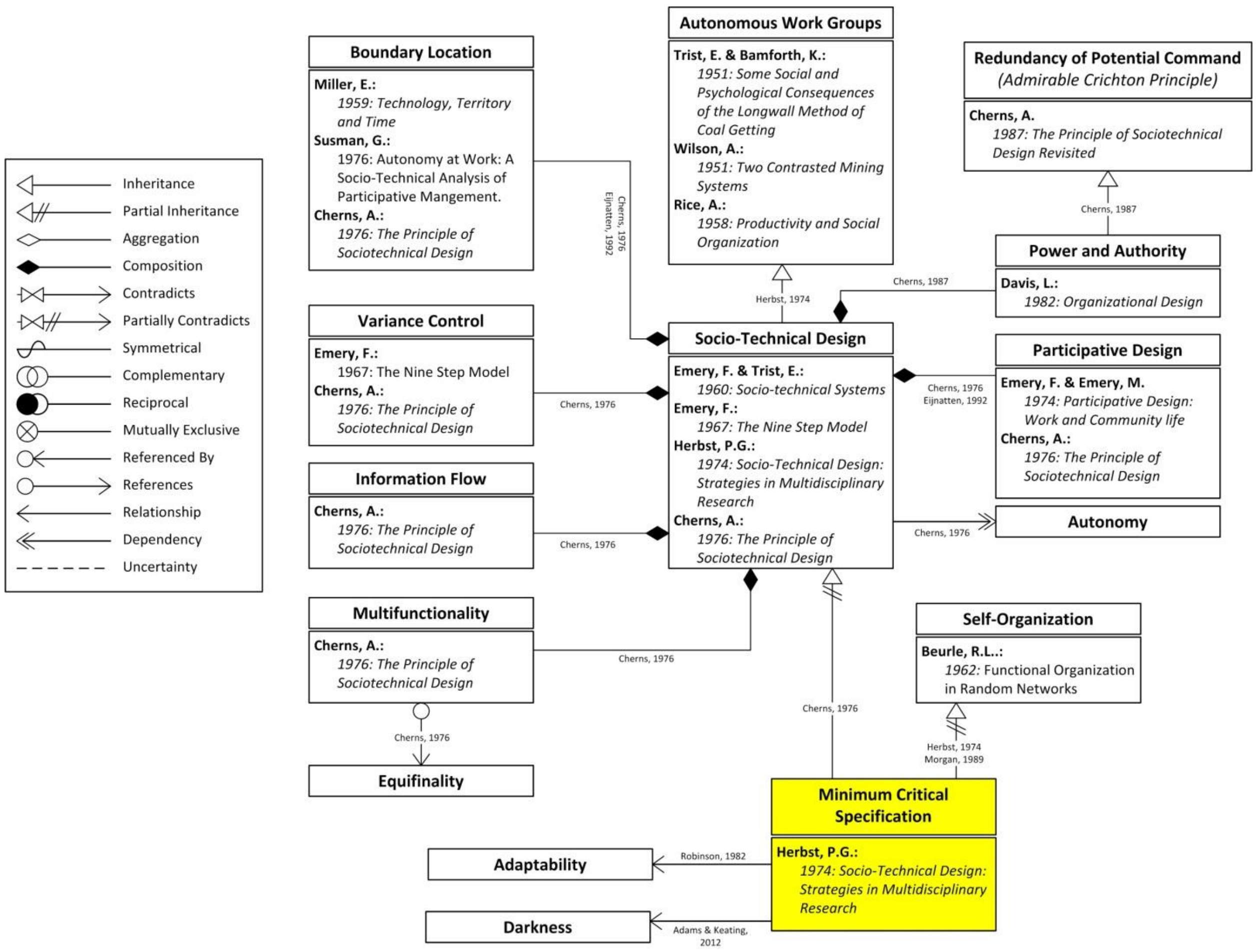

Figure A-21: Concept Model for Minimum Critical Specification

- **Definition:**

Minimum Critical Specification: The minimum set of core requirements with which an operable unit can produce a satisfactory result without external control of its internal functions (Herbst, 1974)

- **Commentary**

In approaching this topic, I must acknowledge a certain bias toward its viability as a standalone principle. As with some of the other principles that were identified in the Adams/Keating model, it appears that this one may be better represented as an intersection of other ideas and principles. Nonetheless, it is still highly valuable to examine this topic individually, if only to potential identify and isolate other underlying principles that have not been called out.

In evaluating the completed model, it is clear that Minimum Critical Specification is a significant outlier and that the bulk of the relationships revolve around its predecessor: *Socio-Technical Design.*

■ Contributing Scholars

a. Fred Emory

i. Basic Concept

"A practical difficulty is the tendency to collect too much detail. An effort should be made to identify only key information under each step heading and to avoid getting caught up in an abundance of detail" (Emery, 1967).

ii. Variances Mentioned in Cherns

"The objectives of this stage are to identify the key process variances and the interrelationships between them. A variance is a deviation from some standard or from some specification" (Emery, 1967).

b. P.G. Herbst

i. Minimum Critical Specification

(1) "Without going into the detail of recent, more sophisticated, work, what we find here is a new approach to the problem of design which is no longer concerned with complete detailed specification but with minimal critical specifications" (Herbst, 1974).

(2) "The principle of minimal critical specification design can be stated as that of identifying the minimal set of conditions required to create viable self-maintaining and self-adjusting production units. An optimal solution is obtained if the unit requires no external supervision and control of its internal functioning and no internal staff concerned with supervision, control or work coordination. The management function should primarily be supportive and concerned with mediating the relationship of the unit to its environment" (Herbst, 1974).

ii. Minimum Critical Specification Related to Autonomous Work Groups

"What emerged at this stage was the concept of autonomous work groups that would overcome the dysfunctional properties of fractionated work organizations (Trist and Bamforth, 1951; Wilson, 1951; Rice, 1958; Emery and Trist, 1960; Herbst, 1962; Trist et al, 1963). This work converged with new principles that were being developed in the field of job design (Davis, 1962; 1966)" (Herbst, 1974).

References:

(1) Trist, E., & Bamforth, K. (1951). Some Social and Psychological Consequences of the Longwall Method of Coal Getting. Human Relations, Vol. 4, No. 1, 3-38.

(2) Wilson, A. (1951). Two Contrasted Mining Systems. In F. E. Emery (Ed.), The Emergence of a New Paradigm of Work. Canberra: Australian National Unversity.

(3) Rice, Albert K. (1958). Productivity and Social Organization. London, Tavistock Publications.

(4) Emery, F.E. and Trist, E.L. (1960). Socio-technical Systems. In C.W. Churchman & M. Verhurst (Eds), Management Science, Models and Techniques, Vol. 2, 83-97. London: Pergamon Press.

iii. Referencing the Contributions of Beurle (Self-Organization)

"An interesting point of departure is the non-specification technique described by Beurle (1962) in a paper on the properties of random nets. These are generally a set of elements with random connections. Beurle argues that the nervous system may initially be somewhat like this but that later, in response to transactions with an already structured environment, an internal adjusted structure which corresponds to a biased network structure should gradually emerge. Clearly, a random network can learn practically any desired response, but something has to be added to get to a workable model.2 Without going into the detail of recent, more sophisticated, work, what we find here is a new approach to the problem of design which is no longer concerned with complete detailed specification but with minimal critical specifications" (Herbst, 1974).

References:

(1) Beurle, R.L. (1962) "Functional Organization in Random Networks." In Principles of Self-Organization, edited by H.V. Foerster and G.W. Zopf. Oxford: Pergamon.

c. Albert Cherns

i. Recognizing the Originator of the Idea as Herbst

"To this end, we have described nine principles, which we offer as a checklist, not a blueprint. They represent a distillation of experience and owe more to the writings of others (Emery, Vol. II, "The Nine-Step Model"; Emery and Trist, 1972; Herbst, 1974/Vol. II, "Designing With Minimal Critical Specifications") than to our own originality. They have not, however, previously been systematized" (Cherns, 1976).

References:

(1) Emery, F. (1967). The Nine Step Model. In E. Trist, & H. Murray (Eds.), The Social Engagement of Social Sciences: Volume II, The Socio-Technical Persective (1993) (pp. 369-379). University of Pennsylvania Press.

(2) Emery, Fred E., Eric L. Trist (1972). Towards a Social Ecology. Harmondsworth, U. K.: Penguin.

(3) Herbst, P. (1974). Socio-Technical Design: Strategies in Multidisciplinary Research. London: Tavistock Publications.

ii. Definition

"At each stage of the design what is critical should be identified and only that should be specified" (Cherns, 1977).

iii. Minimum Critical Specification as a Principle of Sociotechnical Design

(1) *"This principle has two aspects, negative and positive. The negative simply states that no more should be specified than is absolutely essential; the positive requires that we identify what is essential"* (Cherns, 1976, p. 786).

(2) *"While it may be necessary to be quite precise about what has to be done, it is rarely necessary to be precise about how it is to be done"* (Cherns, 1976, p. 786).

(3) *"In any case, it is a mistake to specify more than is needed because by doing so options are closed that could be kept open"* (Cherns, 1976, p. 786).

iv. Compatibility as a Principle of Sociotechnical Design

"The process of design must be compatible with its objectives" (Cherns, 1976, p. 785).

v. Participation as a Principle of Sociotechnical Design

"If the objective of design is a system capable of self-modification, of adapting to change, and of making the most use of the creative capacities of the individual, then a constructively participative organization is needed. A necessary condition for this to occur is that people are given the opportunity to participate in the design of the jobs they are to perform" (Cherns, 1976, p. 785).

vi. Variance Management as a Principle of Sociotechnical Design

Note: This concept originates with Emery (Emery, 1967).

(1) *"This principle states that variances, if they cannot be eliminated, must be controlled as near to their point of origin as possible. We need here to define variance, a word much*

used in sociotechnical literature. Variance is any unprogrammed event; a key variance is one which critically affects outcome" (Cherns, 1976, p. 787).

(2) On Managing Variances: *"Identifying variances and determining the key variances is a process often requiring lengthy analysis, and from time to time efforts have been made to codify it. One version, known as the nine-step analysis, has been developed by Davis and Cherns (in press)"* (Cherns, 1976, p. 787).

vii. Multifunctionality as a Principle of Sociotechnical Design *(Linked* to *Equifinality)*

"The same function can be performed in different ways by using different combinations of elements. There are several routes to the same goal-the principle sometimes described as equifinality" (Cherns, 1976, p. 788).

viii. Power and Authority

Note: Power and Authority are mention by Cherns in 1987, this appears to be a reference to 'Redundancy of Potential Command'. The reference to Louis E. Davis is for (Davis, 1982).

"Louis E. Davis has coined the term "work authority" to describe two linked concepts. Those who need equipment, materials, or other resources to carry out their responsibilities should have access to them and authority to command them. In return, they accept responsibility for them and for their prudent and economical use. They exercise the power and authority needed to accept responsibility for their performance. But there is also the power and authority that accompanies knowledge and expertise. Confronted by forest fires, authority and power are granted in the U.S. Forest Service to whoever has the knowledge and experience regardless of rank and post; the Admirable Crichton principle" (Cherns, 1987, p. 157).

ix. Boundary Management

(1) *"In any organization, departmental boundaries have to be drawn somewhere. Miller (1959) has shown that such boundaries are usually drawn so as to group people and activities on the basis of one or more of three criteria: technology, territory, time"* (Cherns, 1976, p. 788).

(2) *"The more the control of activities within the department becomes the responsibility of the members, the more the role of the supervisor/foreman/manager is concentrated on the boundary activities-ensuring that the team has adequate resources to carry out its functions, coordinating activities with those of other departments, and foreseeing the*

changes likely to impinge upon them. This boundary maintenance role is precisely the requirement of the supervisor in a well-designed system" (Cherns, 1976, p. 789).

x. Autonomy

"Under favorable circumstances, working groups can acquire and handle a greater degree of autonomy and learn to manage their own boundaries. This implies locating responsibility for coordination clearly and firmly with those whose efforts require coordination if the common objectives are to be achieved" (Cherns, 1976, p. 789).

xi. Information Flow as a Principle of Sociotechnical Design

"This principle states that information systems should be designed to provide information in the first place to the point where action on the basis of it will be needed" (Cherns, 1976, p. 789).

d. Eric Miller

i. On Boundaries and Complexity

Referencing (Herbst, 1957)

"Herbst has this to say about the transition from a simple to a complex system: 'As the size of the simple system increases, and depending also on the extent of both its internal and external linkages, more and more work has to be carried out on the co-ordination of component functioning, so that a critical boundary value with respect to size is reached, beyond which intrinsic regulation breaks down. An increase in size beyond this point will become possible by differentiating out a separate integrating unit, which takes over the function of both control and co-ordination of component units, thus leading to a transition from a simple to a complex system. The point at which intrinsic regulation breaks down will be determined by the effectiveness of the organizational structure. The less efficient the organizational structure happens to be the earlier the point at which intrinsic regulation breaks down'" (Miller, 1959, pp. 244-245).

ii. Boundaries

(1) "It is postulated here that there are three possible bases for clustering of role relationships and thus for the internal differentiation of a production system. These are technology, territory, and time. Whenever forces towards differentiation operate upon a simple production system, it is one or more of these dimensions that will form the boundaries of the emergent sub-systems and will provide the basis for the internal solidarity of the groups associated with them" (Miller, 1959, p. 246).

(2) *"The sharp territorial boundary - for example, between one building and another-is generally more relevant than any technological affinity between processes that are territorially remote and not sequential. Poorly planned layouts are not only inefficient from the point of view of material handling but also create organizational difficulties"* (Miller, 1959, p. 258).

e. Gordan Robinson

i. Minimum Critical Specification and Adaptability

"The important gain when decision making and method selection is close to the actual work floor is adaptability to change" (Robinson, 1982).

f. Gareth Morgan

i. The Holographic Organization

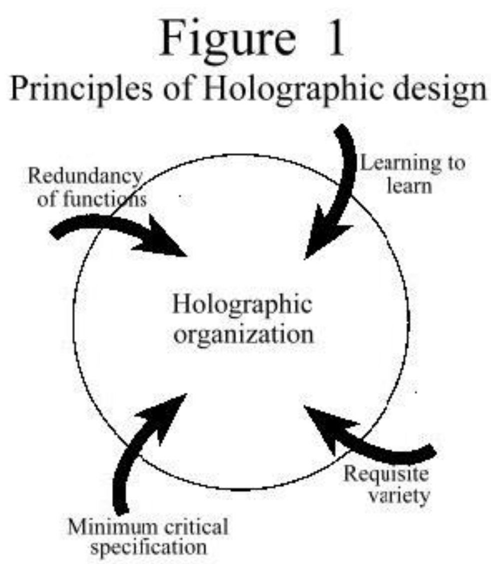

Figure A-22: Principles of Holographic Design (Morgan, 1989)

"It is possible to build organizations that have holographic, brain-like capacities by developing the implications of four interrelated principles (Figure 1). Collectively, these principles provide a means of designing organizational forms so that each part of the system strives to embrace the qualities of the whole and to self-organize in an ongoing way. The principle of redundant functions shows a means of building wholes into parts by creating redundancy, connectivity and simultaneous specialization and generalization. The principle of requisite variety helps to provide practical guidelines in the design of part/whole

relations by showing exactly how much of the whole needs to be built into a given part. And the principles of learning to learn and minimum critical specification show how we can enhance capacities for self-organization" (Morgan, 1989).

ii. Minimum Critical Specification as Self-Organization

"The principle of minimum critical specification (Herbst, 1974/ Vol. II, "Designing With Minimal Critical Specifications") suggests that managers and organizational designers should primarily adopt a facilitating or orchestrating role, creating "enabling conditions" that allow a system to find its own form" (Morgan, 1989).

g. Frans M. van Eijnatten

i. Model of Sociotechnical System Design (Eijnatten, 1992)

Table 3.4 Outline of sociotechnical design principles of Classical STSD.
** emphasis on process of change.*

- compatibility/participant design *)
  (Emery, 1974/1976; Cherns, 1976/1987)
- minimum critical specification (inspired on Beurle, 1962)
  (Herbst, 1974; Cherns, 1976/1987)
- the socio-technical criterion/variance control
  (Emery & Thorsrud, 1969; Cherns, 1976/1987)
- the multifunctional principle/redundancy of functions
  (Emery, 1967; Emery & Trist, 1972; Cherns, 1976/1987)
- boundary location
  (Susman, 1976; Cherns, 1976/1987)
- information flow
  (Cherns, 1976/1987)
- support congruence
  (Cherns, 1976/1987)
- design and human values
  (Thorsrud, 1972; Cherns, 1976)
- incompletion/Forth Bridge principle/double loop learning *)
  (Cherns, 1976/1987; Argyris & Schön, 1978)
- power and authority/Admirable Crichton principle
  (Cherns, 1987)
- transitional organization *)
  (Cherns, 1987)

Figure A-23: Outline of Sociotechnical Design Principles (Eijnatten, 1992)

References:

(1) Emery, F.E., & Emery, M. (1974). Participative design: work and community life. Canberra: Australian National University, Centre for Continuing Education.

(2) Susman, G.I. (1976). Autonomy at work: a socio-technical analysis of participative management. New York: Praeger.

h. Kevin Adams and Charles Keating

i. Cherns as the father of Sociotechnical Design

Note: This appears to be incorrect. Specifically, a book on Socio Technical Design was penned in 1974 by P.G. Herbst, which explicitly discusses (and names) Minimum Critical Specification.

"Albert Cherns, the father of modern Sociotechnical Design offered a number of basic principles he felt were essential in the design and redesign of organizations (1976)" (Adams & Keating, 2012).

ii. Relationship to System Darkness

"There are several reasons for placing bounds on a design. We never have complete knowledge (principle of system darkness) of a system or total control of the resources required to completely specify a design" (Adams & Keating, 2012).

A-19. Multifinality

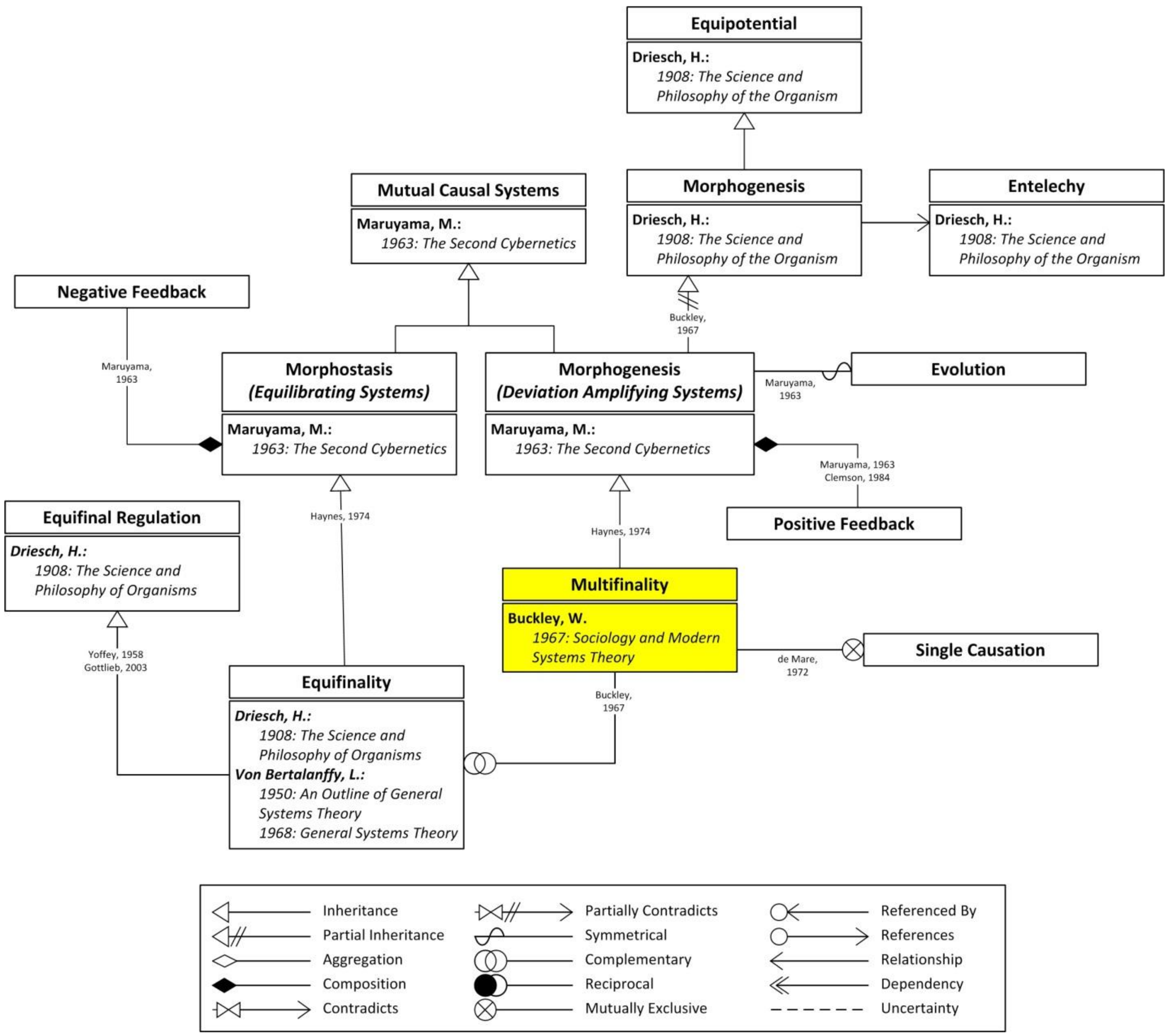

Figure A-24: Concept Model of Multifinality

■ Definition

Multifinality: The ability of an open system that begins at similar initial conditions to reach a variety of dissimilar end-states (Maruyama, 1963)

■ Commentary

Equifinality, a complementary principle, has already been covered in a prior analysis. This analysis will begin by introducing the prior references to multifinality and will then expand it with other evaluations.

Upon exploring the topic, it was quickly determined that while the term multifinality may have been posited by Buckley (1967), the concept was largely developed and documented by Magoroh Maruyama (1964).

Note: The following reference was discussed by several sources, but was not available at the time of this research: Campbell, D. (1959). Methodological suggestions from a comparative psychology of knowledge processes. Inquiry, 2, 152-167.

- **Contributing Scholars**

a. Hans Driesch

i. Equipotential and Morphogenetic Systems

"If we now borrow a very convenient term from mechanics, and call any part of the organism which is considered as a unit from any morphogenetic point of view, a morphogenetic "system"; we may sum up what we have learnt by saying that both the blastoderm of the echinoderms, at least around its polar axis, and also the germ-layers of these animals, are "systems" possessing an equal potentiality in all of their elements, or, in short, that they are equipotential systems" (Driesch, 1908).

ii. Entelechy/Vitalism and Morphogenesis

"But shall we not give a name to our vitalistic or autonomous factor E, concerned in morphogenesis? Indeed we will, and it was not without design that we chose the letter E to represent it provisionally. The great father of systematic philosophy, Aristotle, as many of you will know, is also to be regarded as the founder of theoretical biology. […]Let us then borrow our terminology from Aristotle, and let that factor in life phenomena which we have shown to be a factor of true autonomy be called Entelechy" (Driesch, 1908, p. 144).

b. Magoroh Maruyama

i. Mutual Causal Systems as the Parent of Deviation Amplifying and Equilibrating Systems

"The deviation-counteracting mutual causal systems and the deviation-amplifying mutual causal systems may appear to be opposite types of systems. But they have one essential feature in common: they are both mutual causal systems, i.e., the elements within a system influence each other either simultaneously or alternatingly" (Maruyama, 1963).

ii. Deviation Amplifying Systems versus Equilibrating Systems

"In contrast to the progress in the study of equilibrating systems, the deviation-amplifying systems have not been given as much investment of time and energy by the mathematical

scientists on the one hand, and understanding and practical application on the part of geneticists, ecologists, politicians and psychotherapists on the other hand" (Maruyama, 1963).

iii. The Effect of Feedbacks

"The difference between the two types of systems is that the deviation-counteracting system has mutual negative feedbacks between the elements in it while the deviation amplifying system has mutual positive feedbacks between the elements in it" (Maruyama, 1963).

iv. Morphostasis vs. Morphogenesis

"The deviation-counteracting mutual causal process is also called 'morphostasis', while the deviation-amplifying mutual causal process is called 'morphogenesis'" (Maruyama, 1963).

v. Morphogenesis as a Driver of Evolution

"The process of evolution, or in other words phylogenetic morphogenesis including the pattern of behavior, is deviation-amplifying in several ways. First, there is deviation-amplifying mutual process between the mutations and the environment. For example, suppose that some mutants of a species can live at a lower temperature than the "normal" individuals. Then the mutants may move to an environment which is colder.[…] Secondly, there is interspecific deviation-amplification. For example, a species of moth has predators. Because of the predators, the mutants of the moth species which have a more suitable cryptic coloration (camouflage) and cryptic behavior than the average survive better.[…] Thirdly, the intraspecific selection has a deviation-amplifying effect, for example many animals prefer supernormal (above-average) members of its species to normal members for mating and for carrying on other cooperative activities.[…] Fourthly, the effect of inbreeding is deviation-amplifying for purely statistical reasons - Marriage between close relatives produce individuals in whom certain characteristics are extremely amplified" (Maruyama, 1963).

c. Walter F. Buckley

i. Earliest Identified Use of Term Multifinality

"The classical principle of causality held that similar conditions produce similar effects, and consequently dissimilar results are due to dissimilar conditions. Bertalanffy, in analyzing the self-regulating, or morphostatic, features of open biological systems, loosened this classical conception by introducing the concept of "equifinality." This holds that, in ontogenesis for example, a final normal adult state may be reached by any number of devious

developmental routes. Morphogenetic processes, however, go even further and suggest an opposite principle that might be called "multifinality": similar initial conditions may lead to dissimilar end-states. Thus, two cultures developing in very similar ecological environments may end up with very different sociocultural systems" (Buckley, 1967, p. 60).

ii. Equipotential and Multifinality

"This concept is perhaps implied in the biological notion of 'equipotential'" (Buckley, 1967, p. 60).

d. Paul A. Haynes

i. Associating Equifinality/Morphostasis and Multifinality/Morphogenesis as Pairs

"Positive, or deviation-amplifying feedback is seen in biological evolution and societal development, which exhibit processes of morphogenesis or, the elaboration of the system's form, organization or state discussed earlier. The implications of this distinction for the classic principle of causality has led to the further concept of equifinality in morphostatic system processes, which holds that an ultimate state may be reached by various developmental routes, and to the opposite principle of multifinality in morphogenetic situations where by similar initial conditions may lead to dissimilar end states" (Haynes, 1974).

e. Anthony Wilden

i. Definition Referencing Maruyama(1963) as the Originator

"Consequently, we need also an explicit conception of MULTIFINALITY (perhaps similar to the biological concept "equipotential"), which can be defined as a process by which 'similar initial conditions, and/or routing by different paths, may lead to dissimilar end-states' (modified from Maruyama, 1963, as quoted in Buckley, 1967: 60)" (Wilden, 1980).

f. Barry Clemson

i. Positive Feedback and Multifinality

"Given initial conditions may give different final conditions (with a positive feedback loop)" (Clemson, 1984, p. 23).

g. Candice Feiring and Michael Lewis

i. Morphogenesis/Morphostasis and Multifinality

"*From these four propositions we can derive two basic principles of development, morphostasis and morphogenesis. Morphostasis refers to those processes in complex system-environment exchanges which tend to maintain a systems given form or organization. Morphostasis may represent developmental processes that lend themselves to observation of continuity. Morphogenic processes may by their nature be harder to observe and predict since they involve changes in a systems structure, state or functioning. Morphogenic processes may involve discontinuities in development. At the extreme morphogenesis can be related to catastrophes and radical changes (e.g. in terms of continuing levels of Y at some point leading to a steep change in X). Morphogenesis involves at least two kinds of developmental paths: 1) equifinality and 2) multifinality. Equifinality holds that a given outcome can be reached from any number of different developmental paths. In this case, similar outcomes may not be the result of similar initial conditions or mediating processes.[…] Multifinality is the opposite developmental principle to equifinality, Where by similar initial conditions may lead to dissimilar outcomes"* (Feiring & Lewis, 1987).

h. Jamshid Gharajedaghi

i. Definition

"Buckley (1967), in his discussion of morphogenic processes in sociocultural systems, goes even further and suggests an opposite principle, 'multifinality'" similar initial conditions may lead to dissimilar end states. So the process, rather than the initial conditions, is responsible for future states" (Gharajedaghi, 2011).

i. P.B. de Maré

i. As Mutually Exclusive to Single Causation and Related to Information Flow

"The classical Aristotelian approach was to isolate and analyse, to reduce to simple, lineal, unidirectional cause-effect chains on a time sequence of prior cause and present effect - the 'why' of single causation. Sociological structures have replaced this by complex reticulate circuits, by networks of field and system and process, appealing to timeless, simultaneous states of related variables of 'equifinality', of 'multifinality', that is of devious developmental routes leading to similar final results or of similar conditions leading to dissimilar end-states, ranging from past and present to future and marking a revolutionary conceptual shift of attention from energy to information flow" (de Maré, 1972).

j. Tibor Muller and Harmond Muller

i. Related to Panta Rei and Minor Variations in Starting Conditions

"Multifinal systems start from (almost) the same initial conditions, but they lead to final states that are far apart from each other. We would expect a system to end in the same final state whenever it starts from the same initial starting point, and, likewise, two systems leaving the same starting point should come to the same destination. But, as we have seen in the discussion of time-dependence, there is the effect of pantha rei, and thus a system cannot really be twice in the same initial state; it is impossible to have exactly identical initial conditions to start from at two different moments. Therefore, no two different systems will ever be started from the same position: though they may appear to be indistinguishable, they will certainly be different" (Muller & Muller, 2003).

Note: Panta Rhei is a Greek phrase attributed to Heraclitus (535 – 475 B.C.E) meaning "Everything flows."

k. Kevin Adams & Charles Keating

i. Complementary to Equifinality

"Walter Buckley [1922-2006], in his discussion of morphogenetic processes in socio-cultural systems suggests a principle opposite to Bertalanffy‟s Principle of Equifinality (Gharajedaghi, 1999). Buckley (1967) calls this multifinality where similar initial conditions may lead to dissimilar end states" (Adams & Keating, 2012).

ii. Nature of Multifinality

"In multifinality, the process, rather than the initial conditions, is responsible for the future end state" (Adams & Keating, 2012).

l. Rob Dekkers

i. Multifinality and Homeostasis/Heterostasis

(1) "Another overlooked phenomenon, called heterostasis, makes it possible that systems operate at multiple points of equilibrium, even though a limited number exist in practice (Selye, 1973)" (Dekkers, 2014, p. 53).

(2) Multifinality is the opposite developmental principle to equifinality, whereby similar initial conditions lead to dissimilar outcomes. This indicates that for the investigator either the mechanisms are not understood or the relevant aspects have been left out" (Dekkers, 2014, p. 53).

(3) *"The principles of equifinality, multifinality, homeostasis and heterostasis have far-stretching implications for the application of deductive reasoning The paradox of equifinality and multifinality means that when observing the behaviour of a system, it might be moving towards a final state irrespective of the initial state or moving away from an initial state without being able to predict the final outcome"* (Dekkers, 2014, p. 54).

m. Arie Kruglanski, Catalina Köpetz, Jocelyn Bélanger, Woo Young Chun, Edward Orehek, and Ayelet Fishbach

Note: The information garnered from this source focuses on the nature of multifinality from a social science perspective. Rather than examining multifinality as a process that can potentially have a variety of distinct outcomes, these authors consider multifinality as a process that results in multiple outcomes. This is not necessarily applicable to systems science, but it is a worthwhile examination from the perspective of doing a comprehensive examination of the topic area.

i. A Different Definition of Multifinality

(1) *"The multifinality construct denotes a motivational structure wherein a single means is linked to several ends. A multifinality configuration maximizes value that a given means promises to deliver while sacrificing expectancy of attainment due to a dilution effect"* (Kruglanski, Köpetz, Bélanger, Chun, Orehek, & Fishbach, 2013).

(2) "*The case where a single behavior is performed in the service of multiple goals has been described by the term multifinality (Kruglanski et al., 2002) whose specific features we explore in the pages that follow*" (Kruglanski, Köpetz, Bélanger, Chun, Orehek, & Fishbach, 2013).

(3) *"For instance, dining at a gourmet restaurant may appear in a configuration that links a single means with three goals—satisfying one's hunger, eating enjoyment, and impressing one's date—or a configuration that links a means with a single goal only (satisfying hunger), and so on"* (Kruglanski, Köpetz, Bélanger, Chun, Orehek, & Fishbach, 2013).

ii. (Alt.) Multifinality and Goal-Directed Behavior, Self-Regulation, Judgment and Choice

"[M]ultifinality phenomena are ubiquitous within the broad domains of goal-directed behavior, self-regulation, and judgment and choice phenomena" (Kruglanski, Köpetz, Bélanger, Chun, Orehek, & Fishbach, 2013).

iii. (Alt.) Multifinality as Related to Self-Regulation

"Because of its general concern with goals and means of whatever type, the multifinality concept holds a considerable integrative potential and affords new insights into classic findings and fundamental phenomena in motivated cognition and self-regulation" (Kruglanski, Köpetz, Bélanger, Chun, Orehek, & Fishbach, 2013).

iv. (Alt.) Multifinality and Judgement

"According to the multifinality framing, in forming a judgment, individuals may strive to satisfy two goals. The focal and explicit goal of judgment is veridicality; by definition, a judgment is assumed to represent a state of affairs the individual believes to be true. In addition, however, judgments often might aim to attain "biasing" background goals as well, that is, form judgments that are self-enhancing, esteem promoting, or optimistic in another way. Where such biasing goals are present, individuals may strive to find multifinal means, that is, form a judgment that while serving those goals concomitantly serves also the focal goal of veridicality or validity" (Kruglanski, Köpetz, Bélanger, Chun, Orehek, & Fishbach, 2013).

v. (Alt.) Multifinality and Dilution

"In application to multifinality, the number of goals associated with a given means dilutes the association strength between the means and any of the goals" (Kruglanski, Köpetz, Bélanger, Chun, Orehek, & Fishbach, 2013).

n. Marvin M. Black

i. Purposivism or Goal-Seeking Behavior as a Contradiction to Mechanism

"The most outstanding exponent of purposivism in psychology today, William McDougall, in his contribution to the Psychologies of 1930, scores American psychologists for their complete blindness to the most peculiar, characteristic, and important feature of human activity, its goal-seeking. They have regarded all bodily actions and phases of experience as mechanical reactions to stimuli, and all learning as the modification of such reactions by the principle of association" (Black, 1935).

Note: William McDougall was also a proponent of Animism, which contradicted mechanism. (McDougall, 1911)

o. Albert J. Levine

i. McDougall as a Purposivist

"McDougall, the foremost Purposivist, maintains that the driving forces for consciousness are innate urges or tendencies, chief of which are the submissive and self-assertive tendencies. This purposivism is exercised in goal-seeking" (Levine, 1940).

p. Dante Cicchetti and Fred Rogosch

i. Another View of Multifinality

"The principle of multifinality (Wilden, 1980) suggests that any one component may function differently depending on the organization of the system in which it operates. Multifinality states that the effect on functioning of any one component's value may vary in different systems" (Cicchetti & Rogosch, 1996).

References:

(1) Wilden, A. (1980). System and Structure. London: Tavistock

A-20. Negative Entropy

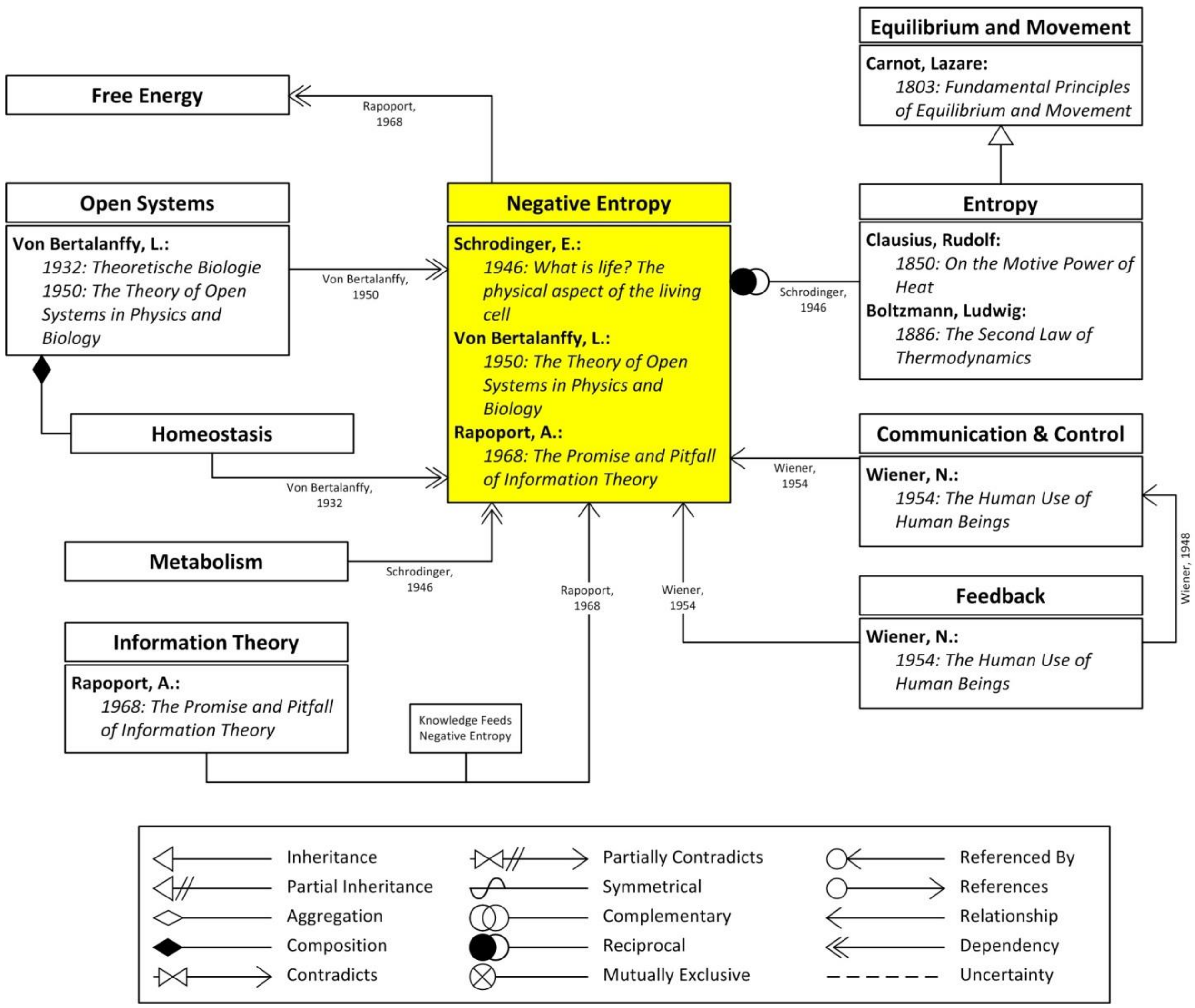

Figure A-25: Concept Model of Negative Entropy

■ Definition

Negative Entropy: The process by which a system absorbs free-energy in order to reduce the accumulation of entropy (or disorder) within the system (Flear, 1948)

■ Commentary

Negative entropy was not a part of the initial catalog of principles that were being explored; however, it was a recurrent theme that deserved examination.

■ Contributing Scholars

a. Erwin Schrodinger

i. Negative Entropy and Metabolism

"Or, to put it less paradoxically, the essential thing in metabolism is that the organism succeeds in freeing itself from all the entropy it cannot help producing while alive" (Schrodinger, 1946).

ii. Negative Entropy and Life

(1) *"It is by avoiding the rapid decay into the inert state of 'equilibrium' that an organism appears so enigmatic....What an organism feeds upon is negative entropy"* (Schrodinger, 1946).

(2) *Life persists because "it feeds on negative entropy"* (Schrodinger, 1946).

b. C.T.G. Flear

i. Free Energy as Negative Entropy

"Free energy is provided by the processes of cellular respiration by means of which circulating compounds — derived from foodstuffs ... Thus the free energy or negative entropy extracted from the foodstuffs is necessary only for activity" (Flear, 1948).

c. Murray Gell-Mann

i. Complexity and Negative Entropy

"The second law of thermodynamics, which requires average entropy (or disorder) to increase, does not in any way forbid local order from arising through various mechanisms of self-organization, which can turn accidents into frozen ones producing extensive regularities. Again, such mechanisms are not restricted to complex adaptive systems" (Gell-Mann, 1995).

d. Ludwig Von Bertalanffy

i. Open Systems and Negative Entropy

(1) *"But in an open system, and especially in a living organism, not only is there entropy production owing to irreversible processes, but the organism feeds, to use an expression of Schrodinger's, from negative entropy, importing complex organic molecules, using their energy, and rendering back the simpler end products to the environment. Thus, living systems, maintaining themselves in a steady state by the importation of materials*

rich in free energy, can avoid the increase of entropy which cannot be averted in closed systems" (Von Bertalanffy, 1950).

(2) *"In open systems we have not only production of entropy due to irreversible processes, but also import of negative entropy. This is the case in the living organism which imports [consumes nutrients with] complex molecules that are high in free energy. Thus, living systems, maintaining themselves in a steady state, can avoid the increase of entropy, and may even develop towards states of increased order and organization"* (quoted in Uncommon Sense, The Life and Thought of Ludwig von Bertalanffy (1983), p.83).

ii. **Steady-State (Homeostasis) and Negative Entropy**

"According to the second law of thermodynamics a closed system must eventually attain a time-independent equilibrium state, with maximum entropy and minimum free energy. An open system may, under certain conditions, attain a time-independent state where the system remains constant as a whole and in its phases, though there is a continuous flow of component materials. This is called a steady state" (Von Bertalanffy, 1932).

e. Daniel Katz and Robert Kahn (Katz & Kahn, 1966)

i. Negative Entropy as a Requirement of Open Systems

As referenced by Miner (2011), an open system has the following characteristics:

"The defining characteristics of such an open-system are (1) energic inputs from the social environment; (2) throughput so that work is done within the system; (3) output into the environment; (4) a cycle of events such that the product exported provides the energy to repeat the cycle; (5) negative entropy, whereby more energy is imported from the environment than is expended in work; (6) information inputs about how the environment and the system are functioning; negative feedback , which provides information to correct deviations; and a coding process that simplifies energic and information inputs and permits their selective reception; (7) a steady state marked by a stable ratio of energy exchanges; (8) movement to increasing differentiation (or elaboration or specialization); (9) the operation of the equifinality principle, whereby the system can achieve the same final state from multiple paths and conditions; and (10) integration and coordination to counter the differentiation" (Miner, 2011).

f. Anatol Rapoport

i. Negative Entropy and Free Energy

"A living organism must ingest at least enough free energy, which contains a negative entropy term, to account for any local decrease of entropy concomitant to its organizational activity" (Rapoport, 1968).

ii. Negative Entropy and Maxwell's Demon

"Maxwell's Demon, or Maxie, as we will call him for short, now 85 years old, is still a subject of serious theoretical discussion. A paper of historical significance for information theory was devoted entirely to him by L. Szilard. Szilard has shown that in lowering the entropy of a gas by his "decisions" Maxie causes an increase of entropy elsewhere which, as calculations show, more than compensates for the decrease and thus vindicates the dictum of the Second Law that the entropy of a closed system (which in this case must include Maxie and his apparatus) can only increase. More recently, L. Brillouin emphasized Maxwell's assumption that Maxie can see the molecules. Thus he cannot be sitting in the total darkness of the enclosed gas (even if the gas is hot and radiates light, it doesn't help him to distinguish the molecules if the whole system is in equilibrium). To see the molecules Maxie must use a flashlight and thus, as, Brillouin shows, feeds "negative entropy" in the form of a light beam into the system. It is this negative entropy which is more than an ample source to account for the resulting decreased entropy of the gas alone. Thus Maxie is shown to be cheating like any charlatan exhibiting a perpetual motion machine" (Rapoport, 1968).

iii. Information Theory and Negative Entropy

"'Knowledge' evokes strong intuitively felt similarity to information and since knowledge has been traditionally the subject matter of philosophic speculation. Accordingly, one finds a wealth of discussion about fighting the inexorable Second Law by increasing our knowledge (knowledge = information = negative entropy), about the inevitable collapse of totalitarian societies (totalitarian society = closed society =closed system, in which entropy is bound to increase)" (Rapoport, 1968).

g. Derek Hitchins

i. Negative Entropy as Fundamental Aspect of a System

"A System is a collection of interrelated entities such that both the collection and the interrelationships together reduce local entropy" (Hitchins, 1992).

h. Lars Skyttner

i. Negative Entropy Drives an Increase in System Elaboration

"Expressed in terms of entropy, open systems are negentropic, that is, tend toward a more elaborate structure. As open systems, organisms which are in equilibrium are capable of working for a long time by use of the constant input of matter and energy. Closed systems, however, increase their entropy, tend to rundown and can therefore be called 'dying systems'. When reaching a steady state the closed system is not capable of performing any work" (Skyttner, 2005).

i. Norbert Wiener

i. Reducing Entropy (Increasing Negative Entropy) Through Communication and Control

"In control and communication we are always fighting nature's tendency to degrade the organized and to destroy the meaningful; the tendency,[...] for entropy to increase" (Wiener, 1954).

ii. Reducing Entropy (Increasing Negative Entropy) Through Feedback

"It is my thesis that the physical functioning of the living individual and the operation of some of the newer communication machines are precisely parallel in their analogous attempts to control entropy through feedback" (Wiener, 1954).

A-21. Recursion

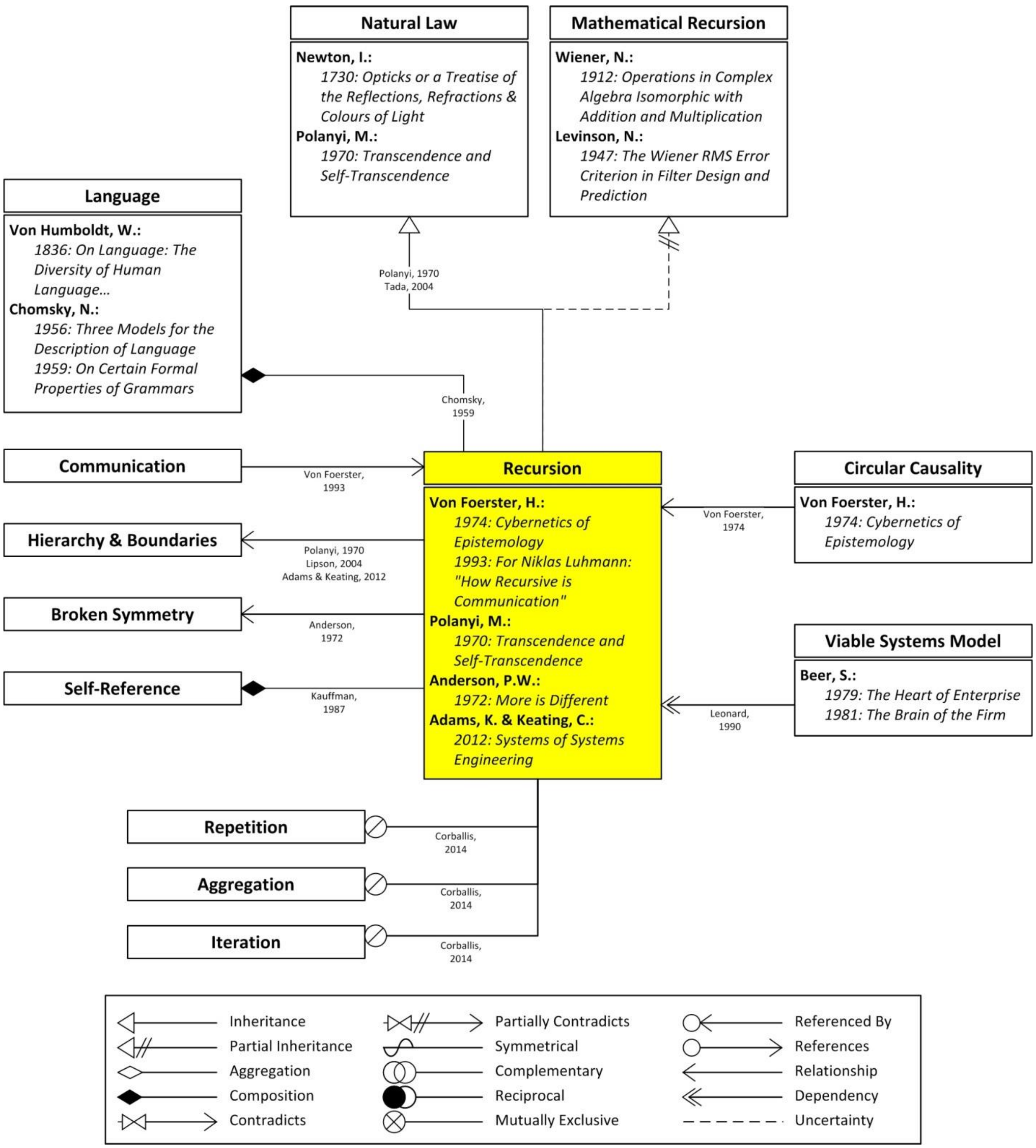

Figure A-26: Concept Model of Recursion

■ Definition

Recursion: The fundamental laws governing the processes at one level are also present at the next higher level (Adams & Keating, 2012)

Commentary

The Principle of Recursion is one of the elements in the Adams/Keating catalog. In exploring the literature, I have yet to find any originating sources that directly support the assertion that *"the fundamental laws governing the processes at one level are also present at the next higher level"* (Adams & Keating, 2012). On the surface, the assertion appears dubious when one considers that higher levels of authority often subject their underlings to rules and regulations that the *authorities* are not subject to. However, the term *fundamental laws* in this principle, if applied to physical laws (which are manifest in the environment rather than the system) make this concept highly supportable. *This is the assumption that will guide the research.*

There are a variety of places where recursion does appear in the literature. It couples tightly to the mathematical principle of recursion, it is recurrent in music theory and linguistics, and, most significantly, it is a key feature of Viable Systems. While these relationships do not directly connect to the principle as described by Adams/Keating, they are still significant to the research.

Note: Mathematical Recursion appears to originate with Norbert Wiener (1912) in Operations in Complex Algebra Isomorphic with Addition and Multiplication, and is continued by N. Levinson (1947) in "The Weiner RMS Error Criterion in Filter Design and Prediction".

Note 2: As yet, I haven't found a smoking gun for the origination of recursion in domain of systems theory. Because of that, I'll lean toward Heinz Von Foerster as the mastermind based on the works that have been identified thus far.

Contributing Scholars

a. Isaac Newton

i. Opticks

"And thus nature will be very comfortable to her self and very simple, performing all the great motions of the heavenly bodies by the attraction of gravity which intercedes those bodies, and almost all the small ones of their particles by some other attraction and repelling powers which intercede the particles" (Newton, 1730).

b. Heinz Von Foerster

i. Recursion and Circular Causality

"If 'epistemology' is taken to be the theory of knowledge acquisition, rather than of knowledge per se, then-it is argued-the appropriate conceptual framework for such an epistemology is that of cybernetics, the only discipline that has given us a rigorous

treatment of circular causality. The processes by which knowledge is acquired, i.e., the cognitive processes, are interpreted as computational algorithms which, in turn, are being computed. This leads to the contemplation of computations that compute computations, and so one, that is, of recursive computations with a regress of arbitrary depth" (Von Foerster, 1974).

ii. Communication is Recursion

"Communication is recursion. You could understand this as if it were an entry in a dictionary. If you do not know what communication is, just look in the dictionary under c. And there is: "Communication is recursion." Aha, you say, good. What does recursion mean? And then again you go to the dictionary, and look under r: "Recursion is communication." And so it is with all dictionaries. If you work with it, you will soon find that the dictionary is always self-referential: You will be sent from A to B, from B to C, and then from C back again to A. That is the game of the dictionary. You could also choose to see this proposition as simply a tautology: communication is recursion" (Von Foerster, 1993).

c. Michael Polanyi

i. Physical Laws and Hierarchy

"But even physics cannot be defined from an atomic topography. We could not, for example, arrive at a principle like that of entropy without introducing some additional principle, such as randomness, to this topography" (Polanyi, 1970).

ii. Governance of Physical Laws from Lower to Upper Hierarchy

"Here I introduce the concept of hierarchical levels. A machine, for example, cannot be explained in terms of physics and chemistry. Machines can go wrong and break down--something that does not happen to laws of physics and chemistry. In fact, a machine can be smashed and the laws of physics and chemistry will go on operating unfailingly in the parts remaining after the machine ceases to exist. Engineering principles create the structure of the machine which harnesses the laws of physics and chemistry for the purposes the machine is designed to serve. Physics and chemistry cannot reveal the practical 1 principles of design or co-ordination which are the structure of the machine" (Polanyi, 1970).

iii. Manipulation of Physical Laws from Upper to Lower Hierarchy

"No inanimate object is ever fully determined by the laws of physics and chemistry. [...]The higher principle of structure controls the lower principles of physics and chemistry. Here I find the first trace of something higher and something lower. Neither set of principles can be

derived from the other. The laws of physics and chemistry are used by the application of engineering principles which control the boundary conditions left open by the laws of physics and chemistry" (Polanyi, 1970).

iv. Recursion as related to Hierarchy and Boundaries

"The conception of hierarchical levels and boundary conditions, so far introduced in a simple, two-level example, can be elaborated by noticing the complex hierarchical character of speaking or composing" (Polanyi, 1970).

v. Dual Control

"This brief explication of a hierarchy may be concluded by noting that the content of our speech transcends grammar; grammar transcends vocabulary, and vocabulary transcends voice production. Every superior level in this hierarchy can be said to represent the meaning of the lower level which it controls. Each level is subject to dual control; first, by the laws that apply to its elements in themselves, and second, by the laws that control the comprehensive entity formed by them" (Polanyi, 1970).

vi. Intelligence and Social Control

"The next step is to note that living beings are possessed of intelligence, another supervening principle, which controls and directs the operations of their sensory-motor faculties. [...] Human beings exercise responsibilities within a social setting and a framework of obligations which transcend the principle of intelligence. Responsible choice in a convivial setting controls the indeterminate powers of intelligence and sets the boundary conditions for their applications" (Polanyi, 1970).

vii. Contradictory to LaPlace

"The more intangible the matter in the range of these hierarchies, the more meaningful it is. This is my criticism of all redactionist, mechanistic programs founded on the Laplacean ideal which identifies ultimate knowledge with an atomic topography, the lowest level of the universe" (Polanyi, 1970).

d. Philip W. Anderson

i. Emergence of Laws at Higher Levels of Hierarchy

"That is, it seems to me that one may array the sciences roughly Iinearly in a hierarchy, according to the idea: The elementary entities of science X obey the laws of science Y. [...] But this hierarchy does not imply that science X is "just applied Y." At each stage entirely

new laws, concepts, and generalizations are necessary, requiring inspiration and creativity to just as great a degree as in the previous one" (Anderson, 1972).

ii. Symmetry

"By symmetry we mean the existence of different viewpoints from which the system appears the same. It is only slightly overstating the case to say that physics is the study of symmetry. The first demonstration of the power of this idea may have been by Newton, who may have asked himself the question: What if the matter here in my hand obeys the same laws as that up in the sky --- that is, what if space and matter are homogeneous and isotropic?" (Anderson, 1972).

iii. Broken Symmetry

"The regularity of crystals could be deduced semi-empirically in the mid-19th century without any complicated reasoning at all. But sometimes, as in the case of superconductivity, the new symmetry--now called broken symmetry because the original symmetry is no longer evident--may be of an entirely unexpected kind and extremely difficult to visualize" (Anderson, 1972).

e. Stafford Beer

i. Recursive System Theory

"If a viable system contains a viable system, then the organizational structure must be recursive, or, in a recursive organizational structure any viable system contains, and is contained in a viable system" (Beer, 1979, p. 118).

f. Louis Kauffman

i. Recursion and Self-Reference

"This essay has moved from the bare notion of self-reference through many transformations and reformulations of this idea . We have touched on feedback, re-entry, recursion, language, geometry, and topology. None of these excursions is meant to be the final word, but rather the opening for new ideas and greater discussion" (Kauffman, 1987).

g. Allenna Leonard

i. Recursion

"When a series of systems is embedded, one within another according to a common pattern, it is called a recursive structure. In such a structure, the same features are repeated

invariantly from a system to its metasystem to its metasystem as in a set of Russian dolls or Chinese boxes" (Leonard, 1990).

h. Kevin Adams and Charles Keating

i. Recursion and Hierarchy

"Recursion is closely related to hierarchy. The Principle of Recursion states that the fundamental laws governing the processes at one level are also present at the next higher level. The principle can be expressed by understanding the following:

• Although level n+1 is more complex than level n, the fundamental laws present at level n are still present at level n+1

• When you apply the principle of recursion, you can deduce the fundamental principles of level n+1 from empirical observations at level n" (Adams & Keating, 2012).

i. Noam Chomsky

i. Recursion in Natural Language

(1) "If a grammar has no recursive steps (closed loops, in the model discussed above) it will be prohibitively complex--- it will, in fact, turn out to be little better than a list of strings or of morpheme class sequences in the case of natural languages. If it does have recursive devices, it will produce infinitely many sentences" (Chomsky, 1956).

(2) "Conceptually, at least, the theory of grammar can be viewed as a study of special classes of recursive functions" (Chomsky, 1959).

j. Dorothy Stroh Becvar

i. Recursion and Circular Causality

"Families have a sense of their mutuality, or shared influence and responsibility (Kaslow, 1982) that is consistent with the idea of recursion and circular causality" (Becvar, 2007).

k. Tomio Tada

i. Natural Recursion

"The laws of Nature's lower levels restrict those governing the higher level of its hierarchy, and many of the phenomena at the higher level are explained and restricted by the rules governing the lower" (Tada, 2004).

l. Hod Lipson

i. Hierarchy and Recursion

(1) "Hierarchy is the recursive composition of function and structure into increasingly larger and adapted units, allowing evolution to search efficiently increasingly complex spaces" (Lipson, 2004).

(2) "Hierarchy of a system is the recursive composition of structure and/or function" (Lipson, 2004).

m. Steven Pinker and Ray Jackendoff

i. Recursion

(1) "a procedure that calls itself, or . . . a constituent that contains a constituent of the same kind" (Pinker & Jackendoff, 2005).

(2) "The only reason language needs to be recursive is because its function is to express recursive thoughts. If there were not any recursive thoughts, the means of expression would not need recursion either" (Pinker & Jackendoff, 2005).

n. Wilhelm Von Humboldt

i. Basis of Recursion

"The infinite use of finite means" (Von Humboldt, 1836).

o. Michael C. Corballis

i. Mathematical Recursion

"The use of recursion to create infinite sequences is also exploited by mathematics. One such sequence is the set of natural (i.e. whole) numbers, which I'll write as N. Thus we can generate all of the positive natural numbers by the definitions

1 is in N

If n is in N then (n + 1) is in N.

This second definition is recursive, because N appears in the condition that needs to be satisfied for N" (Corballis, 2014).

Note: Corballis also references mathematical factorials and the Fibonacci sequence.

ii. Repetition is Not Recursion

"Simple repetition can lead to sequences of potentially infinite length, but does not classify as true recursion. For example, the sentence that opens chapter 9 of A. A. Milne's Winnie the Pooh goes "It rained and it rained and it rained". This could go on forever—or at least until Piglet is drowned—but the repetition simply conveys the information that it rained rather a lot, causing Piglet some ennui. It is not recursive because each addition of and it rained is not driven by the previous one; it is simply added at the discretion of the writer" (Corballis, 2014).

iii. Aggregation is Not Recursion

"Aggregation of different phrases similarly compounds meaning additively, as when the historian Peter Hennessy wrote: "The model of a modern Prime Minister would be a kind of grotesque composite freak—someone with the dedication to duty of a Peel, the physical energy of a Gladstone, the detachment of a Salisbury, the balls of a Lloyd George, the word-power of a Churchill, the administrative gifts of an Attlee, the style of a Macmillan, the managerialism of a Heath, and the sleep requirements of a Thatcher." The sentence itself has recursive elements, but the aggregation of phrases to describe the freakish composite is not recursive in that each does not call the next. Instead, they are effectively elements in a list, inserted to add information. Nonhuman species may well have a similar ability to accumulate information, as when understanding a predator as large, fierce, and with sharp teeth and claws" (Corballis, 2014).

iv. Iteration is Not Recursion

"A slightly more subtle variant on repetition and aggregation is iteration, where a process is repeated, but in this case there is input from the previous application of the process. In this respect it is like recursion, and indeed considered by mathematicians to belong to the class of "general recursive functions." For the main purposes of this book, though, it does not qualify as true recursion because each output is discarded once it has been entered into the next application" (Corballis, 2014).

A-22. Redundancy of Potential Command

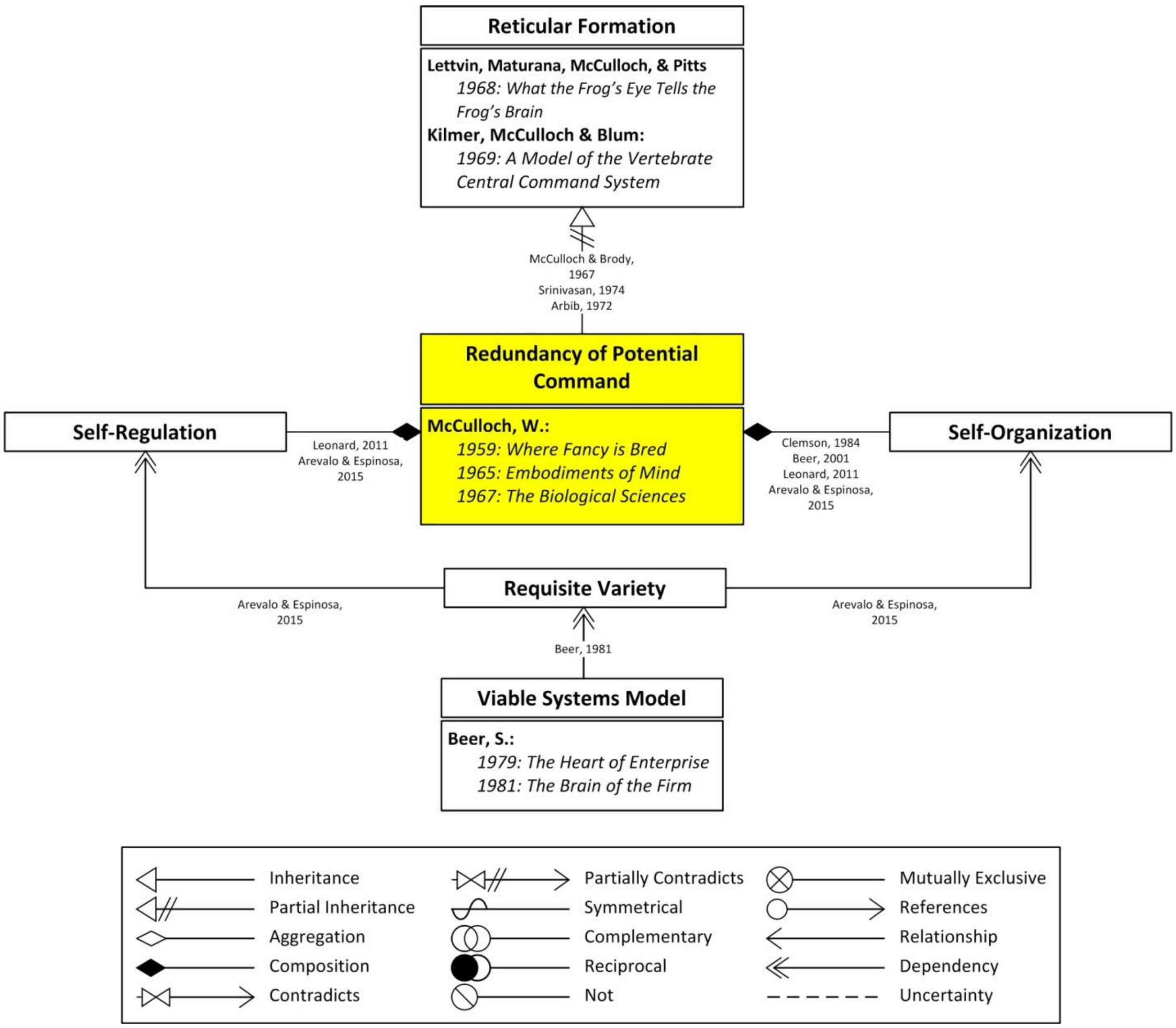

Figure A-27: Concept Model of Redundancy of Potential Command

■ Definition

Redundancy of Potential Command: Power and control should be vested in the location that has the most information or is best equipped to use it (McCulloch W. , 1965)

■ Commentary

This principle is one that is very tightly defined; it packages itself neatly into a small grouping of concepts. The principle, originally posited by Warren McCulloch, is an extension of ideas of self-organization and self-regulation advanced by Heinz Von Foerster and Gordon Pask. Accordingly, at every restatement, the principle becomes more tightly coupled to both self-regulation and self-organization.

The concept appears to have originated in the biological sciences in the study of the Reticular Formation, but was later embraced as a key element of the Viable Systems Model.

■ Contributing Scholars

a. Warren McCulloch

i. Redundancy of Potential Command

(1) *"Every ship of any size or consequence receives information from the others and sweeps the sky for hundreds of miles and water for tens of miles with its own sense organs. In war games and in action, the actual control passes from minute to minute from ship to ship, according to which knot of communication has then the crucial information to commit the fleet to action. This is neither the decentralized command proposed for armies, nor a fixed structure of command of any rigid sort. It is a redundancy of potential command wherein knowledge constitutes authority"* (McCulloch, 1959).

(2) *"Power resides where information resides"* (McCulloch, 1965, p. 229).

(3) *"Characteristically, RF cells rapidly cease to respond to any repeated insignificant input. Multiple electrodes disclose activity wheeling around among its cells. Probably this is part of its distributed memory by reverberation that may account for its ability to be conditioned. We know the system enjoys a redundancy of potential command in which information constitutes authority; for, whichever scattered members of its neuronal pool get the crucial information are capable of sweeping the whole system into essential agreement on one course of conduct committing the whole organism. In the most urgent cases the system cannot reverse its decision in less than about a third of a second, which means that agreement can be achieved in, say, a hundred interaction times - the minimum time for every one neuron to talk to almost all others"* (McCulloch & Brody, 1967).

ii. Reticular Formation

Lettvin, J.Y., Maturana, H.R., McCulloch, W.S., and Pitts, W.H. (1968)What the Frog's Eye Tells the Frog's Brain. In Corning, W. and Balaban, M. (Eds.) The Mind Biological Approaches to its Functions, pp. 233-258.

Kilmer, W.L., McCulloch, W.S., and Blum, J. (1969) A model of the vertebrate central command system. *International Journal of Man-Machine Studies*, Vol. 1, 279-309

b. A.A. Verveen

i. Redundancy of Potential Command

"According to this principle, co-functioning abstract systems demand redundancy of the potential command without which the whole will disintegrate. This principle carries the implication that several potential commanders must always be present and that the one possessing the most data about the immediate and expectable situation exerts command at that moment" (Verveen, 1971).

c. C. A. Srinivasan

i. Reticular Formation

"Kilmer, McCulloch, and Blum hypothesize that the core of the central nervous system, called the reticular formation (RF), is the structure (the control mechanism) in the vertebrates that commits the whole animal to one rather than another of a small number of mutually exclusive modes of behavior. An animal is said to be in a (behavior) mode if the main focus of its attention throughout its central nervous system is on doing things of that mode. Their computer simulation of the concepts of reticular formation - employing design strategies of modular redundancy of potential command (McCulloch concept where information constitutes authority), and modular decoupling under input changes - demonstrates how the RF is able to reach within a fraction of a second a workable consensus as to the proper mode of total commitment" (Srinivasan, 1974).

d. Michael Arbib

(1) "[When] America joined World War I, McCulloch, given a family history of patriotism, wanted to join the Navy. He therefore moved to Yale University, where he joined the Officers' Training Program. There he divided his time between officers' training courses and time on a ship, combining "marlin spike sailing" and signaling by semaphore. Perhaps some of his ideas about coding in the nervous system were shaped by his concern for coding messages and transmitting them from ship to ship. Another idea from the World War I Navy, to which we will return, was what he refers to as "redundancy of potential command." In a naval battle, there are many ships widely separated at sea, and normally command rests in the ship with the Admiral. But if some fighting breaks out or some crucial information becomes available locally, then

temporarily the ship that has that information is the one with command. This notion of redundancy of potential command, rooted in McCulloch's experience in World War I, came in the 1960s to yield the view that the nervous system is not to be seen as a pure hierarchy but rather operates by cooperative computation" (Arbib, 1972).

(2) *"Flatworms avoid the light, but if signals indicating food come from the direction of a light, the animal must resolve the conflict between approach and avoidance if it is to act. A key question is thus, 'How is the central nervous system structured to allow coordinated action of the whole animal when different regions receive contradictory local information?' McCulloch suggested that the answer lay in the principle of redundancy of potential command, which states, essentially, that command should pass to the region with the most important information. He cited the example of a naval fleet where the behavior of the whole World War I naval fleet is controlled, at least temporarily, by the signals from whichever ship first sights the enemy, the point being that this ship need not be the flagship, in which command normally resides"* (Arbib, 1971).

(3) *"McCulloch further suggested that this redundancy of potential command in vertebrates would find its clearest expression in the reticular formation, RF, of the brainstem"* (Arbib, 1972).

e. Barry Clemson

i. Self-Organization and the Redundancy of Potential Command

"The decision making process within the organization will be largely self-organizing and in many cases the particular people involved will be unique to that particular decision situation (by the self-organization law and the redundancy of potential command law)" (Clemson, 1984, p. 148).

f. Stafford Beer

i. Redundancy of Potential Command and the Viable Systems Model

"Authority does not lie in the chains of command, but in the relevance of the information" (Beer, 2001).

g. Allenna Leonard

i. Redundancy of Potential Command with Self-Organization and Self-Regulation

"It is well known that, although hub and spoke or tree structures are efficient for simple governance situations, heterarchies and networks are more robust when tasks and goals become more complex. Authority is not static but depends on the redundancy of potential command. It follows the relevant information. But many times, the way forward is not obvious. Then, the best strategy is to engage in dialogues and processes that allow people to pool their knowledge and move on from there. A practical step is to encourage approaches that involve a high degree of self-organization and self-regulation" (Leonard, 2011).

h. Luz E. Bohórquez Arévalo & Angela Espinosa

i. Self-Regulation and Variety Inhibitor (Requisite Variety)

"McCulloch (1965) explained in great detail self-organization as the most massive variety inhibitor. He explained the nature of reflexive and homeostatic mechanisms in the brain and the way that a 'neural-network' type of organization is goal directed, self-regulated and can achieve purposeful behaviors" (Arevalo & Espinosa, 2015).

ii. Self-Organization

"A system is self-organized when the information flow is distributed in such a way that the command center can be anywhere in the organization: this "redundancy of potential command" was originally postulated by McCulloch, and means that teams have distributed autonomy to take decisions at any time regarding the modes of action of the organization (Beer, 1981). A prerequisite for any self-organizing system is the redundancy of potential command (RPC)" (Arevalo & Espinosa, 2015).

A-23. Relaxation Time

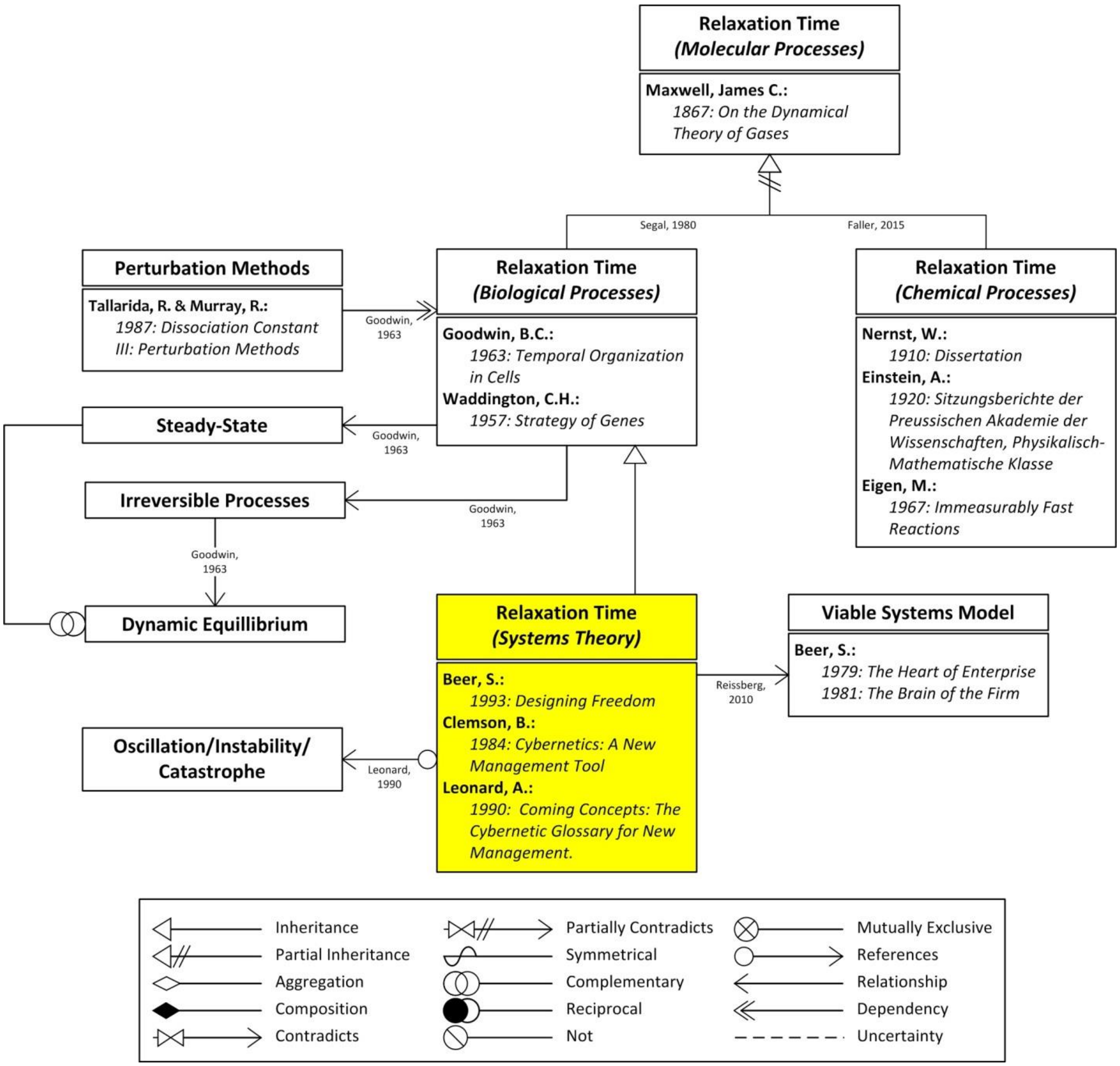

Figure A-28: Concept Model of Relaxation Time

■ Definition

Relaxation Time: The time required for a system to return to a steady-state after being perturbed (Goodwin, 1963)

■ Commentary

The examination of relaxation time actually generated an expansive web of connections that linked systems theory, kinetic chemistry, quantum theory and mechanics. Note that in discussing kinetic chemistry, the concept of perturbation methods can be directly linked to relaxation time; however, the perturbation methods of differential equations (where a close approximation is reached by substituting solvable parameters) is a more distant connection (if related at all).

■ Contributing Scholars

a. James Clerk Maxwell

i. Originator of Term *Relaxation* for Molecular Processes

(1) "The quantity ET, by which the rate of displacement must be multiplied to get the force, may be called the coefficient of viscosity. It is the product of a coefficient of elasticity, E, and a time T, which may be called the "time of relaxation" of the elastic force" (Maxwell, 1867).

(2) "This would account for the gradual untwisting of wires after being twisted beyond the limit of perfect elasticity. For if T diminishes as F increases, the parts of the wire furthest from the axis will yield more rapidly than the parts near the axis during the twisting process, and when the twisting force is removed, the wire will at first untwist till there is equilibrium between the stresses in the inner and outer portions. These stresses will then undergo a gradual relaxation; but since the actual value of the stress is greater in the outer layers, it will have a more rapid rate of relaxation, so that the wire will go on gradually untwisting for some hours or days, owing to the stress on the interior portions maintaining itself longer than that of the outer parts. This phenomenon was observed by Weber in silk fibres, by Kohlrausch in glass fibres, and by myself in steel wires" (Maxwell, 1867).

b. Manfred Eigen

i. On History of Chemical Relaxation Effect

"For the reaction rates of the different stages we get a system of linked differential equations from which, after reduction to linear form, the relaxation times are found as (negative, reciprocal) eigenvalues. [...]The principle of the method described above is quite well-known to physicists. Albert Einstein had already shown in 1916 that relaxation effects appear in a dissociating gas subjected to the periodic temperature variations of a sound wave, and that these effects result in a dispersion of the velocity of sound. At about the same time, Walter Nernst and his associates attempted to detect this effect experimentally in the $2NO_2=N_2O_4$ system. However, these measurements were unsuccessful because the techniques of sound transmission were still insufficiently developed" (Eigen, 1967).

References:

(1) A.Einstein (1920) Sitzungsberichte der Preussischen Akademie der Wissenschaften, Physikalisch-Mathematische Klasse, p. 380.

(2) W.Nernst, see F.Keutel, Dissertation, Berlin, 1910; E.Grüneisen and E.Goens, Ann. Physik, Vol. 72, No. 1923, p. 193.

Note: The link connecting Eigen, Einstein, Nernst and Maxwell is established by Larry Faller in his 2015 article "Relaxation Phenomenon" in the Encyclopedia Brittanica.

c. B.C. Goodwin

i. Biological Relaxation Time and *Perturbation Methods*

"The relaxation time of a system is, roughly speaking, the time required for the variables to reach a steady state after a "small" disturbance. Without a fully mathematical description of the system being studied the relaxation time cannot be rigorously defined, for the size of a small disturbance is determined by the mathematical requirement that the perturbation be consistent with a linearization of the system equations in the neighbourhood of a steady state. Students of chemical kinetics are becoming familiar with this concept through the use of perturbation methods for determining the rate constants in steady state reaction systems, and these methods are rapidly being adapted to the field of enzyme kinetics" (Goodwin, 1963).

ii. Relaxation Time and Steady State

"The significance of this concept in the present study is the fact that if two systems have very different relaxation times (say one is 100 times larger than the other), then relative to the time required for significant changes to occur in the "slower" system (larger relaxation time), the variables of the "faster" one (shorter relaxation time) can be regarded as being always in a steady state" (Goodwin, 1963).

iii. Relaxation Time, Irreversible Processes and Dynamic Equillibrium

"If some microscopic parameter […] changes to a new value, then a new steady state is defined and there will be a certain time lag before the statistical properties of the system settle down to new equilibrium values, thus giving new values to the macroscopic variables" (Goodwin, 1963).

References: Waddington, C.H. (1957) Strategy of the Genes. Allen and Unwin, London.

d. Ronald Tallarida and Rodney Murray

i. Perturbation Methods

"It may be possible to determine the forward and reverse rate constants K_1 and K_2 by the method of chemical relaxation. In this method the system is subjected to a small but sharp variation in some physical parameter upon which the value of $K(=k_2/k_1)$ depends. The restoration to equilibrium after this perturbation follows first-order kinetics" (Tallarida & Murray, 1987).

e. Lee A. Segel

i. Identifying Waddington and Goodwin for Biological Relaxation Time

"Following Waddington's (1957) format, Goodwin (1963) has classified biological systems according to their relaxation time. The relaxation time of a process can be loosely defined as the time required to return to equilibrium after a 'small' disturbance" (Segel, 1980).

f. Stafford Beer

i. Relaxation Times in Dynamic Systems

"A dynamic system is in constant flux; and the higher its variety, the greater the flux. Its stability depends upon its new state reaching equilibrium following a perturbation. The time this process takes is the relaxation time" (Beer, 1993).

ii. Relaxation Time and the Representative Point

(1) "The relaxation time of a system is the time it takes the representative point to reach stability after it has been perturbed" (Beer, 1993).

g. Barry Clemson

i. Relaxation Time vs. Stability

"System stability is possible only if the system's relaxation time is shorter than the mean time between disturbances" (Clemson, 1984).

h. Allenna Leonard

i. Relaxation Time

(1) "The relaxation time of a system is the time it takes to return to equilibrium after a disturbance" (Leonard, 1990).

(2) *"Generally speaking, the larger and more complex the system, the longer the relaxation time will be" (Leonard, 1990).*

ii. Relaxation Time and Oscillation/Equillibrium

"Relaxation time becomes a serious problem for a system when the relaxation time is, on the whole, longer than the time between disturbances. Systems can only learn and adapt when they can recognize when they have returned to equilibrium. If the rate of disturbances overtakes relaxation time uncontrolled oscillation or a crisis pattern of response will occur and planning will be likely to be wrong or ineffectual. If the system cannot recognize its state of equilibrium, due to inadequate relaxation time it may not recognize when it is entering a region of instability which could result in catastrophe" (Leonard, 1990).

i. Anja Reissberg

i. Explicitly Linking Relaxation Time to System Viability

"Ultimately, the requirement for viability is that the Algedonic Alarms have to be fixed within the relaxation time for the HHMS to remain viable. For example, the relaxation time for Level of Recursion 1 is the annual cycle along the mentioned exercises, for Level of Recursion 3 could be the training status, measured monthly and set subjectively. For the HHMS, a constant alarm signal would sound and would be loud. The HHMS in its current status is certainly not viable, due to its many deficiencies" (Reissberg, 2010).

Note: HHMS stands for Hurricane Hazard Management System

A-24. Requisite Hierarchy

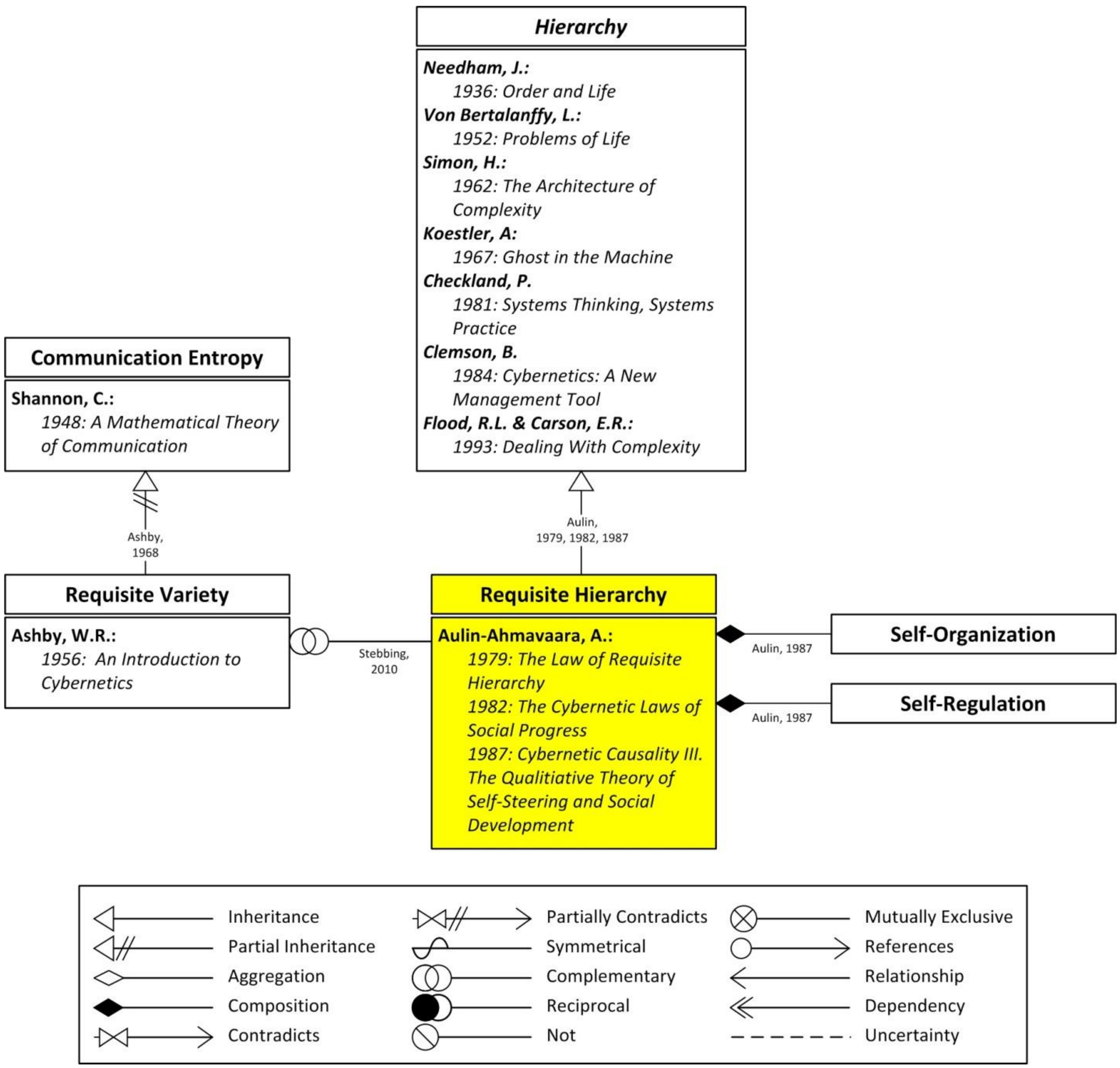

Figure A-29: Concept Model of Requisite Hierarchy

■ Definition

Requisite Hierarchy: A lack of regulatory ability within a system can be compensated for, to some extent, by increased hierarchy in its organizational structure (Aulin-Ahmavaara, 1979)

■ Commentary

The concept of Requisite Hierarchy is a complementary process that emerged from Ashby's Law of Requisite Variety. Interestingly, it suggests that greater hierarchy can compensate for high variety, and that as a society begins to stabilize, its hierarchy can be greatly compressed or flattened because of ‘variety dampening’ efficiencies that are bred into the system.

- **Contributing Scholars**

a. Arvid Aulin-Ahmavaara:

i. Law of Requisite Hierarchy

(1) “The weaker the average regulatory ability and the larger the average uncertainty of available regulators, the more requisite hierarchy is needed in the organization of regulation and control for the same result of regulation” (Aulin-Ahmavaara, 1979).

(2) “In view of the Law of Requisite Hierarchy, social hierarchy including the class differences can be eliminated with the progress of productive forces without risking the survival of human community; however, the pace at which this kind of human emancipation can materialize is strictly determined by the advancement of productive forces, allowing no ”leap” straight into a classless society but only gradual, relative steps” (Aulin, 1982).

ii. Requisite Hierarchy: Linked to Requisite Variety, Self-Organization, and Self-Regulation

“The laws of requisite variety and requisite hierarchy are connected with a stochastic process of self-organization in complex self-regulating actors and actor-hierarchies, respectively” (Aulin, 1987).

iii. Requisite Hierarchy and the Comte-Pareto Hypothesis

“In a society with a developing economic system the effective regulatory ability of the economic system increases on average, improving the means of survival of the population and at the same time as the need for hierarchy decreases (the law of requisite hierarchy for developing economic systems). As a consequence there is, in a society with a developing economic system, a favorable situation where internal social hierarchy can be dismantled or relaxed without jeopardizing the growth of security of the population. The emergence of such a situation for the first time in human history surely has been a remarkable turning point. Thus, the law of requisite hierarchy supports the 'Comte-Pareto hypothesis', stated by Auguste Comte at the beginning of the nineteenth century and completed by Vilfredo Pareto towards the end of it, to the effect that the history of human societies can be divided into two great developmental periods that are qualitatively different from each other” (Aulin, 1987, pp. 124-125).

b. Kevin Adams & Charles Keating

i. Requisite Hierarchy

(1) *"The Law of Requisite Hierarchy states that regulatory ability can be compensated for, up to a certain amount, by a greater hierarchy in organization"* (Adams & Keating, 2012, p. 47).

(2) *"The weaker in average are the regulatory abilities and the larger the uncertainties of available regulators, the more hierarchy is needed in the organization of regulation and control to attain the same result, if possible at all"* (Adams & Keating, 2012, p. 49).

References Aulin-Ahmavaara, A. (1979). The Law of Requisite Hierarchy. Kybernetes, 8(4), 259-266.

c. Lars Skytner

i. Requisite Hierarchy

"The weaker and more uncertain the regulatory capability, the more hierarchy is needed in the organization of regulation and control to get the same result" (Skyttner, 2005, p. 100).

References Aulin-Ahmavaara, A. (1979). The Law of Requisite Hierarchy. Kybernetes, 8(4), 259-266.

d. Tony Stebbing

i. Requisite Hierarchy as Complementary to Requisite Variety

"The Finnish cyberneticist, A.Y. Aulin-Ahmavaara extended Ashby's thinking with her complementary Law of Requisite Hierarchy. She stated that 'the lack of regulatory capacity can be compensated for [...] by greater hierarchy in the organization'. For simplicity, Aulin assumed that a number of mechanisms at different levels within a hierarchy each have an equal capacity to respond to perturbation. [...] The capacity of a hierarchy to resist disturbances is assumed by Aulin to be the sum of the responses of the levels in the hierarchy of the control mechanism" (Stebbing, 2010).

e. A.K. Kononpka

i. Requisite Hierarchy and Requisite Variety

"Ashby formulated the law of requisite variety for adaptive systems, the principle that every dynamic system will self-organize, and the requirement that every regulator of a system

must also be a model of that system. Aulin proposed a similar law of requisite hierarchy governing both control systems and societies" (Konopka, 2015).

f. R. Felix Geyer and Johannes van der Zouwen

i. Application of Requisite Hierarchy

"Aulin followed a cybernetic line of reasoning that argues for nonhierarchical forms of steering. Ashby's Law of Requisite Variety indeed implies a Law of Requisite Hierarchy in the case where only the survival of the system is considered (i.e., if the regulatory ability of the regulators is assumed to remain constant). However, the need for hierarchy decreases if this regulatory ability itself improves-which is indeed the case in advanced industrial societies, with their well-developed productive forces and correspondingly advanced distribution apparatus (the market mechanism). Since human societies are not simply self-regulating systems, but self-steering systems aiming at an enlargement of their domain of self-steering, there is a possibility nowadays, at least in sufficiently advanced industrial societies, for a coexistence of societal governability with ever less control, centralized planning, and concentration of power" (Geyer & Van Der Zouwen, 1992).

g. Gunilla Bradley

i. Information Communication Technologies, Work Organizations, and Society (3273-3284)

"The present trend toward the flattening of hierarchies can, according to Aulin's law of requisite hierarchy, be explained by the increasing regulatory abilities of individuals and organizations, due to such factors as better education, management and technological support. Another way to express this is that hierarchical regulation and hierarchical organizations are built into information systems and ICT" (Bradley, 2008).

h. Carlos Gershenson

i. Requisite Hierarchy and Multiscale Analysis

"Ashby's law of requisite variety (Ashby, 1956) tells us that a system needs to have proportional variety of actions to respond to the variety of perturbations from its environment (the word variety here could be substituted for the word complexity). A hierarchy could also be necessary for coping with environmental complexity (Aulin, 1979). Multiscale analysis (Bar-Yam, 2005) is a formal tool that can be used to determine when a hierarchy is required. Basically, if the complexity of an environment cannot be coped with by individual agents, these need to aggregate and coordinate to cope collectively. The

organizational relations between agents lead naturally to hierarchies, in the sense that some agents will tell other agents what to do" (Gershenson, 2007).

i. Francis Heylighen and Cliff Joslyn

i. Challenges of Increased Layers of Hierarchy

"A control loop will reduce the variety of perturbations, but it will in general not be able to eliminate all variation. Adding a control loop on top of the original loop may eliminate the residual variety, but if that is not sufficient, another hierarchical level may be needed. The required number of levels therefore depends on the regulatory ability of the individual control loops: the weaker that ability, the more hierarchy is needed. This is Aulin's law of requisite hierarchy. On the other hand, increasing the number of levels has a negative effect on the overall regulatory ability, since the more levels the perception and action signals have to pass through, the more they are likely to suffer from noise, corruption, or delays. Therefore, if possible, it is best to maximize the regulatory ability of a single layer, and thus minimize the number of requisite layers. This principle has important applications for social organizations, which have a tendency to multiply the number of bureaucratic levels. The present trend towards the flattening of hierarchies can be explained by the increasing regulatory abilities of individuals and organizations, due to better education, management and technological support" (Heylighen & Joslyn, 2001).

A-25. Requisite Parsimony

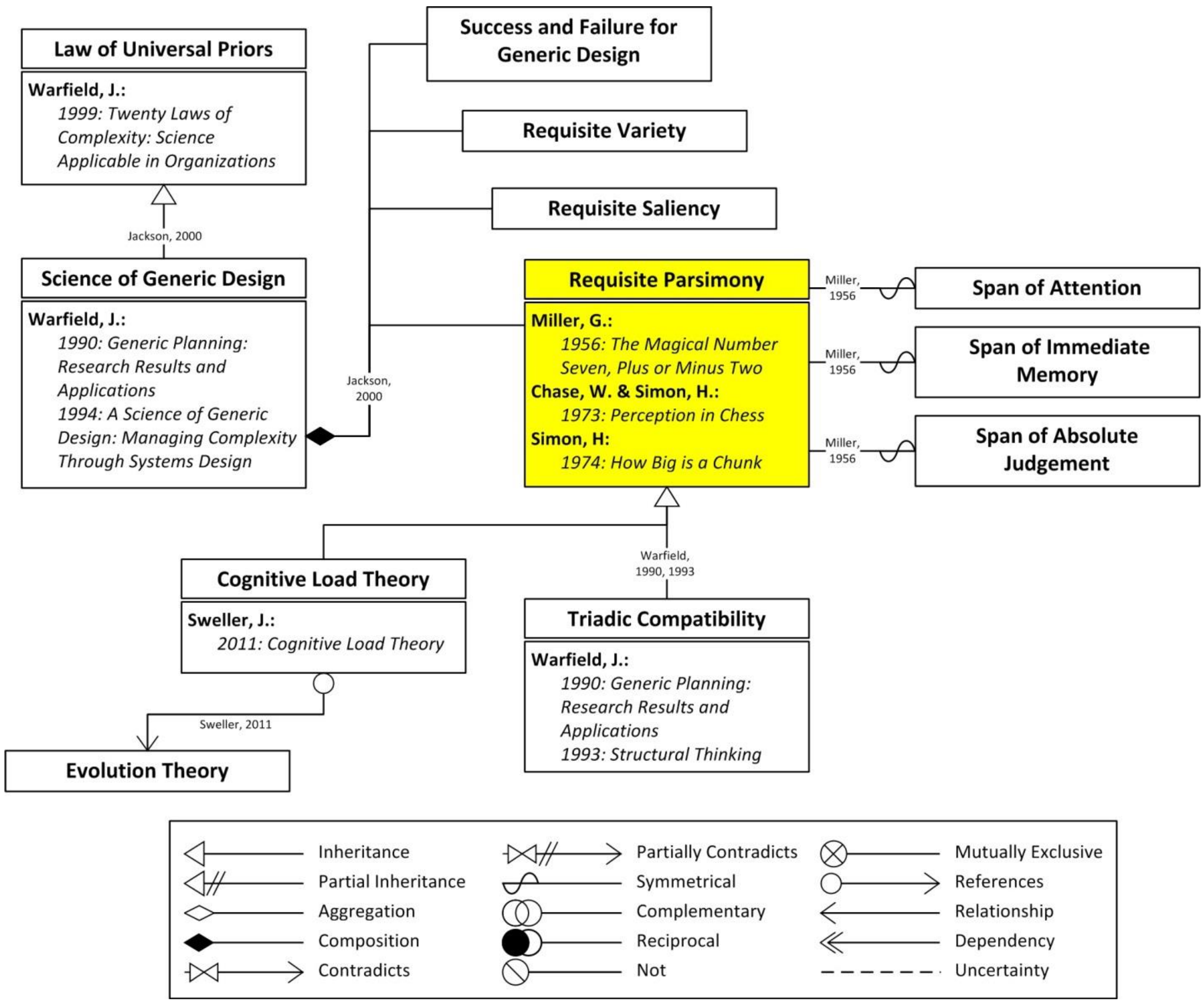

Figure A-30: Concept Model of Requisite Parsimony

■ Definition

Requisite Parsimony: The theory that a normal person can successfully manage between 5 and 9 concepts in their short term memory.(Miller G. , 1956)

■ Commentary

Requisite Parsimony suggests that a normal person can manage between five and nine concepts in his or her short term memory. Miller's work in this field contributed to the 1973 work of Chase and Simon on "chunking" and was followed in 1976 by Sweller's Cognitive Load Theory, and in 1994 by Paas and van Merrienboer's Germain Cognitive Load.

■ Contributing Scholars

a. George Miller

i. Human Channel Capacity

"Now let us see where we are. First, the channel capacity does seem to be a valid notion for describing human observers. Second, the channel capacities measured for these unidimensional variables range from 1.6 bits for curvature to 3.9 bits for positions in an interval. Although there is no question that the differences among the variables are real and meaningful, the more impressive fact to me is their considerable similarity. If I take the best estimates I can get of the channel capacities for all the stimulus variables I have mentioned, the mean is 2.6 bits and the standard deviation is only 0.6 bit. In terms of distinguishable alternatives, this mean corresponds to about 6.5 categories, one standard deviation includes from 4 to 10 categories, and the total range is from 3 to 15 categories. Considering the wide variety of different variables that have been studied, I find this to be a remarkably narrow range" (Miller, 1956).

ii. Span of Absolute Judgment

"There is a clear and definite limit to the accuracy with which we can identify absolutely the magnitude of a unidimensional stimulus variable. I would propose to call this limit the span of absolute judgment, and I maintain that for unidimensional judgments this span is usually somewhere in the neighborhood of seven. We are not completely at the mercy of this limited span, however, because we have a variety of techniques for getting around it and increasing the accuracy of our judgments. The three most important of these devices are (a) to make relative rather than absolute judgments.; or, if that is not possible, (b) to increase the number of dimensions along which the stimuli can differ; or (c) to arrange the task in such a way that we make a sequence of several absolute judgments in a row" (Miller, 1956).

iii. Mental Organization as a Tool for Understanding

"First, the span of absolute judgment and the span of immediate memory impose severe limitations on the amount of information that we are able to receive, process, and remember. By organizing the stimulus input simultaneously into several dimensions and successively into a sequence of chunks, we manage to break (or at least stretch) this informational bottleneck" (Miller, 1956).

iv. The Bit and the Chunk

"The contrast of the terms bit and chunk also serves to highlight the fact that we are not very delicate about what constitutes a chunk of information. For example, the memory span of five words that Hayes obtained [...] might just as appropriately been called a memory span of 15 phonemes, since each word had about three phonemes in it " (Miller, 1956).

b. William Chase and Herb Simon

i. Chunks and Chess

"There was a sharp dropoff in this ability for players below the master level. This result could not be attributed to the masters' generally superior memory ability, for when chess positions were constructed by placing the same numbers of pieces randomly on the board, the masters could then do no better in reconstructing them than weaker players, Hence, the masters appear to be constrained by the same severe short-term memory limits as everyone else (Miller, 1956), and their superior performance with "meaningful' positions must lie in their ability to perceive structure in such positions and encode them in chunks" (Chase & Simon, 1973).

c. Herb Simon

i. Chunking

"I have now reviewed two basic hypothesis: that short-term memory holds a fixed number of chunks and that total learning time is proportional to the number of chunks to be assembled. The weakness of each hypothesis lies in its inability to provide an independent operational definition of the chunk. But by conjoining the two hypothesis, one removes the need for a priori assumptions about what constitutes a chunk" (Simon H. A., How Big is a Chunk, 1974).

d. John Warfield

i. Triadic Compatibility (A Successor of Requisite Parsimony)

"The human mind is compatible with the demand to explore interactions among a set of three elements, because it can recall and operate with seven concepts, these being the three elements and their four combinations; but capacity cannot be presumed for a set that both has four members and for which those members interact" (Warfield, 1993).

References:

(1) G. A. Miller (1956), "The Magical Number Seven, Plus or Minus Two: Some Limitations on Our Capacity for Processing Information", Psychology Review 63(2), 81 -97.

(2) H. A. Simon (1974), "How Big is a Chunk?", Science 183, 482-488.

(3) J. N. Warfield (1988), "The Magical Number Three--Plus or Minus Zero", Cybernetics and Systems 19, 339-358.

ii. Requisite Parsimony and Triadic Compatibility

"This law is based on the dynamics of interpreting and learning implied by the Law of Triadic Compatibility. The Law is prescriptive, with the aim of allowing enough time for sequentially-presented information to be interpreted in terms of the interactions, and to allow enough listening time to help ensure that the information is remembered" (Warfield, 1993).

iii. Requisite Parsimony

"Every individual's short-term brain activity lends itself to dealing simultaneously with approximately seven items.[...] Attempts to go beyond this scope of reasoning are met with physiological and psychological Limits that preclude sound reasoning. For a given designer, there is some number K_d that is characteristic of that designer which typically is chosen from the set (5,6,7,8,9) that represents the Limit of that designer's short-term idea-processing capability. If a design methodology requires a designer to cope intellectually at any one time with some number of concepts K_c, then

i) If $K_c < K_d$, the designer is underburdened, being uninfluenced by the Law of Requisite Parsimony, since the designer is operating in a Situation that exhibits the Requisite Parsimony, through regulation of the rate of flow of information to the designer as the designer engages in the design process

ii) If $K_c = K_d$, the designer is operating at the Limit of reasoning capability

iii) If $K_c > K_d$, the designer is overburdened and no reliance can be placed on the designer's decisions" (Warfield, 1993).

iv. Universal Priors

"The human being, language, reasoning through relationships, and archival representations are universal priors to science (i.e. there can be no science without each of them" (Warfield, 1999).

e. John Sweller

i. Cognitive Load Theory

"Obtaining information from others is the best way of acquiring knowledge according to the borrowing and organizing principle. If knowledge is not held in long-term memory, we must process information in working memory that is limited in capacity and duration when dealing with novel information according to the narrow limits of change principle" (Sweller, 2011).

ii. Cognitive Load Theory and Evolutionary Theory

"Cognitive load theory uses evolutionary theory to consider human cognitive architecture and uses that architecture to devise novel, instructional procedures. The theory assumes that knowledge can be divided into biologically primary knowledge that we have evolved to acquire and biologically secondary knowledge that is important for cultural reasons" (Sweller, 2011).

f. Michael C. Jackson

i. Science of Generic Design

"The Science of Generic Design addresses the management of complexity through systems design. Complexity can take two forms: "situational complexity", arising from the nature of that which is under study, and "cognitive complexity", arising from the limited information processing capacity of human beings (so that they are easily 'overwhelmed' by complexity)" (Jackson, 2000, p. 213).

ii. Science of Generic Design and Universal Priors

"SGD is underpinned, like all science, by 'four universal priors' relating to the human being, language, reasoning through relationships and means of archival representation. These four are brought together by Warfield (1994), into the "Law of Universal Priors" which asserts that: 'The human being, language, reasoning through relationships, and archival representations are universal priors to science (i.e. there can be no science without each of them) (p. 16). Warfield uses this law to establish the foundations of SGD" (Jackson, 2000, p. 213).

iii. Laws Related to Science of Generic Design

"The other four, "the law of success and failure for generic design", "the law of requisite variety", "the law of requisite parsimony", and "the law of requisite saliency" are intrinsic to

SGD. To give a flavor, the law of requisite parsimony indicates a need for "controlling the rate of presenting information for processing to the human mind, in order to avoid its overload during the Design Process" (Warfield, 1994)" (Jackson, 2000, p. 214).

Note: References Warfield, J. (1994) A Science of Generic Design: Managing Complexity Through Systems Design. Ames, IA: Iowa State Press.

g. Kevin Adams and Charles Keating

i. Elements Associated with the Principle

"The Law of Requisite Parsimony states that human beings can only deal simultaneously with between five and nine observations at one time. This is based on George Miller's seminal paper The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information (1956). In this paper Miller shows, through experimentation, three key interrelated elements of our ability to process information.

1. Span of Attention. *Experiments showed that when more than seven objects were presented the subjects were said to estimate and for less than seven objects they were said to subitize. The break point was at the number seven.*

2. Span of Immediate Memory. *He reports the fact that the span of immediate memory, for a variety of test materials, is about seven items in length.*

3. Span of Absolute Judgment. *This is the clear and definite limit based on the accuracy with which we can identify absolutely the magnitude. This is also in the neighborhood of seven"* (Adams & Keating, 2012).

A-26. Requisite Saliency

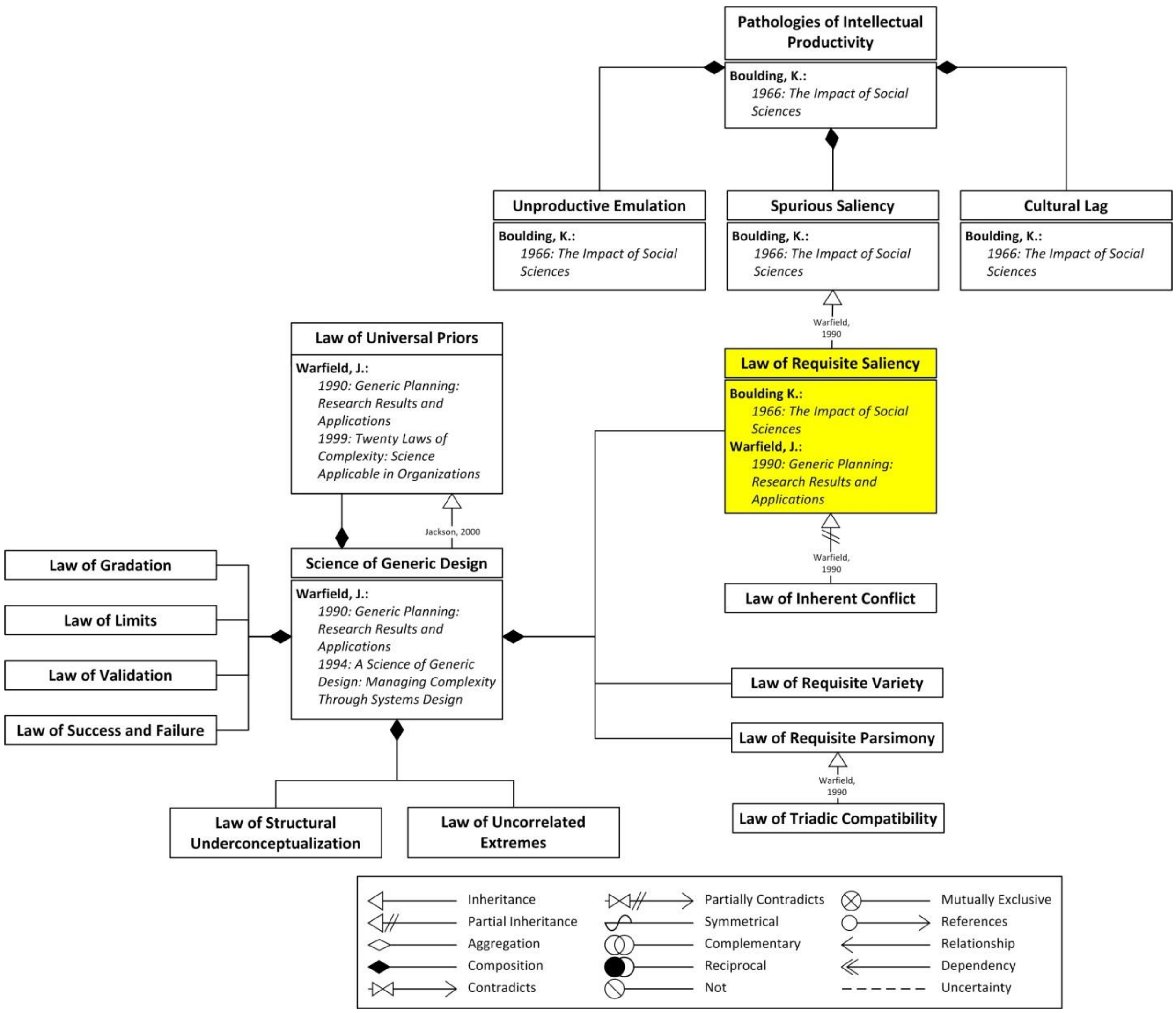

Figure A-31: Concept Model of Requisite Saliency

■ Definition

Requisite Saliency: Factors involved in system design are rarely of equal importance, and there is an underlying logic awaiting discovery that will reveal the relative saliency of each factor. (Warfield, 1995)

■ Commentary

The concept of spurious saliency originates with Kenneth Boulding and is one of three factors contributing to poor intellectual productivity (along with unproductive emulation and cultural lag). It appears that John Warfield was responsible for moving the concept of spurious saliency to its current nomenclature as *requisite saliency* within the domain of his Science of Generic Design.

■ Contributing Scholars

a. Kenneth Boulding

i. Origination of Spurious Saliency

Three processes act "to pervert the allocation of resources, especially intellectual resources", These are "self-justifying and unproductive emulation", "cultural lag", and "spurious saliency" (Boulding, 1966).

ii. Saliency

"What I have done about it is to write this book, in the endeavour to make the problem of saliency salient. Once a problem has been perceived, the arts of rhetoric ought to be called into play to make it salient. To these arts of rhetoric I recommend my fellow social scientists, however distasteful this may be to them" (Boulding, 1966).

b. Kenneth Underwood

i. Application of Spurious Saliency

"But genuine problems are inherent in this state of affairs, particularly at the point of "selective imbalance." For, unlike Buridan's ass, the university has often appeared all too willing to partake of every possibility when the price was right, or has been moved by what Kenneth Boulding calls "spurious saliency" in which the "dramatic quality of events" dictates university research and teaching, rather than their actual or intrinsic importance in the social system" (Underwood, 1969).

c. John Warfield

i. Spurious Saliency

"One consequence of this is that taxonomies tend to become the slaves of relations instead of the master. Put another way, it is often easy to establish a relation in detail and build upon it, while not addressing the question as to whether the relation is relevant to broad issues. Boulding[9] suggests the term "spurious saliency" for such efforts" (Warfield, 1973, p. 193).

ii. Referencing Boulding's Spurious Saliency

(1) "Kenneth Boulding identified three major reasons for poor intellectual productivity. These are: spurious saliency (emphasizing the wrong things, out of proportion to what

they deserve); unproductive emulation (behaving like those who help create rather than resolve problems); and cultural lag (not using established knowledge with dispatch)" (Warfield, 1993).

(2) *"In a wonderful book, Kenneth Boulding identified "spurious saliency" as one of the three primary reasons for poor intellectual productivity. Spurious saliency generally refers to a practice of misperceiving the relative importance which well-designed criteria would suggest should be attached to different situations from a particular set. Yntema and Mueser described results from psychology showing that individuals could do a lot better at dealing with several attributes of a single entity than they could in dealing with one attribute of several entities. Misassignment of saliency apparently reflects a frequently-made error. This can be described as the result of behavior that allows a superficial assessment to be made when several distinct entities are involved" (Warfield, 1995).*

iii. Requisite Saliency

"The situational factors that require consideration in developing a design Target and introducing it in a Design Situation are seldom of equal saliency. Instead there is an underlying logic awaiting discovery in each Design Situation that will reveal the relative saliency of these factors" (Warfield, 1993).

References:

(1) Kenneth Boulding (1966) The Impact of the Social Sciences, New Brunswick: Rutgers University Press.

(2) J. N. Warfield (1990) A Science of Generic Design: Manaqinq Complexitv Throuqh Svstems Design, Salinas, CA: Intersystems, 1990

iv. Twelve Laws of Generic Design

*"**The Law of Gradation** asserts that any conceptual body of knowledge can be graded in stages, such that there is a simplest stage, a most comprehensive stage, and intermediate stages whose content lies between the extremes.*

***The Law of Universal Priors** asserts that the human being, language, reasoning through relationships, and archival representations are universal priors to all science, in that there can be no science that does not explicitly incorporate all of them in its corpus, and especially in its foundation.*

The Law of Inherent Conflict *asserts that if a group of people elects to work together to resolve a complex issue, there will be inherent conflict within the group concerning the relative significance of the factors involved in the issue and, moreover, the likelihood is very small that any two people will agree on the relative importance of the factors. Moreover, the stability of initially-held views of any group member, under the impact of taking part in the (Interpretive Structural Modeling) learning process (Warfield, 1976) that uncovers the patterns among the factors, will be very low (Kapelouzos, 1989).*

The Law of Limits *asserts that to any activity in the universe there corresponds a set of limits upon that activity, that determines the feasible extent of the activity.*

The Law of Validation *asserts that the validity of a science depends on substantial agreement within the scientific community of meaning at its highest grade; such as, meaning attained through definition by relationship (as opposed to definition by intension or extension).*

The Law of Success and Failure *asserts that there are seven critical factors in the success package for the generic design process. These factors are: empowered leadership, financial support, component availability, design environment, designer participation, documentation support, and design processes that coverage to informed agreement. Moreover, inadequacy in any one of these areas is sufficient to cause the process to fail.*

The Law of Requisite Saliency *asserts that the situational factors that require consideration in developing a design target and introducing it into a design situation are seldom of equal saliency. Instead there is a underlying logic awaiting systematic discovery in each design situation that will reveal the relative saliency of the factors.*

The Law of Requisite Variety *asserts that a match must be present between the dimensionality of the design situation and the dimensionality of the target of the design process. If such a match is not present as a design outcome, the outcome will be ineffective, either because the design is overspecified or because it is underspecified.*

The Law of Triadic Compatibility *asserts that the analysis of interactions involving conceptual triads is compatible with human mental limitations, while the analysis of larger sets is not mind-compatible.*

The Law of Structural Underconceptualization *asserts that any group that works to resolve any complex issue with which it is familiar will produce, at best, a highly underconceptualized version of the issue unless the process itself is designed to facilitate the group production of any hybrid structures that may underlie the issue.*

The Law of Requisite Parsimony *asserts that the rate at which information is presented to groups for processing in a planning and design process must be controlled in order to avoid conceptual overload.*

The Law of Uncorrelated Extremes *describes how the formal pattern of a complex issue that is developed early in the Interactive Management processes (i.e., "Pattern One") is correlated with the formal pattern of that same issue that is developed late in the Interactive Management processes (i.e., "Pattern Two"). The law asserts that the correlation between Pattern One and Pattern Two is essentially zero, due to the substantial learning that takes place during the process (Kapelouzos, 1989)"* (Warfield, 1990).

d. T.B. Ryan and J. Mothibi

i. Pathologies of Intellectual Productivity: Spurious Saliency, Unproductive Emulation and Cultural Lag

"The national norms problem, worldview problem and human behavioural constraints significantly aggravate issues identified by Boulding (1966) as the chronic diseases of intellectual productivity: spurious saliency, unproductive emulation, and cultural lag" (Ryan & Mothibi, 2000).

ii. Spurious Saliency

"Spurious saliency results in the emphasis of wrong things, out of proportion to what is deserved. Inability to understand the structural complexity of the problems of the nation results in striving to solve the wrong problems" (Ryan & Mothibi, 2000).

e. Kevin Adams and Charles Keating

i. Definition of the Principle

"The Law of Requisite Saliency: The factors that will be considered in a system design are seldom of equal importance. Instead, there is an underlying logic awaiting discovery in each system design that will reveal the saliency of these factors (Boulding, 1966)" (Adams & Keating, 2012).

ii. Importance to System Engineers

"Requisite Saliency is particularly important to systems engineers because they conduct trade-off analyses, solve problems, and process data into information and information into knowledge, on a routine basis. Saliency is a very valuable concept in simplifying design

choices, for example when systems engineers create alternative solution scenarios from a set of options" (Adams & Keating, 2012).

A-27. Requisite Variety

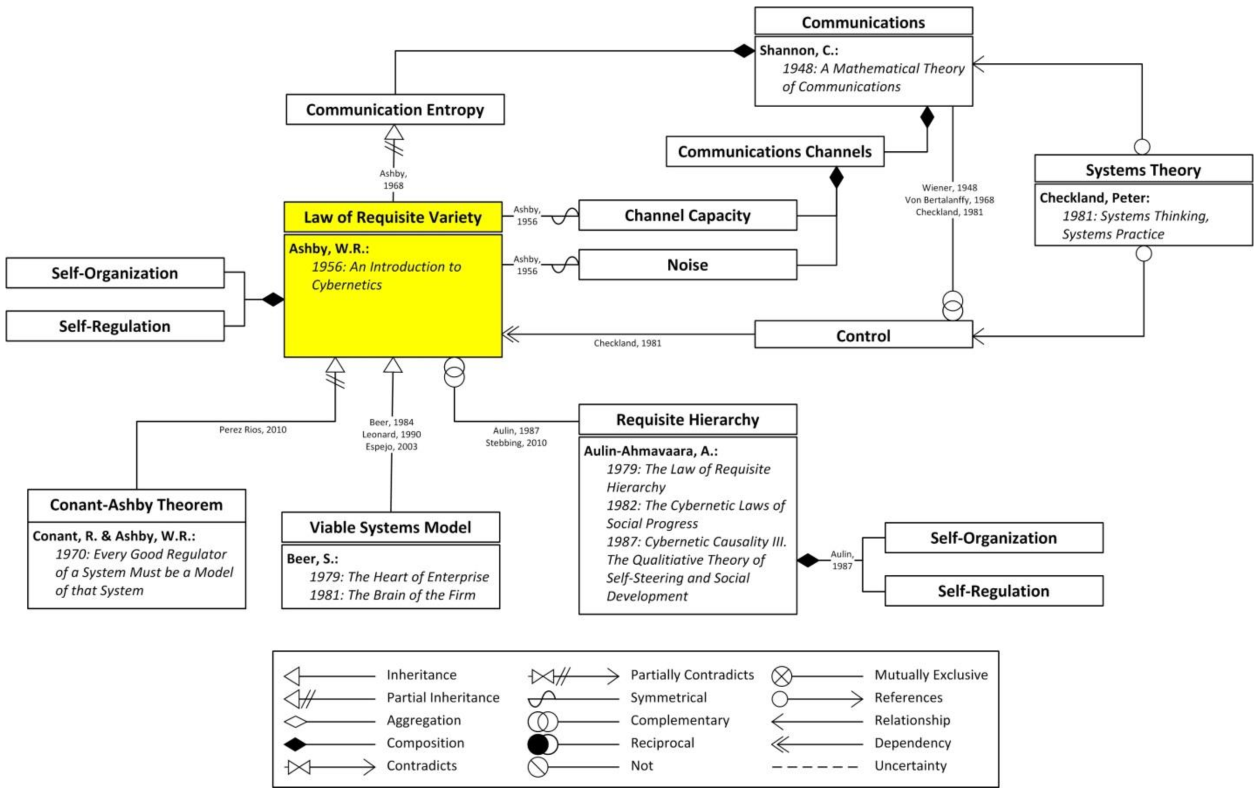

Figure A-32: Concept Model of Requisite Variety

■ Definition

Requisite Variety: The variety of a controller must match the variety of the system being controlled and the variety of the environment. (Ashby, 1956)

■ Contributing Scholars

a. W. Ross Ashby

i. Requisite Variety as Related to Regulation

(1) *"In this chapter we shall examine the process of regulation itself, with the aim of finding out exactly what is involved and implied. In particular we shall develop ways of measuring the amount or degree of regulation achieved, and we shall show that this amount has an upper limit"* (Ashby, 1956, p. 202).

(2) *"This is the law of Requisite Variety. To put it more picturesquely: only variety in R can force down the variety due to D;* ***variety can destroy variety****. This thesis is so fundamental in the general theory of regulation that I shall give some further*

illustrations and proofs before turning to consider its actual application" (Ashby, 1956, p. 207).

(3) *"We can now take up again the subject of regulation, ignored since the beginning of this chapter, for the law of Requisite Variety enables us to apply a measure to regulation"* (Ashby, 1956, p. 209).

ii. Requisite Variety and Channel Capacity

"The law of Requisite Variety says that R's capacity as a regulator cannot exceed R's capacity as a channel of communication. In the form just given, the law of Requisite Variety can be shown in exact relation to Shannon's Theorem 10, which says that if noise appears in a message, the amount of noise that can be removed by a correction channel is limited to the amount of information that can be carried by that channel" (Ashby, 1956, p. 211).

iii. Law of Requisite Variety and Noise/Communications Channels

"The answer can be given with some assurance, for all processes of regulation are dominated by the law of requisite variety. (It has been described in i". to C, Chapter 11 ; here will be given only such details as are necessary.) This law (of which Shannon's theorem 10 relating to the suppression of noise is a special case) says that if a certain quantity of disturbance is prevented by a regulator from reaching some essential variables, then that regulator must be capable of exerting at least that quantity of selection" (Ashby, 1952, p. 229).

iv. Amplification

"The possibility of such 'amplification' is well known in other ways. If a child wanted to discover the meanings of English words, and his father had only ten minutes available for instruction, the father would have two possible modes of action. One is to use the ten minutes in telling the child the meanings of as many words as can be described in that time. Clearly there is a limit to the number of words that can be so explained. This is the direct method. The indirect method is for the father to spend the ten minutes showing the child how to use a dictionary. At the end of the ten minutes the child is, in one sense, no better off ; for not a single word has been added to his vocabulary. Nevertheless the second method has a fundamental advantage; for in the future the number of words that the child can understand is no longer bounded by the limit imposed by the ten minutes. The reason is that if the information about meanings has to come through the father directly, it is limited to ten-minutes' worth; in the indirect method the information comes partly through the father

and partly through another channel (the dictionary) that the father's ten-minute act has made available" (Ashby, 1952, p. 236).

b. Paul Haynes

i. Requisite Variety and Modeling

"The application of a low-variety symbolic model to a particular situation requires that it be reinflated with data, thus increasing variety to a level commensurate with the state of the system under study. Similarly, the transition from plan making to implementation involves an increase in variety to meet the circumstances of societal control. The implication of Ashby's cybernetic law of requisite variety for planning is that the mechanism for controlling the systems with which planning deals must be capable of generating requisite variety to match those real world systems at the level of variety which is appropriate to secure an adequate level of performance" (Haynes, 1974, p. 12).

c. Peter Checkland

i. Requisite Variety and Control

"Some of Ashby's most important work has been his demonstration that continuing effective control in a changing environment requires a controller with a variety of response which can match the variety of the environmental information—the so-called Law of Requisite Variety" (Checkland, 1981, p. 88).

d. Stafford Beer

i. Requisite Variety and the Viable Systems Model

"What was perhaps novel, for the record, was the recognition that in the V.S.M. homeostats requisite variety applies in three distinct ways: to the blocks of variety homeostatically related, to the channels carrying information between them, and to the transducers relaying information across boundaries" (Beer, 1984, p. 12).

ii. Requisite Variety as Derived from Shannon's Communication

"Ashby saw his Law as bearing particularly on the second question, that of channel capacity, probably because he had derived it from Shannon's communication model which deals with the transmission of information. Indeed he comments that Shannon's Tenth Theorem is a special case of the law of Requisite Variety" (Beer, 1984, p. 12).

e. Arvid Aulin

i. Requisite Hierarchy and Requisite Variety

"The laws of requisite variety and requisite hierarchy are connected with a stoachastic process of self-organization in complex self-regulating actors and actor-hierarchies, respectively" (Aulin, 1987, p. 101).

f. Allenna Leonard

i. Management , Communication Filters, and the Viable Systems Model

"Supported in the proposals of self-organization and requisite variety from Ashby and (living) neural networks from Warren McCulloch, Stafford Beer developed the viable system model (VSM) as a model of a (human) social organization. A viable system is one that has the ability to keep its organization and therefore survive while adapting to environmental changes" (Leonard, 1990, p. 35).

ii. **What is Variety**

"Quite specifically variety is a measure of the number of possible states of a system" (Leonard, 1990, p. 60).

g. Raul Espejo

i. Requisite Variety and the Viable Systems Model

"Ross Ashby's Law of Requisite Variety is at the core of the VSM. Broadly speaking, this law states that a "controller" has requisite variety - that is, has the capacity to maintain the outcomes of a situation within a target set of desirable states - if and only if it has the capacity to produce responses to all those disturbances that are likely to take the outcomes out of the target set. In other words the situational variety must be equaled by the response variety of the controller" (Espejo, 2003).

h. Steve Maguire, Bill McKelvey, Laurent Mirabeau, and Nail Oztas

i. Requisite Variety and Managed Chaos

"Weick (1987) suggests that, analogous to Ashby's (1956) Law of Requisite Variety, organizations may need to match their environment's chaotic nature and become adaptive through 'chaotic acts' rather than 'orderly idleness'…" (Maguire, McKelvey, Mirabeau, & Oztas, 2006, pp. 172-173).

ii. Related to the Law of Excess Variety

"A reconciliation within organization studies may benefit by exploring the implications of Boisot and McKelvey's (2006) modernization of Ashby's Law of Requisite Variety that states firms need to develop internal complexity in the same measure as the imposing external complexity with which they are coping. Following Allen's (2001) extension of Ashby's Law to develop the Law of Excess Variety [Complexity], only excess internal complexity can destroy external complexity" (Maguire, McKelvey, Mirabeau, & Oztas, 2006, p. 202).

i. Carlos Gershenson

i. Requisite Variety and Feedback Control

"Feedback control, however, still requires that we have a sufficiently broad repertoire of counteractions at our disposal (requisite variety), and that we know which action to execute in which circumstances (requisite knowledge) (Heylighen and Joslyn, 2001)" (Gershenson, 2007, p. 20).

j. Jose Perez Rios

i. A Good Regulator Must Be A Good Model of the System

"Conant-Ashby theorem. Affirms: 'Every good regulator of a system must be a model of a system' (Conant and Ashby, 1970). In the context of evaluating the managers' decisions, this means that the quality of those decisions will be limited by the kind and quality of the models they use. Those models must have requisite variety to deal with the pertinent situation" (Perez Rios, 2010, p. 1531).

k. Roger Conant and Ross Ashby

i. Conant-Ashby Theorem (Good Regulator Theorem)

"Every good regulator of a system must be a model of that system" (Conant & Ashby, 1970).

l. Kevin Adams and Charles Keating

i. Variety

"Variety is a measure of complexity based on a mathematical relationship that computes the number of different possible system states that may exist" (Adams & Keating, 2012).

ii. Necessary Level of Variety in Design

"The Law of Requisite Variety simply says "variety can destroy variety" (Ashby, 1956, p. 207). For the systems engineer this means that a design must possess an amount of variety

that is at least equal to the variety of the problem being addressed. It implies that an individual or a group engaged in designing a solution to a SoSE problem can gain control over a design only by making appropriate specifications in all the dimensions of the design, thus reducing the variety (Adams & Keating, 2012).

m. Luz Arevalo and Angela Espinosa

i. Requisite Variety, Self-Organization, and the Viable Systems Model

"Supported in the proposals of self-organization and requisite variety from Ashby and (living) neural networks from Warren McCulloch, Stafford Beer developed the viable system model (VSM) as a model of a (human) social organization. A viable system is one that has the ability to keep its organization and therefore survive while adapting to environmental changes" (Arevalo & Espinosa, 2015, p. 26).

A-28. Resource Redundancy

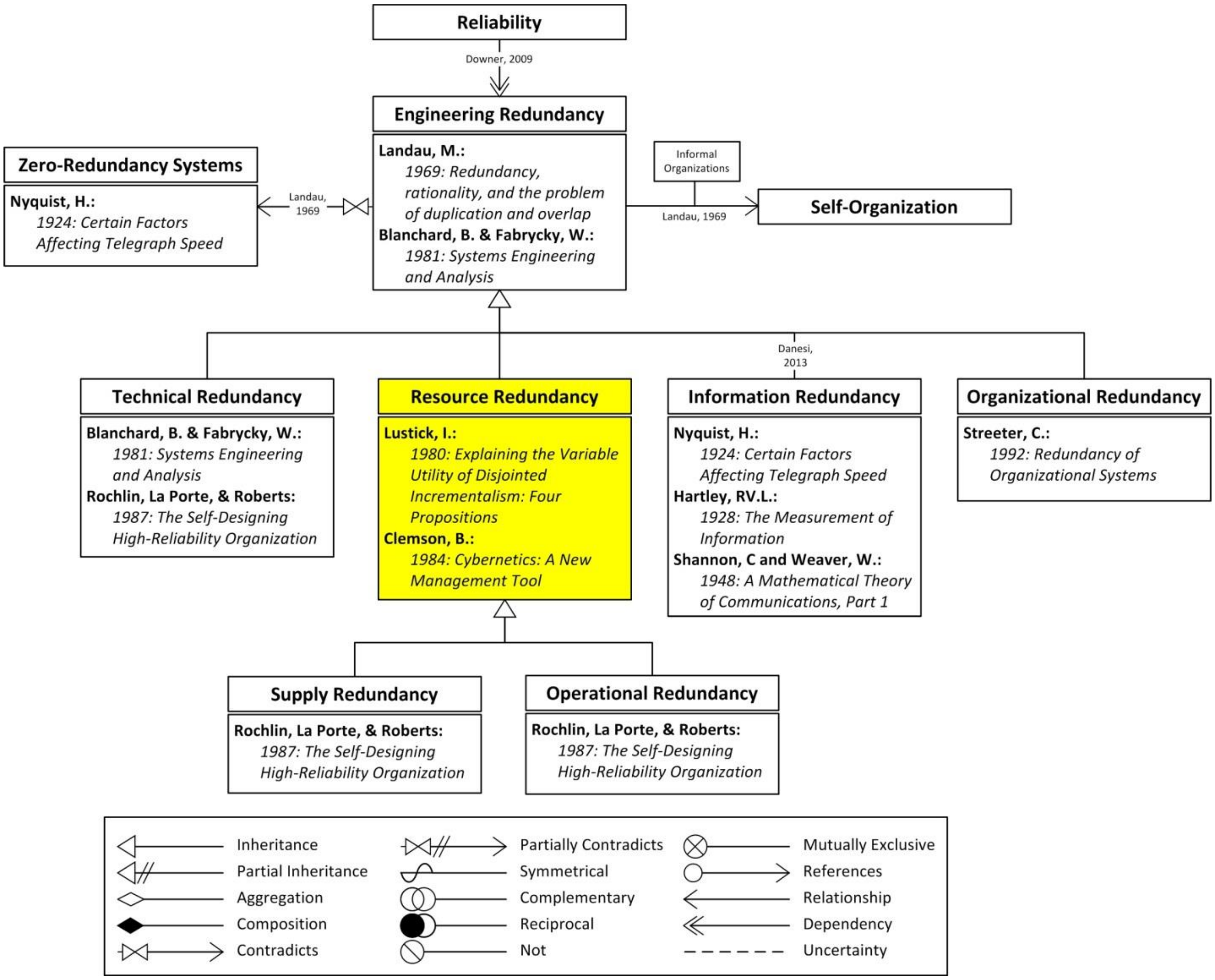

Figure A-33: Concept Model of Resource Redundancy

■ Definition

Resource Redundancy: Maintenance of stability under conditions of disturbance requires redundancy of critical resources (Clemson, 1984)

■ Commentary

In exploring this topic, it seems immediately odd that a redundancy of resources principle would warrant inclusion in a collection of general systems principles. This is not because resource redundancy is unimportant; in fact, it is noted as a key factor in reliability. On the contrary, the concern is not *why would redundancy of resources be included*? but rather, *why would all of the other elements of systems engineering be excluded?* In examining the material, it appears that this principle may have entered the domain of General Systems Theory by way of Barry Clemson, who suggested that it originated with Von Bertalanffy but provided no reference or supporting quotation.

Still, upon further study, the tree did bear some interesting fruit – particularly with the linkage to information redundancy that traces its origins to Nyquist (1924), Hartley (1928), and Shannon (1948), and the early principles of redundancy that originate with Martin Landau (1969).

■ Contributing Scholars

a. Leonard Schwartz

i. Redundancy, Reliability and Communication

"While the key to the reliable transmission of information is redundancy, in its simplest form redundancy is repetition" (Schwartz, 1966).

b. Martin Landau (Landau, 1969)

i. Linguistic Redundacy

"In the context of ordinary language, redundancy is said to exist whenever there is an excess or superfluity of anything. The excess may be of parts, of rules, of words, . . . of anything. Excess, as defined lexically, is some- thing which is more than the normal, the required, the usual, the specified. It is useless, superfluous, needless-terms which are variously employed to define redundancy" (Landau, 1969).

ii. Origination of Redundancy

"So powerful is this convention, that when Harry Nyquist introduced "redundancy" as a technical term in information theory, it referred to the useless portions of a message-those which could be eliminated without any loss of information" (Landau, 1969).

References J. R. Pierce, Symbols, Signals and Noise (New York: Harper, 1961), pp. 35-39.

iii. Technical Redundancy

"There is now a developing theory of redundancy, and while it was originally conceived of in the domains of information science (including computer technology) and natural automata (neural networks), it appears to have very wide application. In many areas, therefore, "over-engineering," "reserve power," and "safety-factors" of all sorts need no longer be dealt with intuitively" (Landau, 1969).

iv. Redundancy and Reliability

"This is the context in which the theory of redundancy bulks so large. For it sets aside the doctrine that ties the reliability of a system to the perfectability of parts and thereby approaches the pragmatics of systems in action much more realistically. That is, it accepts the inherent limitations of any organization by treating any and all parts, regardless of their degree of perfection, as risky actors" (Landau, 1969).

He notes in end note 22: "It is assumed, of course, that any component meets a specified standard of performance"

v. Redundancy as Self-Organization

"The appearance, therefore, of duplication and overlap in administrative agencies are not necessarily signs of waste and inefficiency. On the contrary, it is becoming increasingly evident that large-scale organizations function as self- organizing systems and tend to develop their own parallel circuits: not the least of which is the transformation of such "residual" parts as "informal groups" into constructive redundancies. Where we are sometimes prone to regard such groups as sources of pathology, they may be compensating for the deficiencies of the formal organization in the same way that the "boss" once did" (Landau, 1969).

c. Ian Lustick

i. Redundancy of Resources

"Indeed, an organization that believes its resources to be relatively abundant compared to the scale of the problems with which it is attempting to cope, can afford to adopt decision strategies which involve neither hope nor possibility of streamlining available resources to pursue direct, immediate, and narrowly "efficient" solutions. However, to the extent that an organization perceives its resources to be meagre and possibly inadequate to cope satisfactorily with the challenges of its task environment, then it will be less useful for that organization to adopt strategies of decision that assume the short-run "waste" of resources. That is, the less redundant are an organization's resources, the smaller the proportion of those resources will it rationally be willing to invest in learning processes that promise marginal improvements in future policies" (Lustick, 1980).

d. Barry Clemson

i. Redundancy of Resources

While Clemson references Von Bertalanffy, L. (1968) General Systems Theory as the source of this principle, I can find nothing explicit in the book that supports this assertion.

(1) "Maintenance of stability under conditions of disturbance requires redundancy of critical resources" (Clemson, 1984).

(2) "Maintenance of smooth internal operations and continuous progress toward overall objectives under conditions of disturbance requires redundancy of critical human and material resources" (Clemson, 1984).

e. Benjamin Blanchard and Wolter Fabrycky

i. Redundancy

"Under certain circumstances in system design it may be necessary to consider the use if redundancy to enhance system reliability by providing two or more functional paths (or channels of operation) in areas that are critical for successful mission accomplishment. But the application of redundancy per se will not necessarily solve all problems, because it usually implies increased weight and size, increased power consumption, greater complexity, and higher costs. Conversely, the use of redundancy may be the only solution for reliability improvement in specific situations" (Blanchard & Fabrycky, 1981, p. 389).

f. Charles Perrow

i. When Redundancy Backfires

"The Ranger flights, designed to survey the moon, had five out of nine failures. Ranger 6 failed, incidently, for a reason that should be familiar to u e a safety device. In order to make sure the television cameras would come on to take pictures of the moon's surface, there were redundant power supplies and triggering circuits. According to a Babcock and Wilcox engineer, a short in a safety device (a testing circuit) depleted the power supplies by the time the Ranger reached the moon. The engineer notes that the more redundancy is used to promote safety, the more chance for spurious actuation; 'redundancy is not always the correct design option to use'" (Perrow, 1984).

g. G.I. Rochlin, T.R. La Porte, and K.H. Roberts

i. Operational Redundancy

"Operational redundancy--the ability to provide for the execution of a task if the primary unit fails or falters--is necessary for high-reliability organizations to manage activities that are sufficiently dangerous to cause serious consequences in the event of operational failures" (Rochlin, La Porte, & Roberts, 1987).

ii. Technical Redundancy

"A primary form is technical redundancy involving operations-critical units or components on board--computers, radar antennas, etc. In any fighting ship, as much redundancy is built in as is practicable" (Rochlin, La Porte, & Roberts, 1987).

iii. Supply Redundancy

"Another form is supply redundancy. The ship must carry as many aircraft and spares as possible to keep its power projection and defensive capability at an effective level in the face of maintenance requirements and possible operational or combat losses" (Rochlin, La Porte, & Roberts, 1987).

h. Calvin Streeter

i. Four Types of Redundancy

"By combining the forms and roles, it is possible to identify four different types of redundancy. Table 1 illustrates the four types. Types 1 and 2 represent redundancies based on components designed to perform specific tasks, with additional specialized units designed into the system to monitor, control, or replace operating units when they fail. Types 3 and 4 represent a generalist, rather than a specialist, approach to system operation. Each part of the organization has the capacity to perform multiple (redundant) functions. When crises arise within the organization, it is able to reallocate existing resources to cover the functions of any failed component in the system.

FOUR TYPES OF REDUNDANCY BASED ON THE FORM AND ROLE OF REDUNDANCY

ROLE OF REDUNDANCY	**FORM OF REDUNDANCY**	
	Redundant Parts	Redundant Functions
Standby	Reserve Backup	Extraordinary Roles

	(Type 1)	(Type 3)
Active	Complementary Controls	Auxiliary Services
	(Type 2)	(Type4)

" (Streeter, 1992)

i. John Downer

i. Engineering Redundancy

In synthesizing Landau (1969), John Downer says *"The word redundancy has a specific meaning in engineering: one that is simultaneously similar and yet strangely at odds with its common usage. Both common and engineering usages imply some manner of 'repeating', but, where redundancy usually has negative connotations in its common usage – as something superfluous and excessive – in modern engineering it is equated with safety and integrity"* (Downer, 2009).

ii. Redundancy as Key to Reliability

"Redundancy is the single most important engineering tool for designing, implementing, and – importantly – proving reliability in all complex, safety-critical technologies. It is the sine qua non of ultra-high reliability engineering: deeply implicated in everything from bridges and skyscrapers to computer networks and power plants. Rochlin et al. (1987) identify it as a key strategy of successful high reliability organizations and speak disparagingly of 'mechanistic management models' that seek to eliminate it in the name of efficiency" (Downer, 2009).

iii. Redundancy and Risk Overcompensation

"A closely linked dimension of redundancy, and one even harder to quantify, lies in what Sagan refers to as 'overcompensation' (2004: 941). The extra security that redundancy offers, for example, can lead people to act less cautiously. Perrow echoes this claim. He suggests that people may have a 'risk homeostasis' in which they become accustomed to a specific level of risk and compensate for lower risks in one area by taking greater risks in another (e.g. Peltzman 1975; Perrow 1984: 171; Wilde 1994)" (Downer, 2009).

j. Marcel Danesi

i. Redundancy in Information Theory

(1) "Information theory was pioneered in the 1940s by CIaude Shannon, an electrical engineer at Bell Telephone Laboratories, who was primarily concerned with the

efficiency md clarity of radio, telephone, and telegraphic transmissions during the Second World War. [...]Shannon's investigations considered the effects of factors such as entropy (the randomness or disorder of the information or its source), interference ('noise' or distortion), data redundancy, channel capacity and transmission speed on the rate of errors in transmission - that is, how these factors affected the probability of an error-free transmission - and developed principles concerning the construction of binary codes that would minimize errors and maximize efficiency" (Danesi, 2013).

(2) "Shannon's work on 'information theory' built on research in Harry Nyquist's 1924 article 'Certain Factors Affecting Telegraph Speed,' published in the Bell Systems Technical Journal, which referred to what was transmitted over the telephone wire as 'information.' There are two basic factors governing the maximum speed of data transmission: first, the shape of a signal; and second, the choice of code used to represent the intelligence. Nyquist was able to measure the amount of intelligence that can be transmitted using an ideal code. Four years later and in the same journal, R.V.L. Hartley also an engineer, published 'The Measurement of Information', addressing the 'precision of the information' and the 'amount of information' in the transmission. Hartley argued that information exists in the transmission of symbols that convey 'certain meanings to the parties communicating.' When receiving information, the receipt of each symbol allows for the 'elimination' of other possible symbols and their associated meanings" (Danesi, 2013).

k. Kevin Adams and Charles Keating

i. Resource Redundancy

"Because systems operate in the real world, where they are subjected to externally imposed stress and disturbance, a level of redundancy must be established in order to maintain stability in the system. The ability to respond immediately to threats to system viability and essential operations requires resource levels for critical resources above the bare minimum for statistically normal operations. Establishing levels of redundancy in systems resources ensures that perturbations from the environment external to the system may be responded to without an interruption in system operations" (Adams & Keating, 2012).

A-29. Satisficing

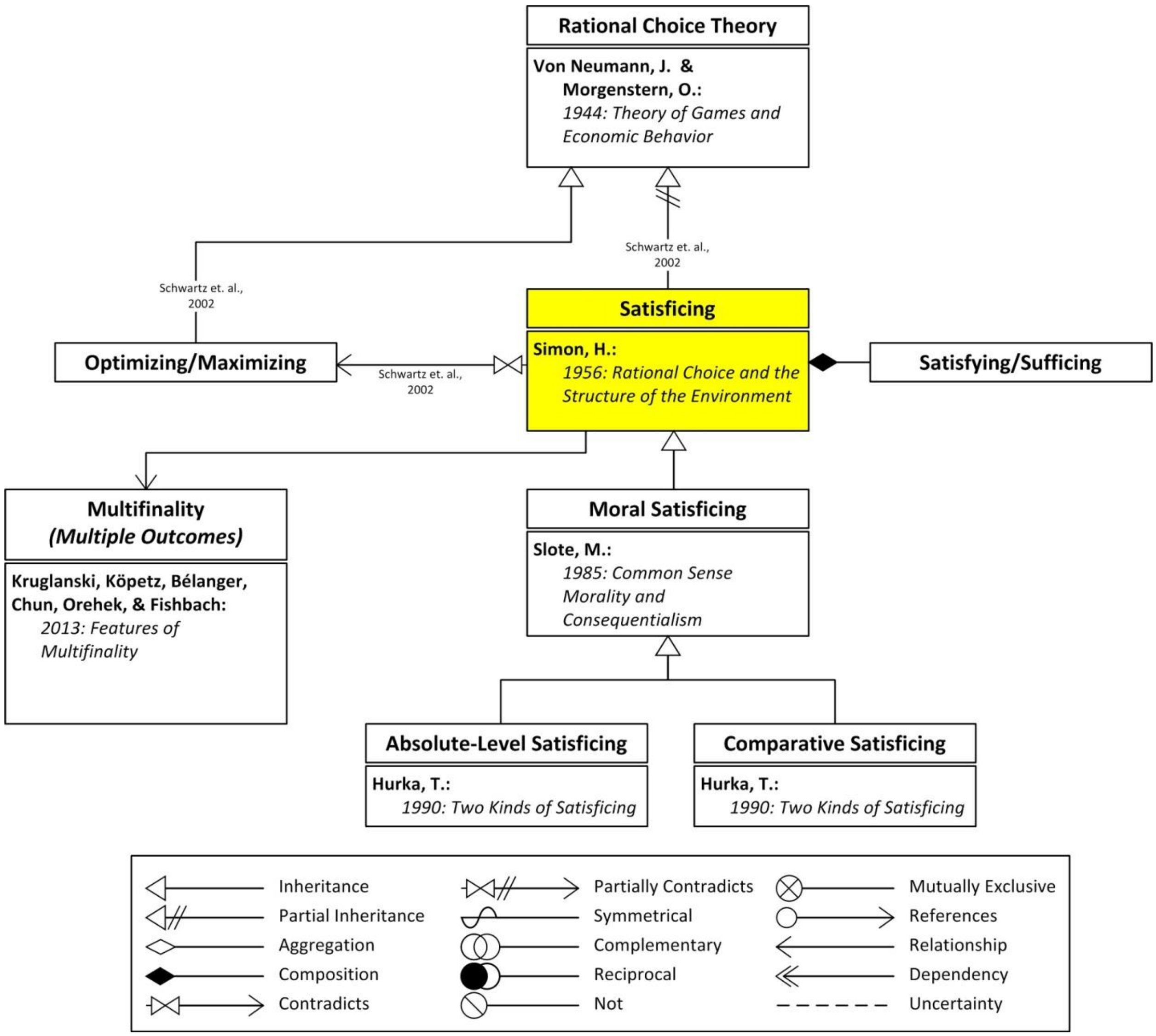

Figure A-34: Concept Model of Satisficing

■ Definition

Satisficing: Rather than optimizing, an organism will generally seek the first solution that adequately satisfies all of its needs. (Simon, 1956)

■ Commentary

When Herb Simon published the concept of satisficing in 1956, it created quite a stir within the administration and management communities. While a generally accepted alternative to optimizing behavior at this point, it was met with both criticism and acclaim when it was posited.

■ Contributing Scholars

a. Herb Simon

i. Origination and Relationship to Optimization

"Both from these scanty data and from an examination of the postulates of the economic models it appears probable that, however adaptive the behavior of organisms in learning and choice situations, this adaptiveness falls far short of the ideal of 'maximizing' postulated in economic theory. Evidently, organisms adapt well enough to 'satisfice', they do not, in general, 'optimize'" (Simon, 1956).

ii. Satisficing and (Alternate) Multifinality

"Since the organism, like those of the real world, has neither the senses nor the wits to discover an 'optimal' path – even assuming the concept of optimal to be clearly defined – we are concerned only with finding a choice mechanism that will lead it to pursue a 'satisficing' path, a path that will permit satisfaction at some specified level of all its needs" (Simon, 1956).

b. John Von Neumann and Oskar Morgenstern

i. Rational Choice Theory and Maximizing Decisions

"Let us now consider an isolated individual with definite physical characteristics and with definite quantities of goods at his disposal. In view of what was said above, he is in a position to determine the maximum utility which can be obtained in this situation. Since the maximum is a well-defined quantity, the same is true for the increase which occurs when a unit of any definite good is added to the stock of all goods in the possession of the individual. This is, of course, the classical notion of the marginal utility of a unit of the commodity in question. These quantities are clearly of decisive importance in the 'Robinson Crusoe' economy. The above marginal utility obviously corresponds to the maximum effort which he will be willing to make-if he behaves according to the customary criteria of rationality-in order to obtain a further unit of that commodity" (Von Neumann & Morgenstern, 1944).

c. C. West Churchman

i. On Misaligned Adaptation and Satisficing

"The adaptive system is not a reflective system. It only becomes so when it first whispers to itself "why don't I like it?" Sometimes the answer that is forthcoming is very simple and direct; for example, "because it hurts," or "I like it because I am in ecstacy." If there is pain,

then it isn't all right. If there is pleasure, it is all right. This is the childish adaptive system, beautiful in design, highly effective in its limited environment. Nature's gift is pain, a resource of infinite value in a world of complicated dangers. As the child becomes an adolescent he typically will ask, "what's wrong with pain?" He will be asking the next question of reflection, and he may well explore-or be forced to explore- the possibilities of adapting to pain. It is the initiation to manhood-this simple doubting of a dearly held principle of adaptation. So the young man substitutes honor, courage, fame, wealth, and now and then love, for the absence of pain. Or now and then evil-amorality, sadism, cruelty, criminality. In such an event we say that his adaptation went wrong. How does one tell oneself that his principle of adaptation is right? How can the satisficing man know that he is properly satisficed?" (Churchman, 1963).

d. Thomas Hurka

i. Moral Satisficing

"The most familiar such moralities are maximizing moralities. They characterize the right act as that which produces the most good, or has the best consequences. In these moralities an agent's duty is always to produce the most good possible. Recently, Michael Slote has defended an alternative that he calls satisficing consequentialism. Less demanding than maximizing, it requires only that agents produce consequences that are 'good enough'. Satisficing consequentialism selects a threshold of goodness in outcomes that is reasonable or satisfactory. Agents are morally bound to aim at outcomes that reach this threshold, but they are not bound beyond that. Although they may, if they wish, bring about outcomes that are more than satisfactory, they need not do so; and, if they do not, they are in no way at fault" (Hurka, 1990).

ii. Absolute-Level Satisficing

"On the first interpretation, satisficing selects its threshold of satisfactory goodness without reference to the alternatives an agent has. It selects some absolute level of goodness in outcomes as satisfactory, and requires agents to aim at that. When a situation is and will remain below the absolute threshold, an agent's duty is the same as under maximizing: she must do everything to move it towards satisfactory goodness. Once the threshold is reached, however, her duty vanishes. If a state of affairs is already, by absolute standards, reasonably good, she has no duty whatever to improve it" (Hurka, 1990).

iii. Comparative Satisficing

"The second interpretation is comparative. It says that an act's outcome is good enough if it is reasonably close to the best outcome the agent could have achieved. On this interpretation, an agent's duty is always but only to bring about some reasonable percentage of the greatest goodness she can, or to make some reasonable percentage of the largest contribution to goodness she can" (Hurka, 1990).

e. Barry Schwartz, Andrew Ward, John Monterosso, Sonja Lyubomirsky, Katherine White and Darrin R. Lehman

i. Satisficing as a Contradictory Child of Rational Choice Theory

"Simon argued that the presumed goal of maximization (or optimization) is virtually always unrealizable in real life, owing both to the complexity of the human environment and the limitations of human information processing. He suggested that in choice situations, people actually have the goal of "satisficing" rather than maximizing. To satisfice, people need only to be able to place goods on some scale in terms of the degree of satisfaction they will afford, and to have a threshold of acceptability. A satisficer simply encounters and evaluates goods until one is encountered that exceeds the acceptability threshold. That good is chosen. In subsequent, accidental encounters with other goods in the relevant domain, the scale of acceptability enables one to reject a formerly chosen good for a higher ranked one should that one turn up. A satisficer thus often moves in the direction of maximization without ever having it as a deliberate goal. Simon's alternative to rational choice theory questions not only the processes by which options are assessed and choices made, but also the motives that underlie choice. To satisfice is to pursue not the best option, but a good enough option" (Schwartz, Ward, Monterosso, Lyubomirsky, White, & Lehman, 2002).

A-30. Self-Organization

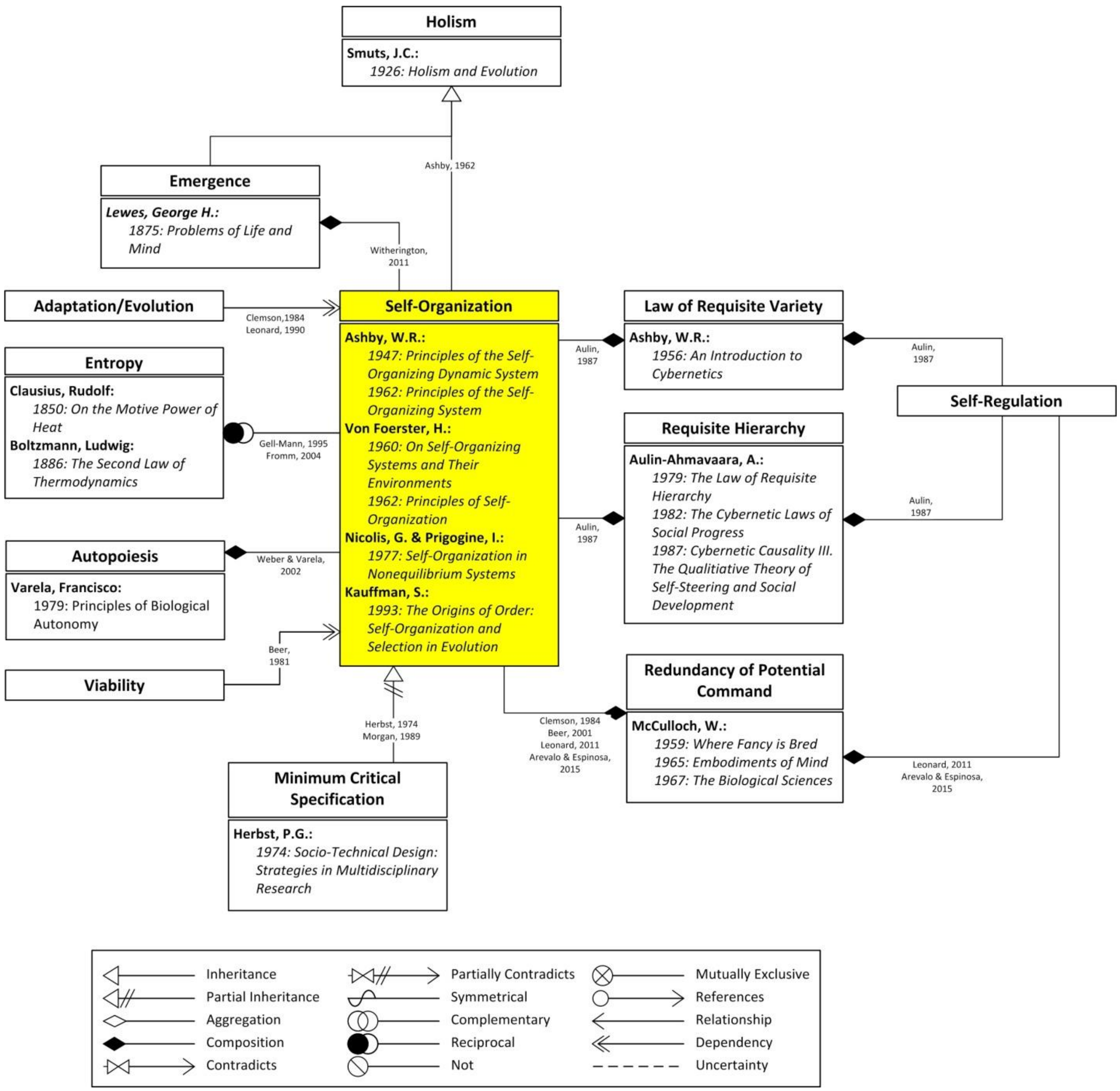

Figure A-35: Concept Model of Self-Organization

■ Definition

Self-Organization: The process by which a system moves beyond self-regulation, to alter its internal structure to increase its level of adaptability (Leonard, 1990)

Commentary

The principle of self-organization is constantly recurring in the examination of systems theory. This is demonstrated by the relatively central nature that the concept has within the diagram and by the fact that it is a compositional element in so many other principles.

Contributing Scholars

a. Jan Smuts (1926)

i. Holism as the Progenitor of Self-Organization

"Holism in all its endless forms is the principle which works up the raw material or unorganised energy units of the world, utilises, assimilates and organises them, endows them with specific structure and character and individuality, and finally with personality, and creates beauty and truth and value from them" (Smuts, 1926).

b. W. Ross Ashby

i. First Occurrence of Self-Organization in Print

"'Principles of the Self-Organizing Dynamic System,' Journal of General Psychology (1947) 37: 125-128 [First known occurrence of 'self-organizing' in print. Uses the same notion of organization as the above, and shows how it can apparently change if some of the variables are step-functions of the others.]" (http://bactra.org/notebooks/ashby.html)

ii. Self-Organization Through Holism

"There is a first meaning that is simple and unobjectionable. This refers to the system that starts with its parts separate (so that the behavior of each is independent of the others' states) and whose parts then act so that they change towards forming connections of some type. Such a system is "self-organizing" in the sense that it changes from 'parts separated' to 'parts joined'" (Ashby, 1962).

iii. Self-Organizing from 'Bad' to 'Good'

"'Organizing' may have the first meaning, just discussed, of 'changing from unorganized to organized'. But it may also mean 'changing from a bad organization to a good one', and this is the case I wish to discuss now, and more fully. This is the case of peculiar interest to us, for this is the case of the system that changes itself from a bad way of behaving to a good. A well known example is the child that starts with a brain organization that makes it fire-seeking; then a change occurs, and a new brain organization appears that makes the child fire-avoiding. Another example would occur if an automatic pilot and a plane were so coupled,

by mistake, that positive feedback made the whole error-aggravating rather than error-correcting. Here the organization is bad. The system would be 'self-organizing' if a change were automatically made to the feedback, changing it from positive to negative; then the whole would have changed from a bad organization to a good" (Ashby, 1962).

c. Barry Clemson

i. Self-Organization as an Agent of Change

"Every system of whatever size must maintain its own structure and must deal with a dynamic environment, i.e., the system must strike a proper balance between stability and change. The cybernetic mechanisms for stability (i.e., homeostasis, negative feedback, autopoiesis, equifinality) and change (i.e., positive feedback, algedonodes, self-organization) are found in all viable systems" (Clemson, 1984).

ii. Self-Organization and the Redundancy of Potential Command

"The decision making process within the organization will be largely self-organizing and in many cases the particular people involved will be unique to that particular decision situation (by the self-organization law and the redundancy of potential command law)" (Clemson, 1984, p. 148).

d. Arvid Aulin-Ahmavaara

i. Requisite Hierarchy, Requisite Variety, Self-Organization and Self-Regulation

"The laws of requisite variety and requisite hierarchy are connected with a stochastic process of self-organization in complex self-regulating actors and actor-hierarchies, respectively" (Aulin, 1987).

e. Gareth Morgan

i. Minimum Critical Specification Depends on Self-Organization

"The principle of minimum critical specification (Herbst, 1974/ Vol. II, "Designing With Minimal Critical Specifications") suggests that managers and organizational designers should primarily adopt a facilitating or orchestrating role, creating "enabling conditions" that allow a system to find its own form" (Morgan, 1989).

f. Allenna Leonard

i. Self-Organization and Adaptation

"A system may be said to be self-organizing if it can alter its internal structure to increase its level of adaptation. A self-organizing system may move beyond self-regulation to alter its feedback loops and sensory information. A self-organizing system may be seen as moving from a state in which its parts are separate to one where parts are joined but usually also includes a criteria of success based on a goal such as becoming better adapted to its environment. If the environment should change, the self-organizing system must change as well in order to remain adaptive" (Leonard, 1990).

g. Murray Gell-Mann

i. Self-Organization as the Reciprocal of Entropy

"The second law of thermodynamics, which requires average entropy (or disorder) to increase, does not in any way forbid local order from arising through various mechanisms of self-organization, which can turn accidents into frozen ones producing extensive regularities. Again, such mechanisms are not restricted to complex adaptive systems" (Gell-Mann, 1995).

h. A. Weber and F.J. Varela

i. Autopoiesis and Self-Organization

"Thus, autopoiesis is a singularity among self-organizing concepts in that it is on the one hand close to strictly empirical grounds, yet provides the decisive entry point into the origin of individuality and identity, connecting it, through multiple mediation with human lived body and experience, into the phenomenological realm" (Weber & Varela, 2002, p. 116).

i. Jean-Marie Lehn

i. Self-Organization and Emergence

"Understanding, inducing, and directing self-processes is key to unraveling the progressive emergence of complex matter. Self-organization is the driving force that led up to the evolution of the biological world from inanimate matter" (Lehn, 2002).

j. Jochen Fromm

i. Self-Organization and Increasing Complexity

(1) *"How can systems organize themselves to higher and higher levels of complexity in a process of self-organization? Although there is no central organizer, self-organizing systems are able to reach higher levels of complexity" (Fromm, 2004, p. 8).*

(2) *"Jean-Marie Lehn mentioned Self-Organization as the main reason for the emergence of complexity. Most complex systems can organize themselves even without a central organizer or central organizing authority, they show signs of Self-Organization. It is "as if all the ingredients in your kitchen somehow got together and baked themselves into a cake" as Bill Bryson has noticed [17]. But of course this won't happen. It only looks like this" (Fromm, 2004, p. 21).*

References Jean-Marie Lehn, Toward complex matter: Supramolecular chemistry and self-organization, PNAS 99 (2002), no. 8, 4763–4768.

ii. Self-Organization is Only in Open Systems

"A self-organized system needs a constant and continuous input of energy from the outside. It is able to dissipate energy and organization from the environment to create and built-up an artificial or abstract organizer in form of emergent critical states, attractors or whirls" (Fromm, 2004, p. 21).

iii. Self-Organization and Negative Entropy

"In isolated systems that exchange neither energy nor matter with their surroundings, the entropy continues to grow according to the second law of thermodynamics until it reaches its maximum value at what is called thermodynamic equilibrium. The opposite is self-organization: a system which tends to become more organized if it is left to itself" (Fromm, 2004, p. 34).

k. David C. Witherington

i. Emergence Through Self-Organization

"Emergence involves the spontaneous coming into being of new, irreducible patterns or forms in a system as a result of self-organizing interactions among the very components that comprise the system" (Witherington, 2011).

l. Kevin Adams & Charles Keating

i. Ashby and Self-Organization

"W. Ross Ashby [1903-1972] proposed what he called the principle of self-organization (1947). He noted that dynamic systems, independently of their type or composition, always tend to evolve towards a state of equilibrium. This reduces the uncertainty about the system's state, and if we view entropy as a function of statistics using Boltzmann's concepts, the system's statistical entropy is also reduced (i.e. equilibrium is an indication of order which has a corresponding decrease in entropy). The reduction in entropy can be regarded as being equivalent to self-organization. The resulting equilibrium can be interpreted as a state where the different parts of the system are mutually adapted" (Adams & Keating, 2012).

References: Ashby, R. (1947). Principles of the Self-Organizing Dynamic System. Journal of General Psychology, 37, 125-128.

ii. Von Foerster and Self-Organization

"Heinz von Foerster [1911-2002] formulated the principle of order from noise (1960). He noted that the larger the noise (his term for random perturbations) on a system, the more quickly it will become ordered. The increased order is, once again, self-organization. Von Foerster's concept is that the more widely a system is made to move through its state space, the more quickly it will end up in a state of equilibrium. If it would just stay in place, no equilibrium would be reached and self-organization would not occur. Prigogine proposed the related principle of order through fluctuations where non-linear systems have several equilibrium states or attractors. A system may reside in between attractors in a chance variation, called fluctuation that will push it either into the one or the other of the attractors" (Adams & Keating, 2012).

References:

(1) Von Foerster, H. (1960). On self-organizing systems and their environments. In M. Yovits & S. Cameron (Eds.), Self-Organizing Systems (pp. 30-50). London: Pergamon.

(2) Von Foerster, H., & Zopf, G. (Eds.). (1962). Principles of Self-Organization. New York: Pergamon.

(3) Kauffman, S. (1993). The Origins of Order: Self-Organization and Selection in Evolution. New York: Oxford University Press.

(4) Nicolis, G., & Prigogine, I. (1977). Self-organization in Nonequilibrium Systems: From Dissipative Structures to Order through Fluctuations. New York: John Wiley and Sons.

m. Luz E. Bohórquez Arévalo & Angela Espinosa

i. Self-Organization, Viability and Redundancy of Potential Command

"For Stafford Beer self-organization becomes the mechanism that ensures the viability or survival of a complex system. A system is self-organized when the information flow is distributed in such a way that the command center can be anywhere in the organization: this "redundancy of potential command" was originally postulated by McCulloch, and means that teams have distributed autonomy to take decisions at any time regarding the modes of action of the organization (Beer, 1981). A prerequisite for any self-organizing system is the redundancy of potential command (RPC)" (Arevalo & Espinosa, 2015).

ii. Self-Regulation and Variety Inhibitor (Requisite Variety)

"McCulloch (1965) explained in great detail self-organization as the most massive variety inhibitor. He explained the nature of reflexive and homeostatic mechanisms in the brain and the way that a 'neural-network' type of organization is goal directed, self-regulated and can achieve purposeful behaviors" (Arevalo & Espinosa, 2015).

A-31. Self-Regulation

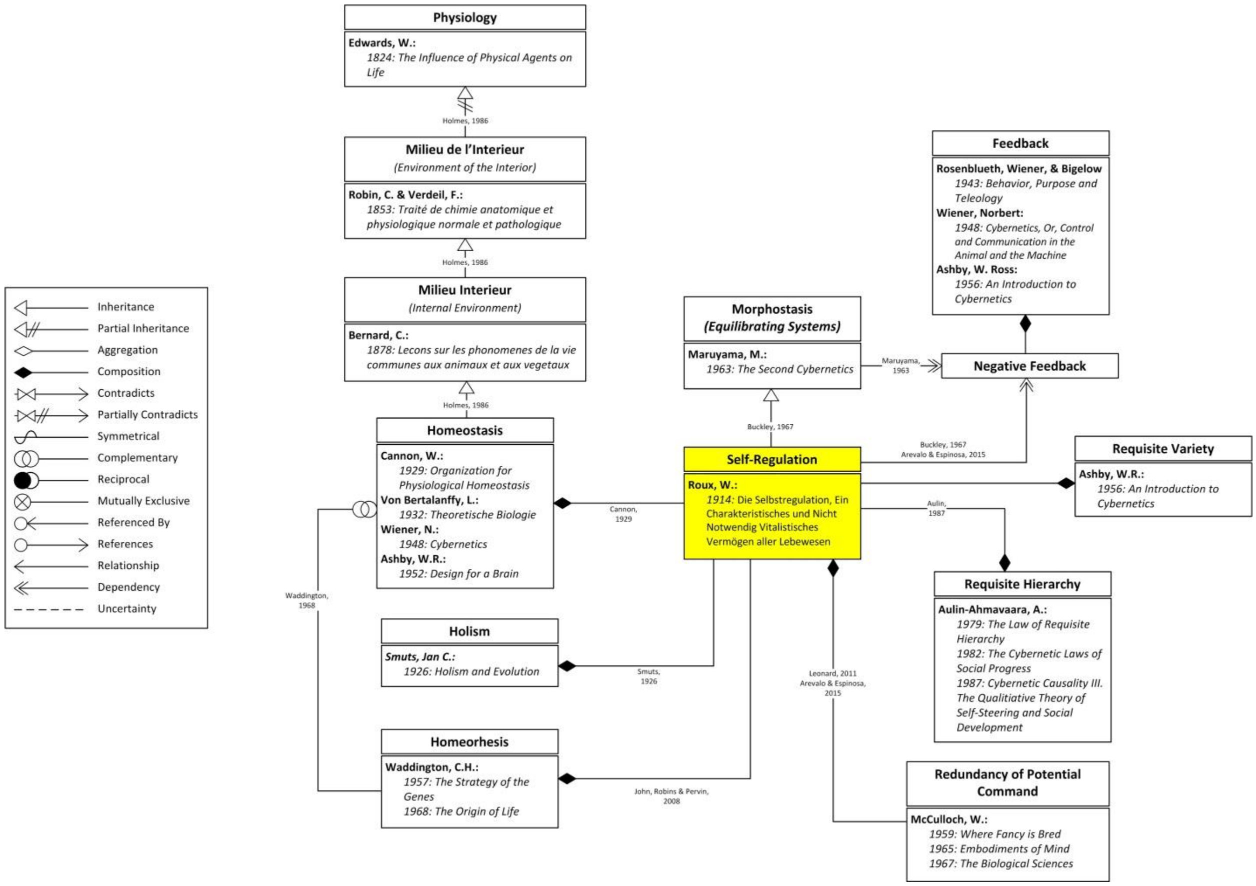

Figure A-36: Concept Model of Self-Regulation

■ Definition

Self-Regulation: The ability of living beings (or systems) to maintain their own stability in the face of the colossal, often adverse, forces which surround them (Cannon, 1929)

■ Commentary

While self-regulation is not included in the Adams/Keating catalog, its recurrence in the literature earned it examination as an independent concept.

■ Contributing Scholars

a. Wilhelm Roux

i. Earliest Reference

Roux, W. (1914). Die Selbstregulation, Ein Charakteristisches und Nicht Notwendig Vitalistisches Vermögen aller Lebewesen (The Self-Regulation, a Characteristic and Not Necessarily Vitalistic Capacity of All Organisms). Berlin: Halle Karras.

b. Jan Smuts

i. Self-Regulation and Holism

"The inner co-ordination and self-regulation in organisms which is the organic phase of Holism is indeed something marvellous, almost something miraculous" (Smuts, 1926).

c. Walter B. Cannon

i. Self-Regulation as Homeostasis

"Biologists have long been impressed by the ability of living beings to maintain their own stability. The idea that disease is cured by natural powers, by a vis medicatrix naturae, an idea which was held by Hippocrates, implies the existence of agencies ready to operate correctively when the normal state of the organism is upset. More precise modern references to self-regulatory arrangements are found in the writings of prominent physiologists. Pfluger (1877) recognized the natural adjustments leading toward the maintenance of a steady state of organisms when he laid down the dictum, "The cause of every need of a living being is also the cause of the satisfaction of the need." Similarly Fredericq (1885) declared, "The living being is an agency of such sort that each disturbing influence induces by itself the calling forth of compensatory activity to neutralize or repair the disturbance. The higher in the scale of living beings, the more numerous, the more perfect and the more complicated do these regulatory agencies become. They tend to free the organism completely from the unfavorable influences and changes occurring in the environment." Further, Richet (1900) emphasized the general phenomenon,-"The living being is stable. It must be in order not to be destroyed, dissolved or disintegrated by the colossal forces, often adverse, which surround it. By an apparent contradiction it maintains its stability only if it is excitable and capable of modifying itself according to external stimuli and adjusting its response to the stimulation. In a sense it is stable because it is modifiable; the slight instability is the necessary condition for the true stability of the organism" (Cannon, 1929).

d. Walter F. Buckley

i. Self-Regulation as a Morphostatic Function

"The classical principle of causality held that similar conditions produce similar effects, and consequently dissimilar results are due to dissimilar conditions. Bertalanffy, in analyzing the self-regulating, or morphostatic, features of open biological systems, loosened this classical conception by introducing the concept of "equifinality" (Buckley, 1967, p. 60).

ii. Self-Regulation as Morphostasis

"Some of the connotations of these concepts of "self-regulation" and the like are misleading, whether applied to modern machines, men, or groups, since the tendency is to overemphasize the independence of the internal system at the expense of situational or environmental variables. For this reason it might be profitable to utilize more neutral terms for the two basic processes of interest to us here, namely, morphostasis and morphogenesis. The former refers to those processes in complex system environment exchanges that tend to preserve or maintain a system's given form, organization, or state. Morphogenesis will refer to those processes which tend to elaborate or change a system's given form, structure, or state" (Buckley, 1967, p. 58).

iii. Self-Regulation and Feedback Loops

"True self-regulating feedback loops, then, constitute a higher level of interrelations of parts, and underlie the complex organization and dynamics of higher level adaptive systems" (Buckley, 1967, p. 70).

e. Arvid Aulin-Ahmavaara

i. Requisite Hierarchy: Linked to Requisite Variety, Self-Organization and Self-Regulation

"The laws of requisite variety and requisite hierarchy are connected with a stochastic process of self-organization in complex self-regulating actors and actor-hierarchies, respectively" (Aulin, 1987).

ii. Self-Regulating Actors forming a Hierarchy to provide Regulation and Control

"Thus we have shown that by arranging a number of complex self-regulating actors in a hierarchy of regulation and control, where some actors concentrate on regulation and others on control, the effective regulatory ability of this community of actors can be greatly improved. Let us call this kind of community actor-hierarchy. It is itself, of course, a complex self-regulating actor, a collective one" (Aulin, 1987).

f. R. Felix Geyer and Johannes van der Zouwen

i. Self-Regulation and Requisite Hierarchy

"Aulin followed a cybernetic line of reasoning that argues for nonhierarchical forms of steering. Ashby's Law of Requisite Variety indeed implies a Law of Requisite Hierarchy in the case where only the survival of the system is considered (i.e., if the regulatory ability of the regulators is assumed to remain constant). However, the need for hierarchy decreases if this regulatory ability itself improves-which is indeed the case in advanced industrial societies, with their well-developed productive forces and correspondingly advanced distribution apparatus (the market mechanism). Since human societies are not simply self-regulating systems, but self-steering systems aiming at an enlargement of their domain of self-steering, there is a possibility nowadays, at least in sufficiently advanced industrial societies, for a coexistence of societal governability with ever less control, centralized planning, and concentration of power" (Geyer & Van Der Zouwen, 1992).

g. Robert Louis Flood

i. Self-Regulation as a Fundamental Element of Cybernetics

"In particular, in Cybernetics and Management, Beer explains the concepts of cybernetics. He concludes that there are three main properties of a cybernetic system. They are exceedingly complex, probabilistic, and self-regulatory" (Flood R. , 1999).

h. Oliver P. John, Richard W. Robins, and Lawrence A. Pervin

i. Homeorhesis as Self-Regulation

"Waddington considered the tendency for the marble to maintain its initial course in the face of external pressures to be an analogue to a fundamental self-regulatory process in cell development, 'homeorhesis'" (John, Robins, & Pervin, 2008).

i. Allenna Leonard

i. Redundancy of Potential Command with Self-Organization and Self-Regulation

"It is well known that, although hub and spoke or tree structures are efficient for simple governance situations, heterarchies and networks are more robust when tasks and goals become more complex. Authority is not static but depends on the redundancy of potential command. It follows the relevant information. But many times, the way forward is not obvious. Then, the best strategy is to engage in dialogues and processes that allow people to pool their knowledge and move on from there. A practical step is to encourage approaches

that involve a high degree of self-organization and self-regulation" (Leonard, Governance in the Relative When, 2011).

j. Arie Kruglanski, Catalina Köpetz, Jocelyn Bélanger, Woo Young Chun, Edward Orehek, and Ayelet Fishbach

Note: The information garnered from this source focuses on the nature of multifinality from a social science perspective. Rather than examining multifinality as a process that can potentially have a variety of distinct outcomes, they consider multifinality as a process that results in multiple outcomes. This is not necessarily applicable to systems science, but it is a worthwhile examination from the perspective of doing a comprehensive examination of the topic area.

i. (Alt.) Multifinality and Goal-Directed Behavior, Self-Regulation, Judgment and Choice

"[M]ultifinality phenomena are ubiquitous within the broad domains of goal-directed behavior, self-regulation, and judgment and choice phenomena" (Kruglanski, Köpetz, Bélanger, Chun, Orehek, & Fishbach, 2013).

ii. (Alt.) Multifinality as Related to Self-Regulation

"Because of its general concern with goals and means of whatever type, the multifinality concept holds a considerable integrative potential and affords new insights into classic findings and fundamental phenomena in motivated cognition and self-regulation" (Kruglanski, Köpetz, Bélanger, Chun, Orehek, & Fishbach, 2013).

k. Luz E. Bohórquez Arévalo & Angela Espinosa

i. Self-Regulation and Variety Inhibitor (Requisite Variety)

"McCulloch (1965) explained in great detail self-organization as the most massive variety inhibitor. He explained the nature of reflexive and homeostatic mechanisms in the brain and the way that a 'neural-network' type of organization is goal directed, self-regulated and can achieve purposeful behaviors" (Arevalo & Espinosa, 2015).

ii. Self-Regulation and Feedback Loops

"From this perspective, self-organizing systems have the ability to modify their own organizational structures – the patterns of interaction between their components – and, as a result, the way they respond to their environment. These interactions allow the development of feedback loops in the system, which facilitate self-regulation and, thus, promote self-organization" (Arevalo & Espinosa, 2015).

iii. Self-Regulation and Redundancy of Potential Command

"For organizational cybernetics a prerequisite for self-organization is the redundancy of potential command manifested in distributed control within the system (self-regulation)" (Arevalo & Espinosa, 2015).

l. George Koob and Michael Le Moal

i. Allostasis and Dysregulation as a Pathology of Self-Regulation

Note: The reference to self-regulation occurs in the heading to this passage.

"Allostasis refers to the concept of physiology where an organism must vary all of the parameters of its internal milieu and match them appropriately to perceived and anticipated environmental demands in order to maintain stability (45). If the threats to the system continue to produce disequilibrium, the process of allostasis continues to regulate where the organism must mobilize enormous amounts of energy to maintain apparent stability at a now pathological 'set point.' The system is at the limit of its capability, and thus a small challenge can lead to breakdown (45). This is the beginning of spiraling distress and the addiction cycle. When the organism has reached a state of dysregulation so severe that it cannot recover by mobilizing its own resources, allostasis has reached the point of what is normally considered illness" (Koob & Moal, 1997).

m. Daniel Gilbert

i. Self-Regulation versus Unregulated Behavior

In his chapter on Inferential Correction, Daniel Gilbert (2002) provides an extensive discussion on the difference between self-regulation and unregulated behavior on the perceptive abilities of a sample group.

A-32. Sub-Optimization

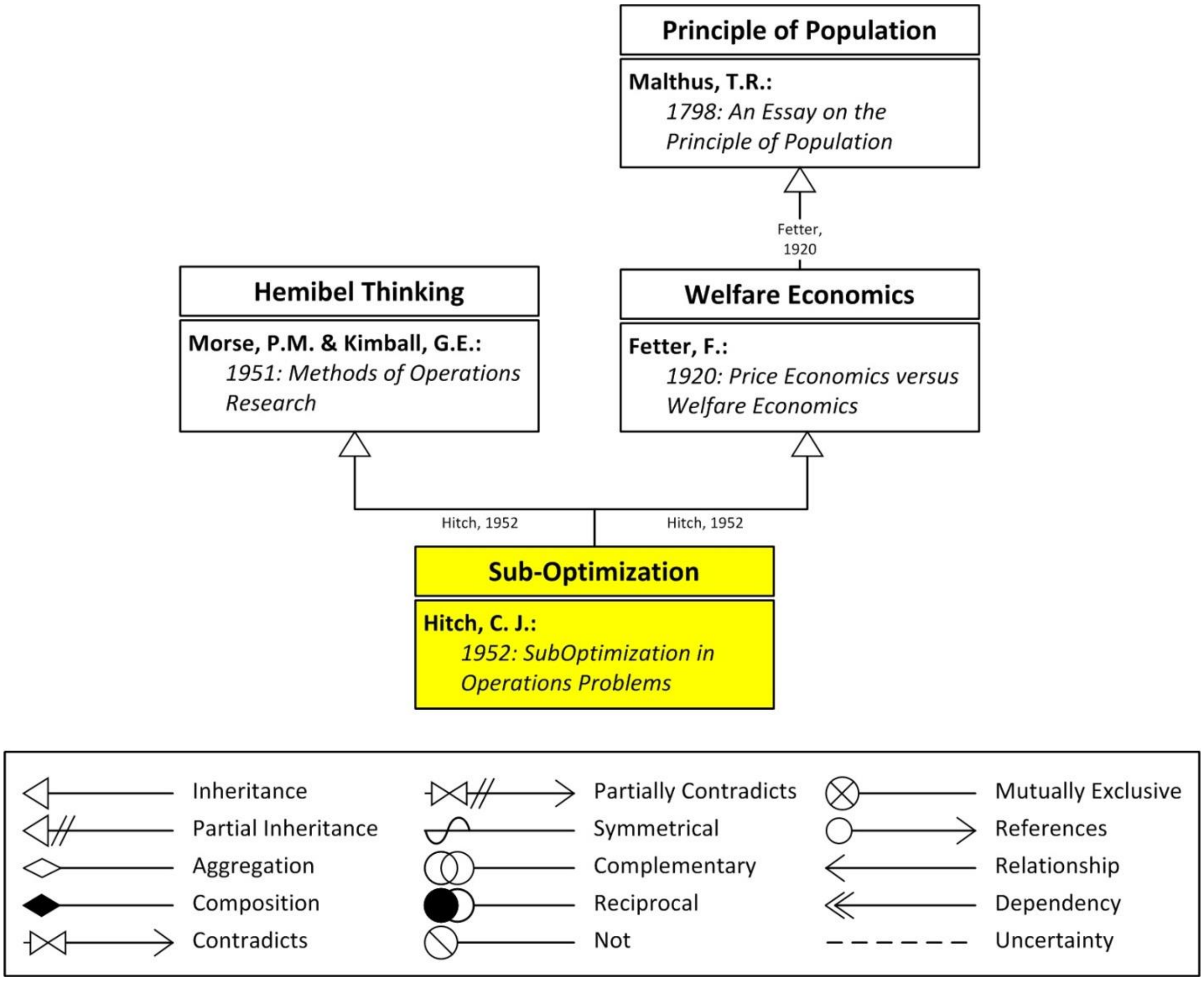

Figure A-37: Concept Model of Sub-Optimization

■ Definition

Sub-Optimization: If each subsystem, regarded separately, is made to operate with maximum efficiency, the system as a whole will not operate with utmost efficiency. (Skyttner, 2005)

■ Commentary

As stated by Beer (1965), it appears that the term sub-optimization has become a pejorative term, although the originator (Charles Hitch, 1952) never intended that to be the case. The definition and model of sub-optimization is very compact. The bulk of the supporting principles was discussed in the seminal work and there were few adaptations to the principle after it was first published.

■ Contributing Scholars

a. Thomas R. Malthus

i. Principle of Population

"Nothing is so common as to hear of encouragements that ought to be given to population. If the tendency of mankind to increase be so great as I have represented it to be, it may appear strange that this increase does not come when it is thus repeatedly called for. The true reason is, that the demand for a greater population is made without preparing the funds necessary to support it. Increase the demand for agricultural labour by promoting cultivation, and with it consequently increase the produce of the country, and ameliorate the condition of the labourer, and no apprehensions whatever need be entertained of the proportional increase of population. An attempt to effect this purpose in any other way is vicious, cruel, and tyrannical, and in any state of tolerable freedom cannot therefore succeed" (Malthus, 1798).

b. Frank Fetter

i. Welfare Economics

"According to one conception the aim of economics is to study prices, profits, and trade; according to the other, it is to study the relations between wealth and human welfare" (Fetter, 1920).

ii. Inheritance from Malthus

"Malthus, the one name that stands out most clearly in the midst of this obscurity, was, by virtue of the one great theme of his life, the population problem, a welfare economist primarily, and his attention was fixed upon material conditions of well-being, extent of territory, fertility, means of production, density of population, and general levels of production, as later embodied in the law of diminishing returns" (Fetter, 1920).

References Malthus, T.R. (1798) An Essay on the Principle of Population

c. Philip Morse and George Kimball

i. Hemibel Thinking

"Having obtained the constants of the operations under study in units of hemibels (or to one significant figure), we compare the value of the constants obtained in actual operations with the optimum theoretical value, if this can be computed. If the actual value is within a hemibel (i.e., within a factor of 3) of the theoretical value, then it is extremely unlikely that

any improvement in the details of the operation will result in significant improvement. [When] there is a wide gap between the actual and theoretical results...a hint as to the possible means of improvement can usually be obtained by a crude sorting of the operational data to see whether changes in personnel, equipment, or tactics produce a significant change in the constants" (Morse & Kimball, 1951).

d. Charles Hitch

i. The Domain of Sub-Optimization

"The optimal (or less ambitiously, good) solutions sought by operations research are almost always "sub-optimizations" in the sense that the explicit criteria used are appropriate to a low (or at least not the highest) level with which the researcher and his client are really concerned" (Hitch, 1953).

ii. Necessity of Sub-Optimization

"Operations researchers have to sub-optimize (use low level criteria) because it is so frequently impossible, either in principle or more frequently in practice, to calculate the consequences of any given action in terms of the appropriate high level criteria" (Hitch, 1953).

iii. Futility of Utility Functions for High Level Optimization

"What can operations research – quantitative common sense and scientific method - do to help the family get the most satisfaction in spending its income? One possibility would be to attempt a full and complete optimization in a single calculation. Formally, this presents no difficulties. For the last 100 years economists have been assuming that each consumer has a "utility" (or preference) function which shows the (rank) value to him of all possible combinations of goods and services which he can buy on the market. […] Any experienced operations researcher knows intuitively that this approach would prove to be sterile and hopeless. It would break down at the first step" (Hitch, 1953).

iv. Challenges of Sub-Optimization

"A common and fatal mistake in selecting sub-optimization criteria is to concentrate on a single input-to maximize some objectives function for a given quantity of the input, or minimize requirements for the input to achieve some given objective. The fallacy, in the jargon of economic theory, consists in treating all other inputs as if they were free goods" (Hitch, 1953).

v. Hemibel Thinking

"'Hemibel thinking' does not come to our rescue here: systems which minimize input A frequently turn out to be utterly different from systems which minimize input B" (Hitch, 1953).

References: Morse, P.M. and Kimball, G.E. (1951) Methods of Operations Research, New York: John Wiley and Sons, Inc.

vi. Welfare Economics

"The 'Golden Rule' for allocating scarce resources is to make each resource equally scarce in all uses. This is a theorem of "welfare economics," with precisely and operationally defined terms, which enables operations researchers to give practical advice on allocation problems even where the values of the alternative uses are incommensurable in the higher level objectives function" (Hitch, 1953).

vii. Good Sub-Optimizing

"This is the principle. This is the test of good sub-optimizing. The operations researcher will do most of his effective work on low level problems. But he will do better work if he studies and bears in mind the characteristics of the optimization at the appropriate higher level, and the relation to it of his sub-optimizing criteria" (Hitch, 1953).

e. Peter Drucker

i. Characteristics of Sub-Optimization

(1) "Unless he can attain a vision of the whole he is forced to try to obtain the optimum for a partial area regardless of the effect on the whole. He is forced to take one characteristic of the business for the whole. He is thus forced to sub-optimize: to obtain a partial or local optimum at the grave risk of damage to the other parts and to the entire business" (Drucker, 1955).

(2) "The basic problem of the Manager of today is that he can no longer manage by sub-optimizing and by "hoping for the best". Soon-very soon-he will not be able to manage at all unless he has tools that enable him to perceive the whole business in all its complexity" (Drucker, 1955).

f. Stafford Beer

i. Sub-Optimization as an Improper Pejorative

"These studies take no account of managerial specialisms or the artificial divisions of a firm's activity. They study, on the basis of an ecological model, the interaction of a firm with its environment at large. Even a little experience of this kind is enough to explain why the term "sub-optimization" was quickly taken to all our professional hearts as a pejorative word-although Charles Hitch has explained that in inventing it he meant nothing of the kind" (Beer, 1965).

g. Jacob Marschak

i. Sub-Optimization

"The individual user (meta-decider) can achieve a given sequence of transformations only at certain costs and with certain delays (or, more generally, a certain probability distribution of costs and delays). Subject to these constraints, he should maximize the expected benefit simultaneously with respect to all of the transformations, just like an ideal plant designer decides simultaneously about the size and composition of the personnel as well as of the machine park, the ware- houses and the transportation facilities! This is, of course, hardly ever achieved in reality. The humbler meta-decider makes his choices separately for each of several sub-systems; this is what the term "sub-optimization" is often intended to mean, I believe. Hopefully, he partitions the total system in such a way that the complementarity between sub-systems (with regard to expected benefit) is small" (Marschak, 1971).

h. Lars Skytter

i. Suboptimilization

"If each subsystem, regarded separately, is made to operate with maximum efficiency, the system as a whole will not operate with utmost efficiency" (Skyttner, 2005).

i. Kevin Adams and Charles Keating

i. On Origination of the Term

"The word sub-optimization was coined by Charles J. Hitch [1910-1995] while working at the RAND Corporation" (Adams & Keating, 2012).

ii. Definition

"Principle of Sub-optimization: If each subsystem, regarded separately, is made to operate with maximum efficiency, the system as a whole will not operate with utmost efficiency (Hitch, 1953)" (Adams & Keating, 2012).

References:

(1) Hitch, C. J. (1952). Suboptimization in Operations Problems. Santa Monica: RAND Corporation.

(2) Hitch, C. J. (1953). Sub-optimization in Operations Problems. Journal of the Operations Research Society of America, 1(3), 87-99.

A-33. Viability

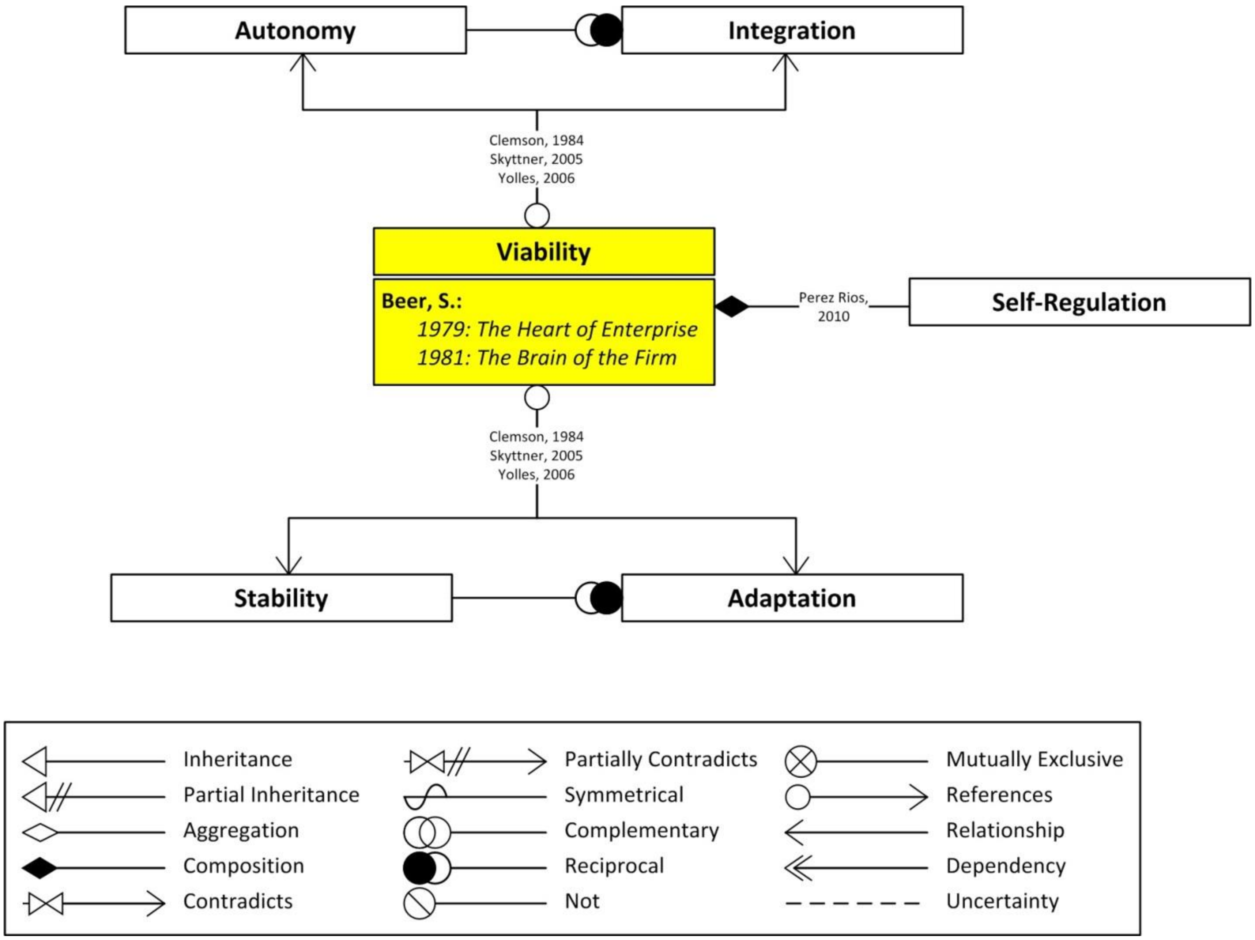

Figure A-38: Concept Model of Viability

■ Definition

Viability: The capacity of an organism to maintain a separate existence, that is, to survive regardless of the changes in its environment. (Perez Rios, 2010)

■ Commentary

Although a direct reference from Stafford Beer is not provided, the bulk of the references included here credit Beer as the originator of the viability principle, drawing its origination to *Heart of Enterprise* and *Brain of the Firm.*

■ Contributing Scholars

a. Barry Clemson

i. The Axes of Viability

"Viability is a function of the balance maintained along two dimensions: 1. Autonomy of sub-systems versus integration of the system as a whole. 2. Stability versus adaptation. Stafford Beer. The Heart of Enterprise and Brain of the Firm" (Clemson, 1984).

b. Lars Skyttner

i. The Axes of Viability

"Viability is a function of the proper balance between autonomy of subsystems and their integration within the whole system, or of the balance between stability and adaptation" (Skyttner, 2005).

c. Maurice Yolles

i. Viability as Adaptability versus Stability

"When organizations are flexible and adaptable, they are also said to be viable. A viable organization is able to support adaptability and change while maintaining stability in its operational behavior. That means that as it tries to cope with the perturbations that it experiences through adaptation, it undergoes a process of change that enables it to maintain operational stability in its states of behavior" (Yolles, 2006).

d. Jose Perez Rios

i. Elements of Viability

"Viability. This term refers to the capacity of an organism to maintain a separate existence, that is, to survive regardless of the changes in its environment. For that, it must have the capacities of self-regulation, learning, adaptation and evolution" (Perez Rios, 2010).

e. Kevin Adams & Charles Keating

i. The Concept of Viability

"The systems viability principle tells us that a systems‟ existence, or integrity, is maintained as a function of balance along two dimensions: change and control. For a system to be viable it needs to adapt on a short-term basis, but keep its integrity in the long term" (Adams & Keating, 2012).

ii. The Axes of Viability

"Principle of Viability: A function of balance must be maintained along two dimensions: (1) autonomy of subsystem versus integration and (2) stability versus adaptation (Beer, 1979, 1981)" (Adams & Keating, 2012).

f. Patrick Hester and Kevin Adams

i. The Axes of Viability

"The systems viability principle tells us that a system is in constant tension, and must maintain balance along two dimensions: change and control. This tension is present along two axes. The first axis is that of autonomy and integration. Systems desire to be autonomous and to perform the purpose, goal, and functions for which they created. However, systems do not exist in a vacuum and must co-exist with other systems. By interfacing with other systems some level of autonomy must be sacrificed. This is the first critical tension. The second axis of tension is stability and adaptation" (Hester & Adams, 2014).

A-34. Combined Model of Systems Concepts

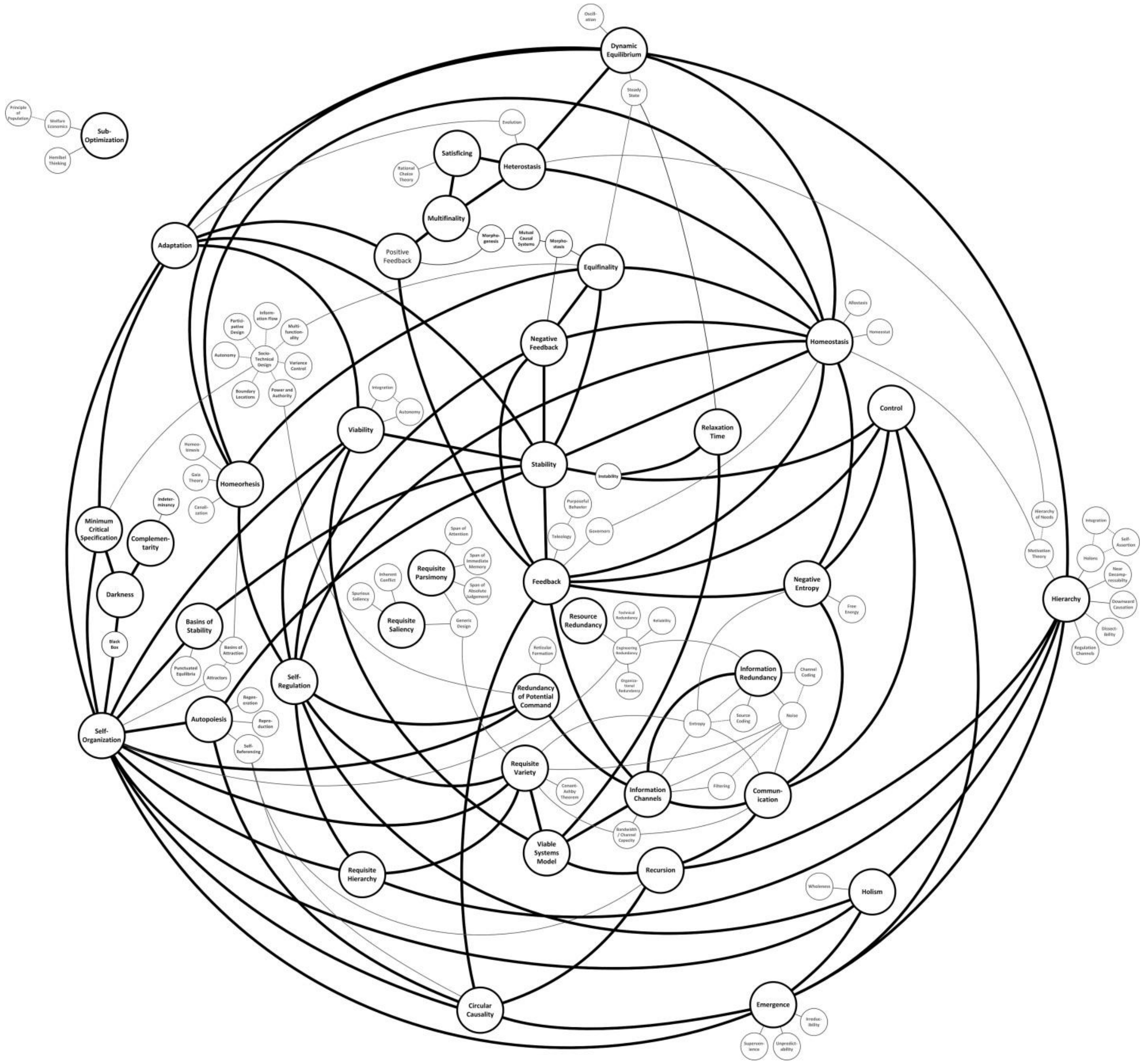

Figure A-39: Combined Model of Systems Concepts

■ Commentary

While some peripheral concepts have been trimmed to create a manageable subset, the figure above illustrates all of the major and minor concepts that have been addressed in this appendix on a single related diagram. Major concepts are shown in large bubbles and minor concepts are smaller. The connecting lines represent relationships that exist between concepts. While this figure is indicative of the breadth of the literature and the complexity that exists within the field, it also demonstrates that cohesive relationships exist and can be visualized.

APPENDIX B: THE APPLICATION OF SYSTEM ARCHETYPES IN A CASE ENVIRONMENT

B-1. Introduction

The purpose of this case study is to demonstrate the applicability of the systems archetypes developed by Walt Akers (2015) within a systems engineering environment. To accomplish this goal, the functions of an industrial Facilities Management department will be examined from the perspective of the systems archetypes. This case study will begin by providing a background of the organization being studied which describes the facility that it supports, the types of activities that it performs, its projected budget for accomplishing these activities, and a manpower profile that identifies the number and skills of workers who are allocated to perform the tasks.

Based on this data, the paper will then identify and justify the system boundary for the study. This process will explicitly identify which elements of the facility and its staff are within the system boundary and which are part of the context. The establishment of this boundary is a critical element in determining when the system is interacting with its environment and how those interactions are archetypically manifested.

Using the collected manpower, budget, and prioritization data, the study will dissect the organization's behavior to determine which archetypes are manifested within it. The predominant archetypes will be identified based on the behavioral criteria identified by Akers (2015). Further, supporting or secondary manifestations of archetypes will also be identified. In conclusion, the paper will discuss implications for the organization in the event that budgetary or environmental conditions change.

B-2. Background and Organization Profile

For any large industrial plant, a plant engineering or facilities management department is a practical necessity. Depending on the organization's tolerance for down time and its operational requirements, the facilities management department may be as simple as a routing service that brings in outside vendors to perform scheduled repairs, or it may consist of a round-the-clock maintenance team that can react quickly to any critical outage. For many organizations, both of these modes of operation exist, and a determination of the appropriate response is based on the criticality of the situation.

For this study, a typical large facilities management department will be examined. This department exists at a contractor-operated government facility that is responsible for energy research.

B-2.1. Facility Size

The facility where the study was conducted is a 206-acre campus with 83 buildings that represent 928,000 square feet of floor space. Buildings on the site include general office space, computing centers, large fabrication facilities, warehouses, and subterranean experimental halls where energy experiments are conducted.

Each of these areas has distinct infrastructure requirements that must be managed, maintained, and updated as necessary by the facilities management department to keep pace with the needs of the larger institutional objectives.

B-2.2. Organizational Mission

The mission of the facilities management department is multi-fold.

- **Maintenance**

  One of the primary duties of this organization is the maintenance and upkeep of existing buildings and facilities. These duties extend to all aspects of building serviceability, from electrical, heating, cooling, plumbing, fire suppression, and security systems to the maintenance of paint, floor coverings, finishes, windows, and roofing. Not limited only to buildings, the department must also maintain and repair the roads and the parking lots on the facility.

- **Infrastructure Management**

  Another responsibility of the studied organization is that it contracts and manages commercial utilities that are delivered to the site. This extends beyond normal electrical and water connections, but also includes the management of the delivery of large volumes of nitrogen and helium gases at a rate that is precisely matched to the demands of the facility. Further, the facilities department is responsible for coordinating the delivery of network and communications services to the site and for managing the vast collection of communication cables that extends between building and equipment.

  The successful management of these entities demands that the facilities department maintain the maps and construction drawings that detail how the facility was built and how it has evolved over time. As elements of the infrastructure are updated, so too must the drawings be, so that future development can be well-informed of present conditions.

- **Improvements**

  Beyond maintenance of the status quo, the facilities department is also responsible for managing and directing the improvements to facilities across the site. This includes designing new buildings as well as improving the existing ones. Improvements might also include the expansion of storage facilities, the creation of new roads to improve access to the site, and the development of drainage/water collection systems to minimize the impacts of seasonal weather events.

- **Property and Logistics**

  Because the facility receives, stores, and ships a large amount of a material, the facilities department is also responsible for caching incoming materials until they are needed. Because annual budgets vary, materials are often purchased well ahead of time and must be stored for several years before they are eventually used. This requires the facilities management department to carefully track the location of goods and materials over time. Further, as work schedules and priorities change within the larger organization, the facilities management department may be required to dynamically alter its storage plans to accommodate longer storage of some materials or an unexpected delivery of others. This unpredictability sometimes results in the cancellation of programs, as well. In these cases, the facilities management department must rapidly identify where the associated materials are stored and must plan for their reuse or disposal, as appropriate.

- **Services**

  Finally, many of the tasks performed by this facilities management department fall under the catch-all category of "general services." These include physical security and the guard force, pest control, refuse and recycling, and janitorial services.

B-3. Analysis

B-3.1. Organizational Structure, Labor and Salary Distributions

There are 49 full-time employees assigned to the facilities management department. With the exception of a top-level manager and some administrative staff, the bulk of these individuals work within a single specific mission area (as defined in the proceeding section).

The distribution of these staff members within each mission, along with their median salary, is as follows:

- **Maintenance**

  There are 16.4 full-time personnel assigned to facility maintenance – slightly more than 1/3 of all personnel in the department. The skills represented within the maintenance section include three engineers, three work coordinators, eight skilled tradesmen, and the balance in shared administrative personnel. The average salary within the maintenance group is $67,266.

- **Infrastructure Management**

  The smallest of the groups within the facilities department, the infrastructure management team consists of 3.9 full time personnel. The group is composed of a work coordinator, a draftsman, and a student intern, and it receives some shared engineering and administrative support from the department. Members of this group have an average salary of $66,671.

- **Improvements**

  The group in the facilities department responsible for improvements is identical in size to the maintenance group, having 16.4 full time personnel assigned. Notably, though, this group has an average salary of $102,394 per person. The disparity in salaries between the improvements group and the others is largely due to the educational, training, and certification requirements of these staff members. Specifically, this group is composed of 14 architects and engineers with two work coordinators and a small amount of administrative support included.

- **Property and Logistics**

  The property and logistics group in the facilities department consists of 7.4 full time personnel, all of whom are classified as administrative or clerical. Because of this, the average salary in this group is $43,664, which is nearly half the departmental average. It is worth noting that the strenuous work in this department (combined with the comparatively low pay) results in rapid turnover of employees.

- **Services**

  There are 4.9 full-time employees assigned to the services group within the facilities department. While this group is also composed almost entirely of administrative staff, their responsibilities require a significant amount of training and expertise in contract management. As a result, their average salary is $84,146 – a pay level only exceeded by the improvements group.

B-3.2. Organizational Budgets

In addition to the portion of the budget that is allocated for salaries, each mission area or work group within the facilities management department is also allocated budgetary funds to execute its mission. This section details the operating budget that is allocated for each area of the organizational mission and also provides the portion of that budget that is allocated for labor costs:

- **Maintenance:**
  - Total Budget: $4,561,808
  - Personnel Costs: $1,103,170
- **Infrastructure Management**
  - Total Budget: $2,136,020
  - Personnel Costs: $260,020

  Note that the bulk of this amount is the cost of electrical utilities and other commercial resource providers.
- **Improvements:**
  - Total Budget: $1,952,979
  - Personnel Costs: $1,679,270

  As evidenced above, virtually the entire improvement budget is allocated to staff salaries. Because of this, large improvement programs are generally allocated from organizational funds that are provided by the institution for specific projects.
- **Property & Logistics:**
  - Total Budget: $592,261
  - Personnel Costs: $323,120
- **Services:**
  - Total Budget: $695,395
  - Personnel Costs: $412,320

B-3.3. Framing the System

In order to discuss the facilities management department from the perspective of systems archetypes, it is first necessary to frame the organization *as a system.* This framing is essential because the archetype definitions largely depend on the manner in which the system interacts with its environment. For such an analysis to be meaningful, the boundary where the system ends and the environment begins must be clearly established.

In framing the system, the facilities department will again be examined through the prism of its individual mission areas, and these *sub-systems* will be bounded together with all of the organizational components that are essential to their continuity as a distinct, viable system.

- **Maintenance:**

  The maintenance activity of the facilities department is wholly dependent on the presence of physical and virtual constructs that it must maintain. As new facilities are constructed, they become part of the maintenance activity; as they are demolished, they are expelled from the system boundary. There is no maintenance activity unless there are things to maintain. As a result, the defining entropy that the maintenance group is attempting to displace is the deterioration of the supported infrastructure that occurs due to age and environmental impacts. Therefore, the buildings, roads, and other engineered systems are all within the system boundary of the maintenance group.

  Notably, the maintenance group *uses* money, materials, contractors, supplies and equipment to accomplish its mission. These things, however, can be obtained on an as needed basis and then expended without altering the identity of the system itself. Accordingly, all of these entities should be considered as related to the system, but not part of it. They are, therefore, analogous to the free energy that the maintenance activity must obtain and consume in order to displace entropy and maintain its supported infrastructure.

  Recognizing that the structures being maintained are within the system boundary and that the elements required to perform maintenance are outside of it, a question naturally arises as to where people fit within this paradigm. This study asserts that the 16.4 personnel who work in the maintenance group must be viewed as competencies, rather than as individuals. This is an important distinction because distinct individuals within the maintenance group may come and go without impacting system viability, as long as they are replaced by similarly skilled individuals.

- **Infrastructure Management**

  Because the infrastructure management group has several distinct activities, it is more difficult to frame. In evaluating the sub-system, it may be best to examine it from the perspective of its three major activities: channeling outside resources, distributing communications, and documenting system configurations.

  - **Resource Channeling Activities**

    As a channeller of resources, the infrastructure management group is responsible for ensuring the delivery of power, water, cryogens, and network services to support the operations of the larger organization. The group does not create or use these resources; rather, it collects them and delivers them for consumption by the organization. Because of this, they are analogous to free energy. Further, while the infrastructure management group does not personally suffer if these resources are delayed or exhausted, it is part of a larger system that is wholly dependent on them. This means that this group is actually displacing the entropy of the entire organization rather than merely its own. Because of this, this part of the infrastructure management activity might be thought of as the outer most surface of the larger system – its interface to the resources that it needs to survive.

    Notably, the delivery of resources from outside providers is not perfect. To protect against resource shortages caused by environmental conditions, this group is also responsible for acquiring generators, water tanks, cryogen reserve tanks, and uninterruptable power supplies. These components are distributed throughout the facility and are maintained by the maintenance activity. Because of this, these elements exist within the boundaries of both the maintenance group and the infrastructure management group.

  - **Communications Distribution**

    Communications throughout the facility is managed by a system of fiberoptic and copper communications cables that link buildings, infrastructure, and virtual systems. This *cabling plant* is analogous to the physical structures that are supported by the maintenance group. As a result, it is considered a part of the infrastructure management group and it rests within its system boundary.

- **System Documentation**

  In this part of the system, the elements that are being maintained are highly conceptual and are representative of real world entities. The quality of these drawings and records, both digital and physical, is measured by how accurately they represent the reality of the existing facility. Entropy is manifested here when the group either fails to produce documentation to describe new systems or fails to maintain existing documentation as the system configuration changes.

Although the infrastructure management group is described as three distinct capabilities, the personnel that are supporting these activities are the same, each of them having a variety of responsibilities. This demands that each of the individuals within this group have a diversity of skills, unlike other groups where specialization is necessary. In spite of this, the members of this sub-system are still seen as competencies rather than individuals. In this case, however, the individual competency must include multiple skills, flexibility, and an ability to rapidly switch activities as conditions emerge.

- **Improvements**

As is shown in the budget allocations described earlier, the improvements group has regular funding for little more than their own salaries. Although it designs and manages the construction of facilities, it does not select which facilities will be constructed nor does it own the facility once it is completed. This represents a challenge in understanding how it accrues energy and where it incurs and displaces entropy. Both of these factors are manifested as part of the larger organization.

For the facilities improvement group, free energy does not come from the organization's outside environment, but rather is generated as part of the growth and expansion of the healthy organization. As the organization grows, it needs new facilities and system improvements, which it allocates funds to provide. Both of these things, *demand* and *funding*, represent the energy that powers the improvements group. If either of them is lost, then the group cannot remain viable.

What, though, of entropy within this group? Because it does not possess the buildings or the finished infrastructure, it does not incur entropy as these things decay. In fact, the degradation of the existing infrastructure often generates the *demand* that fuels new improvements. Entropy within this group occurs when it no longer has sufficient demand or funding to maintain a full complement of staff. For the improvements group, entropy is incurred as the larger organization enters a state of decline and no longer needs (or can afford) improvements. Sadly, displacing this form of entropy is largely outside the capacity of the improvements group and it relies entirely on the success and longevity of the parent organization.

- **Property & Logistics**

As with the maintenance group's relationship to buildings, materials that are in the custody of the property and logistics groups are considered to be part of their system, transient though they may be. Similarly, all of the buildings, warehouses, and heavy equipment that are used to store or facilitate the transport of materials are also within the group's system boundary, even though they may also exist within the boundaries of the maintenance group.

The activities of the property and logistics group are fueled by the demands created by the larger organization in pursuit of its mission. The institution performs activities that require the acquisition and storage of materials and it generates products and wastes which must be cached, queued, and then removed from within the system.

The presence of entropy within the property and logistics group is manifested in two distinct areas: the materials that are being managed and the facilities where they are being stored. While the responsibility for keeping the buildings and warehouses in good repair falls largely on the maintenance group, the impact of poorly maintained buildings has an immediate and detrimental impact on stored property. This makes the need to identify and conduct proper maintenance a shared responsibility between the groups.

Protection of property, however, is a more localized challenge. The property and logistics group is required to maintain the condition of materials during both storage and transit. Stored materials often rely on stable environmental conditions, such as temperature and humidity, in order to remain in usable condition. This group is responsible for monitoring those conditions and reacting when circumstances change. Other materials have finite life spans, even in ideal conditions. The acquisition and storage of these materials must be orchestrated to satisfy the institutional mission and to minimize waste.

Material loss or misplacement is another form of entropy that occurs during storage. To avoid this, the property and logistics group is required to maintain records of where material is stored and to track property as it moves between locations. Because some equipment and hardware might move frequently between storage and use, the group must continue to keep track of these materials even though they may not presently be in storage.

- **Services**

  The services group might be thought of as synonymous with the maintenance group, except that its problems are more abstract or virtualized. This means that while the maintenance group deals with the physical, concrete decay of buildings and structures, the services group must protect against security failures, an increase in unclean/unhygienic conditions, or the accumulation of debris. These issues are all addressed through the procurement of contractors who are responsible from outside of the organization.

  Unlike the improvements group, which is reliant on growth and expansion for its continuity, the services group is a persistent, essential element evident throughout all stages of the organization's lifecycle. While security and janitorial services may be reduced during lean times, it is difficult for them to be eliminated completely without having a significantly detrimental impact on the organization. This is how entropy is manifested within the group.

  Notably, the contractors and service providers that perform the activities of this group are not within the system boundary, as they may be replaced with other service providers, as needed. The contracts themselves, however, are essential elements of the group and define the system. The services group is fueled by the ongoing demand for its services using a funding stream that is provided by the organization to accommodate its work.

B-4. Findings

Based on the information presented in the preceding sections, each of the groups within the Facilities Management department can be placed into one or more archetypes. Notably, the archetype that is most prominently manifested within the group may change as conditions evolve and emerge within the larger organization.

In some cases, the group may be represented by multiple archetypes concurrently. This is likely to occur when the functional aspects of the group (what it does) are largely decoupled from its means of subsistence. As discussed earlier, this is especially true in the case of the improvements group, which has a significant dependency on organizational conditions that are outside of its control or its scope of operation; i.e., not matter how well it performs its task, it may not increase its longevity.

In the following sections, each of the groups will be categorized into one or more archetypes and a justification will be provided for the decision. Further, conditions that may cause a group's archetypical assignment to change will also be considered and discussed.

- **Maintenance:**

  The maintenance group of the facilities management department is almost purely *endurant.* By definition, it has the capacity for autopoiesis and self-maintenance, but it largely deals with a fixed configuration that is established by the system designers within the improvements group. Accordingly, it maintains the viability of the structures within its system boundary by repairing them faster than entropy can degrade them. As buildings become inviable and can no longer be maintained, they are removed from the system and are replaced with new structures designed by the improvements group.

  Despite its *endurant* bent, however, the individuals who work within the system may have competencies that add a secondary archetypical behavior –that of the *organizer.* Through imagination and innovation, staff who work in the maintenance group may use materials within the system in novel ways to address specific problems or in response to emergencies, especially if time or funding do not allow a full design process to be executed. In doing this, they absorb part of the functionality of the improvements group which, in turn, may decrease that group's overall value to the organization. Accordingly, *organizer* behavior by the maintenance group is likely to be discouraged by the improvements group, even when it is economically beneficial to the larger organization.

  Finally, the maintenance group has a responsibility to erect or install protective barriers to the facility during the approach of severe weather, hurricanes, or floods. Although these protective components are often designed by the improvements group, by deploying and retrieving them as needed, the maintenance group also displaces behaviors associated with the *insulator* archetype.

  In summary, the maintenance group is an *endurant* organization which exhibits some *organizer* and *insulator* behaviors during emergent conditions. In the event that the organization loses the financial capacity to support continued design and construction by the improvements group, then it is likely that this group's *organizer* behavior would become more prevalent as it struggles to use available materials to maintain the viability of its supported buildings and infrastructure.

- **Infrastructure Management**

  Where the maintenance group largely exists within a single archetype, the diversity of functions that occur within the infrastructure management group afford it equal footing within several archetypical domains. As a channeller and distributor of external resources, the infrastructure management group alters the environment of the larger organization by delivering power, water, cryogens, and telecommunications to the system. While much of this work is performed by outside contractors and suppliers, the infrastructure management group still retains primary responsibility, placing them in the category of the *manipulator* archetype. Additionally, by acquiring and installing back-up services, such as generators and water towers, to protect the organization from shortfalls of these external resources, they also exhibit *insulator* behavior. Further, if even with backup systems, there are insufficient resources to supply all activities, the infrastructure management group has the capacity to regulate the distribution of resources based on organizational priorities, casting them in the role of the *regulator* archetype.

  In other responsibilities, this group's efforts to maintain the facilities' physical cabling plant, as well as records and documentation of changes to the system, falls within the domain of autopoiesis and self-maintenance. This type of work adds an *endurant* capacity to the roles that are already being played by the infrastructure management group.

  With so many capacities expressed within a single group, it is difficult to assign it to a single, predominant archetype. Nonetheless, because the larger organization should, by definition, operate in a largely non-emergent environment, then this group should be classified by its non-emergent responsibilities. In this case, the infrastructure management group would be equally *manipulator/endurant,* as its primary role during normal conditions is to deliver the resources (power, water, cryogens) which alter the facilities' environment and also maintain the documentation regarding the past and current system configuration.

- **Improvements:**

  The improvements group is a true anomaly, in that its functional characteristics diverge significantly from those that ensure its longevity and viability. Because of this, the improvements group fits tightly into one of two camps, depending on the perspective from which it is viewed.

From a functional standpoint, the improvements group co-exists in the domains of the *insulator* and *manipulator.* This is because the improvements group is almost exclusively responsible for design and creating new buildings and infrastructure for the facility. Its *insulator* characteristics are dominant when it is designing or producing components that are design to protect the facility (or its property), but is not integrated as a permanent part of the facility. Examples of these would include temporary storage structures, weather proof coverings for materials, and other transient solutions. More often, though, the work of the improvements group is manifested as the *manipulator* archetype, since it designs and constructs new buildings that become a permanent part of the facility.

From a viability standpoint, however, the performance of the group's functional tasks may not contribute to its long term survival. A notable exception would be if the group conducts its work very poorly, in which case the larger organization is likely to look for an alternative solution. For the purpose of this research, however, let us assume that the group performs very well and is able to successfully execute all of its improvement work on time, within budget and to the expected level of quality. Still, this does not guarantee that the facility will continue to have demands for new and better facilities to be created. In fact, in a perverse alternative the group may produce facilities that are *so good* that they actually eliminate the need for future improvements to be done. From this perspective, the improvements group is wholly dependent on conditions outside of itself for its ongoing viability and is, therefore, an *endurant* system.

In examining the improvements group from this perspective, one might ask if it can alter its configuration (a la the *organizer* archetype) to make itself better equipped to survive external changes. Notably, there are two challenges that inhibit that behavior. First, the improvements group is externally managed by the larger facilities management department; therefore, its mission and objectives are assigned to it externally. The group is not empowered to alter its structure or organization independently. Second, and more importantly, all systems are largely defined by their identity – that quantity that defines their collective goals and objectives. In each degree that the improvements group behaves as an *organizer* and alters its configuration to address different work, it loses part of its original identity. Thus, it begins to emerge as a different type of system -- perhaps one that is not beneficial to the larger organization.

Therefore, in concluding the examination of the improvements group, it must be seen as a dichotomy of two perspectives. As a functional entity, it is both an *insulator* and a *manipulator,* constructing protective barriers and changing the environment to support its system. As a viable system, however, it is wholly *endurant* and struggles to exist as long as possible without being overwhelmed by external forces.

- **Property & Logistics:**

  Because this group is responsible for managing the receipt, flow, storage, and disposal of all materials at the facility, it is defined by two distinct, but closely related, archetypes: the *organizer* and the *regulator*.

  From the perspective of the *organizer* archetype, the property and logistics group is responsible for reacting to dynamic and rapidly changing demands. When administrative errors occur and materials arrive in an unexpected manner, the group must adapt its work schedule, as well as its utilization plans. Facilities and equipment that were planned for one purpose may be re-tasked to address the emerging issue. Likewise, the untimely arrival of new property may create a cascading reorganization where materials are shuffled between locations to satisfy storage needs.

  Whereas the *organizer* behavior is driven by emergence and unexpected change, the group's *regulator* behavior is closely coupled to its normal operation. The property and logistics group must regulate and prioritize the delivery, storage, and transport of materials in order to best address the needs of the larger organization, and of the materials themselves. This prioritization may be seen in the way staff members, each of whom have multiple competencies, are deployed to perform work. During normal operations, staff members may be assigned to activities on a first-come/first-served basis. In conditions of duress or in the face of high priority work, however, the group leader may take regulatory steps to shift the focus to the most important work – potentially at the expense of lower priority efforts.

  This *regulator* behavior is also observed in the relationship that the group has with the outside world. Rather than simply absorb shipments in an uncontrolled flow from vendors and suppliers, the group attempts to schedule and regulate deliveries so they arrive in a manageable way. This form of extra-regulatory behavior tends to level demand and allows the group to avoid spikes and resource collisions.

While the successful property and logistics group is governed by the *organizer* and *regulator* archetypes, it still has an underlying *endurant* base. This is because it relies on a level of control and regularity that exists outside of its boundaries. If, for whatever reason, deliveries begin to arrive at a very high rate, the group may be overwhelmed and unable to keep up.

- **Services:**

  As with many of the other groups, the services group can be divided along two archetypes. This division is based on two factors: the nature of the condition being addressed, and the condition's relative importance to the organization.

  For the services group, the condition being addressed is synonymous with the type of entropy the organization is attempting to reduce. In the case of waste disposal, this would be the accrual of garbage at the facility; for janitorial services, it is dirty and unhygienic conditions; and for security, it is the occurrence of trespassing, theft, or other criminal activities. In response to these conditions, the services group responds as a *regulator/endurant* system. This is to say that the organization decides the level of insecurity and filth that it is prepared to tolerate, and then it grows or shrinks the size of the contract to stay above that level.

  These levels, however, are not fixed, and their priorities may change over time. During periods of prosperity, the organization may elect to increase landscaping services and beautification programs. However, when financial conditions are constrained, they are equally likely to reduce the frequency of janitorial services and garbage pickup. Because many of these services are essential to the long term viability of the organization, the reader will note that the reduction of these services is a poor health indicator for the larger organization, and the elimination of one or more of them is likely to be harbinger of organizational collapse.

B-5. Conclusion

In conclusion, the groups within the facilities department represent a broad cross-section of the systems archetypes, with the *endurant, regulator, organizer, insulator,* and *manipulator* types being represented in one or more of the groups. Notably, the *endurant* archetype is the most commonly occurring, and it is seen at some level in every group. This is to be expected, since the *endurant*, by definition, is the first responder in the event of emergent conditions and the last resort when the system is overwhelmed. The other archetype manifestations are largely coupled to the type of work that the group performs.

Missing from this study is a manifestation of the *migrator* archetype. This is likely because the mission of the facilities management department is tightly coupled to the facility itself. If the department, or any of its sub-groups, migrates away from the facility, then it loses not only its mission, but its identity. This does not mean that the migrator archetype is not manifested in other parts of the larger organization – only that it is not a purposeful behavior of the facilities management group.

While this case study attempts to make an objective examination of the facilities department based on the functions of its sub-groups, it is recognized that different perspectives exist. As with the improvements group, which may be either an *insulator/manipulator* or an *endurant* depending on the perspective of the observer, other such observational distinctions may exist in this and similar systems. It is the responsibility of the individuals employing these archetypes to understand where their vantage point lies in relation to the observed system, and to recognize that individual perspective will always have a bearing on one's interpretation.

REFERENCES

Ackoff, R. (1971). Towards a System of Systems Concepts. *Management Science, Vol. 17, No. 11*, 661-671.

Ackoff, R., & Gharajedaghi, J. (1996). Reflections on Systems and Their Models. *Systems Research, Vol. 13, No. 1, Mar. 1996*, 13-23.

Adams, K., & Keating, C. (2012). *Systems of systems engineering.* Norfolk, VA: National Centers for System of Systems Engineering.

Adams, K., Hester, P., Bradley, J., Meyers, T., & Keating, C. (2014). Systems Theory as the Foundation for Understanding Systems. *Systems Engineering, Vol. 17, No. 1*, 112-123.

Agassi, J. (1975). Institutional Individualism. *The British Journal o f Sociology, Vol. 26, No. 2*, 144-155.

Airy, G. B. (1840). On the Regulator of the Clock-work for effecting uniform Movement of Equatoreals. *Memoirs of the Royal Astronomical Society, Vol. 11*, 249-268.

Akers, W. (2015). *An Approach for the Development of Complex Systems Archetypes.* Norfolk: Old Dominion University.

Alexander, S. (1922). *Space, Time and Deity.* New York: Dover Publications.

Andersen, W. (1940). Risk avoidance is the expression of the desire to secure all persons against the. *Michigan Law Review, Vol. 38, No. 7*, 1063-1073.

Anderson, J., & Mohan, S. (1991). *Source and Channle Cosing: An Alogorithmic Approach.* Boston: Kluwer Academic Publishers.

Anderson, P. W. (1972). More is Different. *Science, Vol. 177, No. 4047*, 393-396.

Angell, I., & Demetis, D. (2010). *Science's First Mistake: Delusions in Pursuit of Theory.* New York: Bloomsbury Academic.

Arbib, M. (1971). How We Know Universals: Retrospect and Prospect. *Mathematical Biosciences, Vol. 11*, 95-107.

Arbib, M. (1972). Toward an Automata Theory of Brains. *Communications of the ACM, Vol. 15, No. 7*.

Arevalo, L., & Espinosa, A. (2015). Theoretical approaches to managing complexity in organizations: A comparative analysis. *Estudios Gerenciales, Vol. 31*, 20–29.

Aristotle. (350 B.C.E). *Metaphysics.*

Aristotle. (350 B.C.E.). *Topics.*

Aronoff, S., Berkowitz, K., Shreiner, B., & Want, L. (2004). Glucose Metabolism and Regulation: Beyond Insulin and Glucagon. *Diabetes Spectrum, Vol. 17, No. 3*, 183-190.

Ashby, W. R. (1952). *Design for a Brain.* New York: John Wiley & Sons.

Ashby, W. R. (1956). *An Introduction to Cybernetics.* London: Chapman & Hall.

Ashby, W. R. (1958). Requisite variety and its implications for the control of compexl systems. *Cybernetica, Vol. 1, No. 2*, 83-99.

Ashby, W. R. (1958). Requisite variety and its implications for the control of complex systems. *Cybernetica, Vol. 1, No. 2*, 83-99.

Ashby, W. R. (1962). Principles of the Self-Organizing System. In H. Von Foerster, & G. Zopf (Eds.), *Principles of Self-Organization: Transactions of the University of Illinois Symposium* (pp. 255-278). London: Pergamon Press.

Ashby, W. R. (1968). Variety, Constraint, And The Law Of Requisite Variety. In W. Buckley (Ed.), *Modern Systems Research for the Behavioral.* Chicago: Aldine Publishing Co.

Aulin, A. (1982). *The Cybernetic Laws of Social Progress.* Pergamon Press.

Aulin, A. (1987). Cybernetic Causality III. The Qualitiative Theory of Self-Steering and Social Development. *Mathematical Social Sciences, Vol. 14*, 101-140.

Aulin-Ahmavaara, A. (1979). The Law of Requisite Variety. *Kybernetes, Vol. 8, No. 4*, 259-266.

Avery, J. S. (2012). *Information Theory and Evolution, 2nd Ed.* Hackensack: World Scientific Publishing Co.

Bacon, F. (1605). *The Advancement of Learning.* London: Cassell & Company, Ltd.

Bacon, F. (1620). *Novum Organum, by Lord Bacon, ed. by Josepth Devey.* New York: P.F. Collier, 1902.

Badii, R., & Politi, A. (1997). *Complexity - Hierarchical Structures and Scaling in Physics.* Cambridge: Cambridge University Press.

Bancroft, W. (1911). A Universal Law. *Science, New Series, Vol. 33, No. 840*, 159-179.

Banfalvi, G. (2014). *Homeostasis - Tumor - Metastasis.* New York: Springer.

Barnard, G. (1951). The Theory of Information. *Journal of the Royal Statastical Society, Series B, Vol. 13, No. 1*, 46-64.

Bar-Yamm, Y. (1997). *Dynamics of Complexity.* Reading, PA: Addison-Wesley.

Becvar, D. (2007). *Families that Flourish.* New York: W.W. Norton and Company.

Beer, S. (1965). Sigma. *Operations Reserach, Vol. 16, No. 3*, 275-285.

Beer, S. (1979). *The Heart of Enterprise.* New York: John Wiley and Sons.

Beer, S. (1981). *The Brain of the Firm.* New York: John Wiley and Sons.

Beer, S. (1984). The viable systems model: its provenance, development, methodology and pathology. *The Journal of the Operational Research Society, Vol. 35, No. 1, Jan. 1984*, 7-25.

Beer, S. (1993). *Designing Freedom.* Toronto: House of Anansi.

Beer, S. (2001). Vital Aspects of Viability: The Viable System Model in Management. *First International Conference on Systemic Management.* Vienna.

Bell, A. G. (1876). *The Multiple Telegraph: Invented by A. Graham Bell.* Boston: Franklin Press: Ran, Avery & Company.

Ben-David, I., & Raz, T. (2001). An Integrated Approach for Risk Response Development in Project Planning. *The Journal of the Operational Research Society, Vol. 52, No. 1*, 14-25.

Benson, T. (2002). *Stability and Control.* Cleveland: NASA, Glenn Research Center.

Bergson, H. (1907). *Creative Evolution.* (A. Mitchell, Trans.) New York: Heny Holt and Company.

Bernard, C. (1878). *Lecons sur les phonomenes de la vie communes aux animaux et aux vegetaux.* Paris: Bailliere.

Beurle, R. (1962). Functional Organization in Random Networks. In H. V. Foerster, & G. Zopf (Eds.), *Principles of Self-Organization.* Oxford: Pergamon.

Bitbol, M., & Osnaghi, S. (2013). Bohr's Complementarity and Kant's Epistemology. *Seminaire Poincare XVII*, 145-166.

Black, M. M. (1935). Mechanism's Last Stand. *Social Science, Vol. 10, No. 1*, 22-33.

Blanchard, B., & Fabrycky, W. (1981). *Systems Engineering and Analysis.* Upper Saddle River, NJ: Pearson Education.

Bohr, N. (1928). The Quantum Postulate and the Recent Development of Atomic Theory. *Nature, Vol. 121*, 580-590.

Bohr, N. (1949). *Philosophical Writings of Niels Bohr, Vol. 2.*

Bohr, N. (1958). *Atomic Physics and Human Knowledge.* New York: John Wiley and Sons, Inc.

Bohr, N. (1961). *Atomic Theory and the Description of Nature.* Cambridge: The University Press.

Boisot, M., & Child, J. (1999). Organizations as Adaptive Systems in Complex Environments: The Case of China. *Organization Science*, 237-252.

Boltzmann, L. (1905). *Populare Schriften.* Leipzig: J. A. Barth.

Boulding, K. (1956). General systems theory: the skeleton of science. *Management Science, 2, 3 (Apr. 1956)*, 197-208.

Boulding, K. (1966). *The Impact of Social Sciences.* New Brunswick, NJ: Rutgers University Press.

Boulding, K. (1985). *The World as a Total System.* Los Angeles: Sage Publications.

Bourgine, P., & Stewart, J. (2004). Autopoiesis and Cognition. *Artificial Life, Vol 10*, 327–345.

Bradley, G. (2008). ICT, Work Organizations, and Society. In C. Van Slyke (Ed.), *Information Communication Technologies: Concepts, Metholdogies, Tools, and Applications* (pp. 3273-3284). Hershey, PA: Information Science Reference.

Brantbjerg, M., & Jørgenen, S. (2001). *Coping Skills and Survival Strategies in Relation to Trauma and Traumatic Stress.* Retrieved Dec 1, 2015, from Moaiku: http://www.moaiku.com

Braun, W. (2002). The Systems Archetypes. In *The Systems Modeling Workbook.*

Broad, C. (1925). *The Mind and its Place in Nature.* London: Kegan Paul & Company.

Bruner, J. S. (1957). On perceptual readiness. *Psychological Review, Vol 64(2), Mar 1957*, 123-152.

Buckley, W. F. (1967). *Sociology and Modern Systems Theory.* Englewood Cliffs, NJ: Prentice-Hall.

Caldwell, R. (2005). Leadership and learning. a critcal reexamination of Senge's learning organization. *Systemic Practice and Action Research, Vol. 18, No.4, Aug. 2005*.

Cambridge Dictionary of Philosophy. (1999). Cambridge: Cambridge University Press.

Campbell, D. (1974). Downward Causation In Hierarchically Organized Biological Systems. In F. Ayala, & T. Dobzhansky (Eds.), *Studies in the Philosophy of Biology: Reduction and Related Problems* (pp. 179-186). Berkeley, CA: University of California Press.

Cannon, W. (1929). Organization for Physiological Homeostasis. *Physiological Reviews, Vol. 9*, 399-431.

Cannon, W. (1932). *Wisdom of the Body.* New York: Norton.

Cauer, E., Mathis, W., & Pauli, R. (2000). Life and Work of Wilhelm Cauer (1900 – 1945). *Poceedings of MTNS2000.* Perpignan.

Cauer, W. (1941). *Theorie der linearen Wechselstromschaltungen, Vol. 1.* Leipzig: Verlags-Gesellschaft Becker und Erler.

Chalmers, D. (1997). *The Conscious Mind: In Search of a Fundamental Theory.* Oxford: Oxford University Press.

Chapman, C. (1979). Large Engineering Project Risk Analysis. *IEEE Transactions of Engineering Management, EM-26, No. 3*, 78-85.

Chase, W., & Simon, H. (1973). Perception in Chess. *Cognitive Psychology, Vol. 4*, 55-81.

Checkland, P. (1980). Are organizations machines? *Futures Vol. 12, Iss. 5, (Oct. 1980)*, 420-424.

Checkland, P. (1981). *Systems Thinking, Systems Practice.* Hoboken: John Wiley & Sons Ltd.

Chen, P. (1991). Nonequilibrium abd Nonliearity -- A Bridge Between the Two Cultures. In G. P. Scott, *Time, Rythms and Chaos in teh New Dialogue with Nature* (pp. 67-85). Ames, Iowa: The Iowa State University Press.

Cherns, A. (1976). The Principle of Sociotechnical Design. *Human Relations, Vol. 29, No. 8*, 783-792.

Cherns, A. (1976). The Principles of Sociotechnical Design. *Human Relations, Vol. 29, No. 8*, 783-792.

Cherns, A. (1977). Can Behavioral Science Help Design Organizations. *Organizational Dynamics*, 44-64.

Cherns, A. (1987). The Principles of Sociotechnical Design Revisted. *Human Relations, Vol. 40, No. 3*, 153-161.

Child, J., & Rodriques, S. (2012). How Organizations Engage with External Complexity. In A. Davila, M. Elvira, J. Ramirez, & L. Zapata-Cantu (Eds.), *Understanding Organizations in Complex, Emergent and Uncertain Environments* (pp. 13-44). New York: Palgrave Macmillan.

Choi, T., Dooley, K., & Rungtusanatham, M. (2001). Supply networks and complex adaptive systems: control versus emergence. *Journal of Operations Management, Vol. 19, No. 3*, 351–366.

Chomsky, N. (1956). Three Models for the Description of Language. *Information Theory, IRE Transactions, Vol. 2, No. 3*, 113-124.

Chomsky, N. (1959). On Certain Formal Properties of Grammars. *Information and Control, Vol. 2*, 137-167.

Chorley, R. J. (1962). *Geomorphology and General Systems Theory.* Washington: United States Government Printing Office.

Christen, M., & Franklin, L. (2002). The Concept of Emergence in Complexity Science: Finding Coherence between Theory and Practice. *Proceedings of the Complex Systems Summer School.*

Churchman, C. W. (1963). The X of X. *Management Science, Vol. 9, No. 3*, 351-357.

Churchman, C. W. (1971). *The Design of Inquiring Systems.* New York: Basic Books.

Cicchetti, D., & Rogosch, F. (1996). Equifinality and Multifinality in Developmental Psychopathology. *Development and Psychopathology, Vol. 8, No. 4*, 597-600.

Cilliers, P. (1998). *Complexity and postmodernism: Understanding complex systems.* New York: Routledge.

Cilliers, P. (1998). *Complexity and Postmodernism: Understanding Complex Systems.* New York: Routledge.

Clausius, R. (1867). *The Mechanical Theory of Heat.* London: MacMillan and Company.

Clemson, B. (1984). *Cybernetics: A New Management Tool.* Philadelphia: Abacus Press.

Clifford, J. (1982). *Person and Myth: Maurice Leenhardt in the Melanesian World.* Durham, NC: Duke University Press.

Conant, R., & Ashby, W. R. (1970). EVery Good Regualtor of a System Must be a Model of That System. *International Journal of Systems Science, Vol. 1, No. 2*, 89-97.

Console, L., & Torasso, P. (1991). A spectrum of logical definitions of model based diagnosis. *Computational Intelligence, Vol. 7, No. 3*, 133-141.

Corballis, M. C. (2014). *The Recursive Mind: The Origins of Human Language, Thought, and Civilization.* Princeton: Princeton University Press.

Cornell Lab of Ornothology. (2006, June 27). *Migration.* Retrieved June 9, 2015, from All About Birds.

d'Alembert, J. L. (1743). *Traite' de Dynamique.* Paris: l'Academie Royale des Sciences.

Danesi, M. (2013). *Encyclopedia of Media and Communication.* Toronto: University of Toronto Press.

Davis, L. E. (1982). Organizational Design. In G. Salvendy (Ed.), *Handbook of Industrial Engineering* (pp. 2.1.1-2.1.29). New York: Wiley.

Davis, R. (1958). The Domain of Homeostasis. *Psychological Review, Vol. 65, No. 1*, 8-13.

de Bono, E. (1985). *Six Thinking Hats: An Essential Approach to Business Management.* New York: Little, Brown & Company.

de Maré, P. (1972). *Perspectives in Group Psychotherapy.* New York: Routledge.

Dekkers, R. (2014). *Applied Systems Theory.* Springer.

Dempster, B. (2000). Sympoietic and Autopoietic Systems: A New Distinction for Self-Organizing Systems. *Proceedings of the World Congress of the Systems Sciences and ISSS 2000.* Toronto.

Denis, D., & Legerski, J. (2006). Causal Modeling and the Origins of Path Analysis. *Theory and Science*.

Descartes, R. (1637). *Discours de la Méthode.*

Descartes, R. (1637). *La Dioptrique.*

Dewey, J. (1918). Philosophy and Democracy. *University [of California] Chronical, Vol. 21*, 39-54.

Dodis, C., Kitis, K., & Panagiotakopoulos, D. (2005). *Organizational cybernetics for waste management authorities: a case study.* Xanthi, GR: Democritus University of Thrace.

Douglas, M. (1966). *Purity and Danger.* New York: Routledge.

Douglas, W. (1929). Vicarious Liability and Administration of Risk I. *The Yale Law Journal, Vol. 38, No. 5*, 584-604.

Downer, J. (2009). *When Failure is an Option: Redundancy, Reliability and Regulation in Complex Technical Systems.* London: Economic and Social Research Council.

Driesch, H. (1908). *The Science and Philosophy of the Organism.* New York: The Macmillan Company.

Drucker, P. F. (1955). "Management Science" and the Manager. *Managment Science, Vol. 1, No. 2*, 115-126.

Eddington, A. (1928). *The Nature of the Physical World.* New York: The Macmillan Company.

Edmonds, B. (1999). *Syntactic Measures of Complexity.* Manchester: University of Manchester.

Eigen, M. (1967). Immeasurably Fast Reactions. *Nobel Lecture, December 11, 1967*.

Eijnatten, F. M. (1992). *The Paradigm that Changed the Work Place: Annals of STSD.* Eindhoven University of Technology.

Eisenhart, M. (1991). Conceptual frameworks for research circa 1991: Ideas from a cultural anthropologist; implications for mathematics education researchers. *Proceedings of* *the 13th annual meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education, Vol. 1*, (pp. 202-219). Blacksburg, VA.

Eldredge, N., & Gould, S. J. (1972). Punctuated Equilibria: An Alternative to Phyletic Gradualism. In T. Schopf (Ed.), *Models in Paleobiology* (pp. 82-115). San Francisco: Freeman Cooper.

Emery, F. (1967). The Nine Step Model. In E. Trist, & H. Murray (Eds.), *The Social Engagement of Social Sciences: Volume II, The Socio-Technical Persective (1993)* (pp. 369-379). University of Pennsylvania Press.

Emery, F., & Emery, M. (1974). *Participative Design: Work and Community Life.* Canberra: Australian National University, Centre for Continuing Education.

Emery, F., & Trist, E. (1960). Socio-Technical Systems. In C. Churchman, & M. Verhurst (Eds.), *Management Science, Models and Techniques* (pp. 83-97). London: Pergamon Press.

Emery, F., & Trist, E. (1972). *Towards a Social Ecology.* Harmondsworth, U.K.: Penguin.

Enver, T., Pera, M., Peterson, C., & Andrews, P. W. (2009). Stem Cell States, Fates, and the Rules of Attraction. *Cell Stem Cell, Vol. 4, No. 5*, 387-397.

Eriksson, D. (2004). On the Usefulness of the Ackoff–Gharajedaghi Model of System Types for the Design of Business Systems. *Systemic Practice and Action Research, Vol. 17, No. 2, Ap. 2004*, 75-81.

Eriksson, K. (2011). *Communication in Modern Social Ordering: History and Philosophy.* New York: Bloomsbury Publishing.

Eronen, M. (2004). *Emergence in the Philosophy of Mind.* Helsinki: Department of Philosophy, University of Helsinki.

Espejo, R. (2003). *The viable systems model: a briefing about organizational structure.* Syncho Limited.

Estes, R. (1991). *The Behavior Guide to African Mammals.* Berkeley: University of California Press.

Fazar, W. (1959). Program Evaluation and Review Technique. *The American Statistician, Vol. 13, No. 2*, 10.

Feiring, C., & Lewis, M. (1987). Equifinality and Multifinality: Diversity in Development from Infancy into Childhood. *Biennial Meeting of the Society for Research in Child Development.* Baltimore, MD.

Fetter, F. (1920). Price Economics versus Welfare Economics. *The American Economic Review, Vol. 10, No. 3*, 467-487.

Flagle, C., Huggins, W., & Roy, R. (1960). *Operations Research and Systems Engineering.* Baltimore: The Johns Hopkins Press.

Flear, C. (1948). Background to Physiology. *Queens Medical Magazine, Vol. 41*, 26.

Flood, R. (1999). *Rethinking the Fifth Discipline.* New York: Routledge.

Flood, R., & Carson, E. (1993). *Dealing With Complexity: An Introduction to the Theory and Application of System Science.* New York: Plenum Press.

Forrester, J. W. (1961). *Industrial Dynamics.* Cambridge: Pegasus Communications.

Forrester, J. W. (1969). *Urban Dynamics.* Cambridge: Pegasus Communications.

Forrester, J. W. (1971). *World Dynamics.* Cambridge: Wright-Allen Press.

Fromm, J. (2004). *The Emergence of Complexity.* Kassel: Kassel University Press.

Furia, G. (2008). *Project Management Recipes for Success.* Boca Raton: Taylor & Francis Group.

Gagliasso, E. (2001). The Metamorphosis of Holism. In V. Benci (Ed.), *Determinism, Holism, and Complexity* (pp. 339-348). New York: Plenum Publishers.

Gasson, S. (2003). Rigor in grounded theory research - an interpretive perspective on generating theory from qualitative field studies . In M. a. Whitman, *Handbook for Information Systems Research* (pp. 79-102). Hershey, PA: Idea Group Publishing.

Gell-Mann, M. (1994). *The Quark and the Jaguar.* New York: Henry Holt and Company.

Gell-Mann, M. (1995). What is Complexity? *Complexity, Vol. 1, Iss. 1*, 16-19.

Gershenson, C. (2007). *Design and Control of Self-Organizing Systems.* Boston: CopIt ArXives.

Geyer, R. F., & Van Der Zouwen, J. (1992). Sociocybernetics. In C. V. Negoita (Ed.), *Cybernetics and Applied Systems* (pp. 95-124). New York: Marcel Dekker.

Gharajedaghi, J. (2011). *Systems Thinking: Managing Chaos and Complexity, 3rd. Ed.* Burlington, MA: Morgan Kaufmann.

Gibson, R. E. (1964). Our heritage from Galileo Galilei. *Science, Vol 145, No. 3638*, 1271-1276.

Gilbert, D. (2002). Inferential Correction. In T. Gilovich, D. Griffin, & D. Kahneman (Eds.), *Heuristics and Biases: The Psychology of Intuitive Judgment* (pp. 167-184). Cambridge: Cambridge University Press.

Gilbert, G. K. (1877). *Report on the Geology of the Henry Mountains.* Washington: Government Printing Office.

Glaser, B. G. (1978). *Theoretical Sensitivity.* Mill Valley, CA: Sociology Press.

Glaser, B. G. (1992). *Emergence vs. Forcing: Basics of Grounded Theory Analysis.* Mill Valley, CA: Sociology Press.

Glaser, B. G. (1998). *Doing Grounded Theory: Issues and discussion.* Mill Valley, CA: Sociology Press.

Glaser, B. G. (2001). *The Grounded Theory Perspective: Conceptualization Contrasted with Description.* Mill Valley, CA: Sociology Press.

Glaser, B. G. (2007). Remodeling grounded theory. *Historical Social Research, Supplement, No. 19*, 47-68.

Glaser, B. G., & Strauss, A. (1967). *The Discovery of Grounded Theory.* Rutgers, NJ: AldineTransaction.

Goldsmith, J. (1953). A 'Simplexity Principle' and its Relation to 'Ease' pf Crystallization. *Journal of Geology, Vol. 61*, 439-451.

Goodman, M. a. (1993). Using the archetype family tree as a diagnostic tool. *The Systems Thinker, Dec. 1993/Jan. 1994*.

Goodwin, B. (1963). *Temporal Organization in Cells: A Dynamic Theory of Cellular Control Processes.* London: Academic Press.

Gottlieb, G. (2003). Probabilistic Epigenesis of Development. In J. Valsiner, & K. Connolly (Eds.), *Handbook of Developmental Psychology* (pp. 3-17). Thousand Oaks California: Sage Publications Inc.

Hartley, R. (1928). Transmission of Information. *Bell System Technical Journal, Vol. 7, No. 3*.

Hatfield, A., & Hipel, K. (2002). Risk and Systems Theory. *Risk Analysis, Vol. 22, No. 6*, 1043-1057.

Haynes, P. (1974). Toward a Concept of Monitoring. *The Town Planning review, Vol. 45, No. 1*, 5-29.

Haynes, R. H. (1990). Ecce Ecopoiesis: Playing God on Mars. In D. MacNiven (Ed.), *Moral Expertise: studies in practical and professional ethics* (pp. 161-163). London: Routledge.

Hedges, B. (1965). A Methodology for a Course in Risk Management. *The Journal of Risk and Insurance, Vol. 32, No. 4*, 609-615.

Heisenberg, W. (1925). Über quantentheoretische Umdeutung kinematischer und mechanischer Beziehungen. *Zeitschrift für Physik*, 879-893.

Heisenberg, W. (1927). Über den anschaulichen Inhalt der quantentheoretischen Kinematik und Mechanik. *Zeitschrift für Physik* , 172–198.

Hendricks, E., Jannerup, O., & Sorensen, P. (2008). *Linear Systems Control: Deterministic and Stochastic Methods.* Berlin: Springer Science & Business Media.

Herbst, P. (1957). "Measurement of Behaviour Structures by Means of Input-Output Data". *Human Relations, Vol. 10, No. 4*, 335-346.

Herbst, P. (1974). *Socio-Technical Design: Strategies in Multidisciplinary Research.* London: Tavistock Publications.

Hester, P., & Adams, K. (2014). *Systemic Thinking: Fundamentals for Understanding Problems and Messes.* New York: Springer.

Heylighen, F. (1991). Modeling Emergence. *World Futures: The Journal of General Evolution, Vol. 31*, 89-104.

Heylighen, F., & Joslyn, C. (2001). Cybernetics and Second-Order Cybernetics. In R. Meyers (Ed.), *Encyclopedia of Physical Science and Technology* (pp. 155-170). New York: Academic Press.

Hilder, T. (1995). *The viable systems model (Presentation).* Trowbridge, England: Cavendish Software.

Hitch, C. J. (1953). Sub-Optimization in Operations Research. *Journal of the Operations Research Socity of America, Vol. 1, No.3*, 87-99.

Hitchins, D. (1992). *Guide to the Practice of Systems Engineering.*

Hitchins, D. (2003). *Advanced Systems Thinking, Engineering, and Management.* London: Artech House Books.

Hitchins, D. (2007). *Systems Engineering: A 21st Century Systems Methodology.* Hoboken: John Wiley & Sons.

Holmes, F. (1986). Claude Bernard, The Milieu Interieur, and Regulatory Physiology. *History and Philosophy of the Life Sciences, Vol. 8, No. 1*, 3-25.

Holton, J. (2007). The coding process and its challenges. In A. &. Bryant, *The Sage Handbook of Grounded Theory* (pp. 265-289). Thousand Oaks, CA: Sage.

Hoogendoorn, S., & Daamen, W. (2005). Self-Organization in Pedestrian Flow. In S. Hoogendoorn, S. Luding, P. Bovy, M. Schrekenberg, & D. Wolf (Eds.), *Traffic and Granular Flow '03* (pp. 373-382). Berlin: Springer-Verlag.

Huffman, D. A. (1952). A Method for the Construction of Minimum-Redundancy Codes. *Proceedings of the Institute of Radio Engineers, Vol. 40*, 1098-1101.

Hurka, T. (1990). Two Kinds of Satisficing. *Philosophical Studies: An International Journal for Philosophy in the Analytic Tradition, Vol. 59, No. 1*, 107-111.

Hurt, H. H. (1965). *Aerodynamics for Naval Aviators.* Naval Air Systems Command.

Huurdeman, A. (2003). *The Worldwide History of Telecommunications.* New York: John Wiley & Sons.

Iberall, A., & McCulloch, W. (1968). 1967 Behavioral Model of Man - His Chains Revealed. In *Currents in Modern Biology I* (pp. 337-352). Amsterdam: North-Holland Publishing Company.

IHSA. (2011, Feb 15). *Hierarchy of Controls*. Retrieved Dec 4, 2015, from BeSMART.ie: http://besmart.ie/fs/doc/Hierarchy of Controls.15feb11.kb.pdf

Jackson, M. C. (2000). *Systems Approaches to Management.* New York: Kluwer Academic.

Jamshidi, M. (2011). *System of Systems Engineering: Innovations for the Twenty-First Century.* Hoboken: John Wiley & Sons.

John, O. P., Robins, R. W., & Pervin, L. A. (2008). *Handbook of Personality, Third Edition: Theory and Research.* New York: Guilford Press.

Johnson, N. (2007). *Two's Company, Three is Complexity: A Simple Guide to the Science of All Sciences.* Oxford: One World.

Johnson, W. S. (1883). *Patent No. 281884.* USA.

Jones, C., Lawton, J., & Shachak, M. (1994). Organisms as Ecosystem Engineers. *Oikos, Vol. 69*, 373-386.

Kant, I. (1781). *Critique of Pure Reason.*

Kant, I. (1783). *Prolegomena to any Future Metaphysics - Translated 1912.* (P. Carus, Trans.) Chicago: Open Court Publishing.

Katz, D., & Kahn, R. (1966). *The Social Pschology of Organizations.* New York: Wiley.

Kauffman, L. (1987). Self-Reference and Recursive Forms. *Journal of Social and Biological Structures, Vol. 10, No. 1*, 53-72.

Kauffman, S. (1993). *The Origins of Order: Self-Organization and Selection in Evolution.* New York: Oxford University Press.

Kawalek, P., & Wastell, D. (1999). A case study evaluation of the use of the viable systems model in information systems development. *Journal of Database Management, Vol. 10, No. 4, Oct-Dec. 1999*, 24-32.

Keating, C. (2012). *System of Systems Design Class 6: The Design and Information Axioms (Presentation).* Norfolk: Old Dominion University.

Keating, C., & Katina, P. (2012). Prevalence of pathologies in systems of systems. *International Journal of System of Systems Engineering, Vol. 3, Nos. 3/4*, 243-267.

Keating, C., & Morin, M. (2001). An Approach for Systems Analysis of Patient Care Operations. *Journal of Nursing Administration, Vol. 31, No. 7/8*, 355-363.

Keating, C., Katina, P., & Bradley, J. (2014). Concept systems governance: concept, challenges and emerging research. *International Journal of System of Systems Engineering, Vol.5, No.3*, 263-288.

Kelley, J., & Walker, M. (1959). Critical-Path Planning and Scheduling. *Proceedings of the Eastern Joint Computer Conference.*

Kerzner, H. (1979). *Project Management: A Systems Apporoach.* New York: Reinhold Publishers.

Kerzner, H. (2010). *Project Management - Best Practices.* Hoboken: John Wiley & Sons, Inc.

Kilby, R. W. (1948). Psychoneurosis in Times of Trouble: Evidence for a Hierarchy of Motives. *Journal of Abnormal and Social Psychology, Vol. 43, No. 4*, 544-545.

Kilmer, W., McCulloch, W., & Blum, J. (1969). A model of the vertebrate central command system. *International Journal of Man-Machine Studies, Vol. 1*, 279-309.

Kilmer, W., McCulloch, W., & Blum, J. (1969). *The Reticular Formation.* East Lansing, Michigan: Michigan State University.

Kimball, G., & Howard, R. (1959). Sequential Decision Processes. *Notes on Operations Research, 1959*, 153.

Kline, M. (1972). *Mathematical Thought From Ancient to Modern Times, Volume 2.* New York: Oxford University Press.

Koestler, A. (1967). *Ghost in the Machine.* New York: Macmillan.

Konopka, A. (2015). *Systems Biology: Principles. Methods, and Concepts.* Boca Raton. FL: CRC Press.

Koob, G., & Moal, M. (1997). Hedonic Homeostatic Dysregulation. *Science, New Series, Vol. 278, No. 5335*, 52-58.

Korzybski, A. (1933). *Science and Sanity.* New York: E.P. Dutton.

Kosciejew, R. J. (2014). *The Treadmills of Time.* Bloomington, IN: AuthorHouse.

Krippendorff, K. (1981). An Alogorithm for Identifying Structural Models of Multivariate Data. *International Journal of General Systems, Vol. 7, No. 1*, 63-79.

Kruglanski, A. W., Köpetz, C., Bélanger, J. J., Chun, W. Y., Orehek, E., & Fishbach, A. (2013). Features of Multifinality. *Personality and Social Psychology Review, Vol. 17, No. 1*, 22-39.

Kurtz, C., & Snowden, D. (2003). The New Dynamics of Strategy. *IBM Systems Journal*, 1-23.

Landau, M. (1969). Redundancy, Rationality, and the Problem of Duplication and Overlap. *Public Administration Review, Vol. 29, No. 4*, 346-358.

Laplace, P.-S. (1814). *Philosophical Essay on Probability.* (F. W. (1902), Trans.) New York: John Wiley & Sons.

Laszlo, E. (1969). *System, Structure and Experience: Toward a Scientific Theory of Mind.* London: Taylor & Francis.

Le Chatelier, H. L. (1884). A General Statement of the Laws of Chemical Equilibrium. *Comptes rendus, Vol. 99*, 786.

Le Chatelier, H. L. (1888). Recherches Experimentales et Theoriques sur les Equilibres Chimiques (Experimental and Theoretical Research on Chemical Equilibria). In *Annales des Mines, Hutieme Serie, Memiories, XIII.* Paris: Dunod.

Lee, J., Kirlik, A., & Dainoff, M. (2013). *The Oxford Handbook of Cognitive Engineering.* Oxford: Oxford Unversity Press.

Leenhardt, M. (1909). *La Grande Terre.*

Lehn, J.-M. (2002). Toward Complex Matter: Supermolecular Chemistry and Self-Organization. *Proceedings of the National Academy of Science, Vol. 99, No. 8*, 4763-4768.

Lenk, H., & Stephan, A. (2002). On Levels and Types of Complexity and Emergence. In E. Agazzi, & L. Montecucco (Eds.), *Complexity and Emergence* (pp. 13-28). Singapore: World Scientific Publishing Company.

Lenton, T. M., & Wilkiinson, D. M. (2003). Developing the Gaia Theory. *Climatic Change, Vol. 58*, 1-12.

Leonard, A. (1984). Technical Notes. In C. Barry, *Cybernetics: A New Management Tool.* Abacas Press.

Leonard, A. (1990). *Coming Concepts: The Cybernetics Glossary for New Management.* Toronto: Unpublished Work.

Leonard, A. (1990). *Coming Concepts: The Cybernetics Glossary for New Management.* Toronto: Unpublished Work.

Leonard, A. (1990). *Coming Concepts: The Cybernetics Glossary for New Management.* Toronto: Unpublished Work.

Leonard, A. (1999). A Viable System Model: Consideration of Knowledge Management. *Journal of Knowledge Management Practice*.

Leonard, A. (2011). Governance in the Relative When. *Systems Research and Behavioral Science, Vol. 28*, 431–436.

Lester, F. (2005). On the theoretical, conceptual, and philosophical foundations for research in mathematics education. *Zentralblatt für Didaktik der Mathematik 2005, Vol. 37, No. 6*, 457-467.

Lettvin, J., Maturana, H., McCulloch, W., & Pitts, W. (1968). What the Frog's Eye Tells the Frog's Brain. In W. Corning, & M. Balaban (Eds.), *The Mind: Biological Approaches to its Functions* (pp. 233-258).

Levin, P. (1997). *Waking the Tiger: Healoing Trauma.* Berkeley, CA: North Atlantic Books.

Levine, A. J. (1940). The Purposivist School of Psychology. In *Current Psychologies: A Critical Synthesis* (pp. 127-147). Cambridge, MA: Sci-Art Publishers.

Levins, R., & Lewontin, R. (1985). *The Dialectical Biologist.* Cambridge: Harvard University Press.

Lewes, G. (1875). *Problems of Life and Mind.* Boston: Houghton, Osgood and Company.

Lewis, F. (1992). A Brief History of Feedback Control. In F. Lewis, *Applied Optimal Control and Estimation.* Upper Saddle River: Prentice-Hall.

Lewis, G. (1930). The Symmetry of Time in Physics. *Science, Vol. 71*, 569-576.

Libuser, C. (1994). *Organizational Structure and Risk.* Los Angeles: University of California Press.

Linnaeus, C. (1735). Systema Naturae.

Lipson, H. (2004). Principles of Modularity, Regularity, and Hierarchy for Scalable Systems. *Genetic and Evolutionary Computation Conference (GECCO 2004) Workshop on Modularity, Regularity and Hierarchy.* Seattle.

Locke, J. (1689). *Essay Concerning Human Understanding.* London: Rivington.

Lorenz, E. (1972). Predictability: does the flap of a butterfly's wings in Brazil set off a tornado in Texas? In E. Lorenz, *Essence of Chaos (1995)* (pp. 181-184). Seattle: University of Washington Press.

Lovelock, J. E. (1972). Gaia as seen through the atmosphere. *Atmospheric Environment, Vol 6.*, 579-580.

Lovelock, J. E. (1987). The Ecopoiesis of Daisy World. In J. Robson (Ed.), *Origin and Evolution of the Universe: Evidence for Design* (pp. 153-166). Montreal: McGill-Queen's University Press.

Luhman, N. (2000). *Organisation und Entscheidung.* Opladen: Westdeutscher Verlag.

Luhmann, N. (1983). Insistence on Systems Theory: Perspectives. *Social Forces, Vol. 61, No. 4*, 987-998.

Luhmann, N. (1990). The Autopoiesis of Social Systems. In *Essays on Self-Reference* (pp. 1-20). New York: Columbia University Press.

Lustick, I. (1980). Explaining the Variable Utility of Disjointed Incrementalism: Four Propositions. *The American Political Science Review, Vol. 74, No. 2*, 342-353.

Maguire, S., McKelvey, B., Mirabeau, L., & Oztas, N. (2006). Complexity Science and Organization Studies. In S. Clegg, C. Hardy, T. Lawrence, & W. Nord (Eds.), *The Sage Handbook of Organizational Studies, 2nd Ed.* (pp. 165-214). Thousand Oaks, CA: Sage Publications.

Mahoney, M. S. (1994). *The Mathemantical Career of Pierre de Fermat, 1601-1665.* Princeton: Princeton University Press.

Malthus, T. R. (1798). *An Essay on the Principle of Population.* London: J. Johnson.

Marais, K. S. (2006). Archetypes for Organizational Safety. *Safety Science, Volume 44, Issue 7, August 2006*, 565-582.

March, J. (2006). Rationalitym Foolishness, and Adaptive Intelligence. *Strategic Management Journal, Vol. 27, No. 3*, 201-214.

Margulis, L., & Sagan, D. (1986). *Origins of Sex: Three Billion Years of Genetic Recombination.* New Haven: Yale University Press.

Marschak, J. (1971). Economics of Information Systems. *Journal of the American Statistical Association, Vol. 66, No. 333*, 192-219.

Martinelli, D. (2001). Systems hierarchies and management. *Systems Research, Vol. 18*, 69-82.

Martinelli, D. (2001). Systems Hierarchies and Management. *Systems Research and Behavioral Science*, 69-82.

Maruyama, M. (1963). The Second Cybernetics: Deviation-Amplifying Mutual Causal Processes. *American Scientist, Vol. 5, No. 2*, 164-179.

Marvin, W. T. (1918). Mechanism versus Vitalism as a Philosophical Issue. *The Philosophical Review*, 616-627.

Maslow, A. H. (1943). A Preface to Motivation Theory. *Psychosomatic Medicine, Vol. 5, No. 1*, 85-92.

Maslow, A. H. (1943). A Theory of Human Motivation. *Psychological Review, Vol. 50, No. 4*, 370-396.

Maslow, A. H. (1954). *Motivation and Personality.* New York: Harper & Row.

Maslow, A. H. (1955). Deficiency Motivation and Growth Motivation. In M. Jones (Ed.), *Nebraska Symposium on Motivation* (pp. 1-30). Lincoln, NE: University of Nebraska Press.

Maturana, H. (1981). Autopoiesis. In M. Zeleny (Ed.), *Autopoiesis: A Theory of Living Organizations.* New York: North Holland.

Maturana, H., & Varela, F. (1980). *Autopoiesis and Cognition: The Realization of the Living.* Dordrecht, Holland: D. Reidel Publishing Company.

Maupertuis, P. L. (1744). Accord de différentes lois de la nature qui avaient jusqu'ici paru incompatibles. *Mém. de l`Acad. des Sci.*

Maupertuis, P. L. (1746). Les Loix du mouvement et du repos déduites d'un principe metaphysique. *Histoire de l'Académie Royale des Sciences et des Belles Lettres*, 267-294.

Maxwell, J. (1868). Governors. *Proceedings of the Royal Society.*

Maxwell, J. C. (1867). On the Dynamical Theory of Gases. *Philosophical Transactions of the Royal Society of London, Vol. 157*, 49-88.

Mayr, O. (1971). Maxwell and the Origins of Cybernetics. *Isis, Vol. 62, No. 4*, 424-444.

McCulloch, W. (1959). Where Fancy is Bred. In W. McCulloch (Ed.), *Embodiments of Mind* (pp. 216-229). Cambridge: MIT Press.

McCulloch, W. (1965). *Embodiments of Mind.* Cambridge: MIT Press.

McCulloch, W., & Brody, W. (1967). The Biological Sciences. In *Encyclopedia Britannica Review of the Biological Sciences.*

McDougall, W. (1911). *Body and Mind: A History and Defense of Animism.* New York: The Macmillan Company.

McKeown, L. (2006). *The Pencil Metaphor*. Retrieved September 11, 2012, from http://www.teachers.ash.org.au/lindy/pencil/pencil.htm

McMillan, B. (1953). The Basic Theorems of Information Theory. *The Annals of Mathematical Statistics, Vol. 24, No. 2*, 196-219.

Meadows, D. M. (1972). *Limites to Growth.* New York: New York American Library.

Meadows, D., Meadows, D., Randers, J., & Behren III, W. (1973). A Response to Sussex. *Futures, February*, 135-152.

Medina, E. (2006). Designing freedom, regulating a nation: socialist cybernetics in Allende's Chile. *Journal of Latin American Studies, Vol. 38*, 571-606.

Meinhardt, H. (1995). *The Algorithmic Beauty of Sea Shells.* Berlin: Springer-Verlag.

Merriam-Webster. (2015). *Merriam-Webster Online Dictionary*. Retrieved from http://www.merriam-webster.com/

Mill, J. S. (1843). *A System of Logic: Ratioconative and Inductive.* New York: Harper & Brothers, Publishers.

Mill, J. S. (1863). *Utilitarianism.* London: Longmans, Green, Feader and Dyer.

Miller, E. (1959). Technology, Territory and Time: The Internal Differentiation of Complex Production. *Human Relations, Vol. 12*, 243-272.

Miller, G. (1956). The magical number seven, plus or minus two: some limits on our capacity for processing information. *Psychological Review, Vol. 63*, 81-97.

Miller, G. (1956). The Magical Number Seven, Plus or Minus Two: Some Limits on our Capacity for Processing Information. *Psychology Review, Vol. 63*, 81-97.

Miller, J. (1978). *Living Systems.* New York: McGraw Hill.

Mills, J. (1929). Some Universal Principles of Communication. *The Scientific Monthly, Vol. 29, No. 1*, 53-60.

Miner, J. (2011). *Organizational Behavor 6: Integrated Theory Development and the Role of the Unconscious.* M.E. Sharpe.

Morgan, C. L. (1923). *Emergent Evolution.* London: Williams and Norgate.

Morgan, G. (1989). Organizational Choice and the New Technology. In S. Wright, & D. Morley (Eds.), *Learning Works: Searching for Organizational Futures.* Toronto: York University.

Morse, P., & Kimball, G. (1951). *Methods of Operations Research.* New York: John Wiley and Sons, Inc.

Muller, T., & Muller, H. (2003). *Modelling in Natural Science: Design, Validation and Case Studies.* Berlin: Springer-Verlag.

Needham, J. (1936). *Order and Life.* Cambridge: M.I.T. Press.

Newton, I. (1672). A series of Quere's propounded by Mr. Isaac Newton, to be determin'd by Experiments, positively and directly concluding his new Theory of Light and Colours. *Philosophical Transactions, Vol. 7*, 4004-5007.

Newton, I. (1687). *Philosophiae naturalis principia mathematica.* London: The Royal Society, Printed by Joseph Streater.

Newton, I. (1687). *Principia Mathematica.*

Newton, I. (1730). *Opticks or a Treatise of the Reflections, Refractions & Colours of Light.* London.

Nicolis, G., & Prigogine, I. (1977). *Self-Organization in Nonequilibrium Systems: From Dissipative Structures to Order through Fluctuations.* New York: John Wiley.

Niklas, K. (1994). *Plant Allometry: The Scaling of Form and Process.* Chicago: University of Chicago Press.

NYCOSH. (2014, Oct). *Hierarchy of Hazard Controls*. Retrieved 12 4, 2015, from New York Committe for Occupational Safety and Health: http://nycosh.org

Oceanic Research Group. (1995). *Sharks and How They Live.* Retrieved June 17, 2015, from O.R.G. Educational Films: http://www.oceanicresearch.org/education/films/sharkspt.html

Orkin. (2003, June). *How do Honey Bees Make Hives*. Retrieved June 17, 2015, from Honey Bee Hive Facts & Dangers of Hives: http://www.orkin.com/stinging-pests/bees/how-do-honeybees-make-hives/

Overall, J., & Williams, C. (1961). Models for medical diagnosis. *Behavioral Science*, 134-141.

Pappas, S. (2011, April 29). *Why Pigs Love Mud*. Retrieved June 17, 2015, from Live Science: http://www.livescience.com/13953-pigs-evolved-mud-wallowing.html

Perez Rios, J. (2010). Models of Organizational Cybernetics for Diagnosis and Design. *Kybernetes, Vol. 39, No. 9/10*, 1529-1550.

Perrow, C. (1984). *Normal Accidents: Living with High-Risk Technologies.* Basic Books.

Perry, B., Pollard, R., Blakely, T., Baker, W., & Vigilante, D. (1995). Childhood trauma, the neurobiology of adaptation and "use dependent" development of the brain: How "states" become "traits". *Mental Health Journal, Vol. 16, No. 4.*, 271-291.

Phillips, J. (1997). Simplexity and the Reinvention of Equifinality. *Geographical Analysis, Vol. 29, No. 1*.

Phondej, W., Kittisarn, A., & Neck, P. (2011). The seven steps of case study development: a strategic qualitative research methodology in female leadership field. *Review of International Comparative Management, Vol. 12, Iss. 1*, 123-134.

Pinker, S., & Jackendoff, R. (2005). The Faculty of Language: What's Special About It? *Cognition, Vol. 95*, 201-236.

Plotnitsky, A. (2014). What is complementarity?: Niels Bohr and the Architecture of Quantum Theory. *Physica Scripta, T163*.

Poincare, H. (1890). Sur le probleme des trios corps et les equations de la dynamique. *Acta Mathematica, Vol. 13*, 1-270.

Polanyi, M. (1970). Transcendence and Self-Transcendence. *Surroundings, Vol. 53, No. 1*, 88-94.

Pops, M. (1977). Perpetual Motions. *Salmagundi, No. 38/39*, 80-99.

Porges, S. (2001). The polyvagal theory: phylogenetic substrates of a social nervous system. *International Journal of Psychophysiology, Vol. 42*, 123-146.

Priest, C., Eshghi, K., & Bertolino, B. (1991). Consistency-based and abductive diagnoses as generalized stable models. *Annals of Mathematics and Artificial Intelligence, Vol. 11*, 51-74.

Putman, R., & Wratten, S. (1984). *Principles of Ecology.* Berkeley: University of California Press.

Quastler, H. (1953). *Essays on the Use of Information in Biology.* Urbana: University of Illinois Press.

Rapaport, A. (1972). The Uses of Mathematical Isomorphism in General System Theory. In G. J. Klir (Ed.), *Trends in General System Theory* (pp. 52-65). New York: Wiley.

Rapoport, A. (1968). The Promise and Pitfall of Information Theory. In W. F. Buckley (Ed.), *Systems Research for Behavioral Science* (pp. 137-143). New Brunswick: Transaction Publishers.

Reid, R. G. (2007). *Biological Emergences: Evolution by Natural Experiment.* Cambridge: MIT Press.

Reissberg, A. (2010). A Cybernetic Approach to Hurricane Hazard Management on O'Ahu, Hawaii. In A. Leonard (Ed.), *ISSS 2010: Governance for a Reslient Planet.* ISSS.

Reissberg, A. (2012). *Managing natural catastrophes: viable systems to prevent human tragedy.* Frankfurt: Campus Verlag.

Reynolds, E. (2002). The Deep Structure of Communication and Control . *2002 Conference of the American Society for Cybernetics.* Santa Cruz.

Reza, F. (1961). *An Introduction to Information Theory.* New York: McGraw-Hill.

Rice, A. K. (1958). *Productivity and Social Organization.* London: Tavistock Publications.

Richardson, G. (1986). Problems with causal loop diagrams. *System Dynamics Review, Vol. 2, No.2, Summer 1986*, 169.

Richardson, K. (2004). Systems theory and complexity: Part 1. *Emergence: Complexity & Organization, Vol.6, No. 3*, 75-79.

Robin, C., & Verdeil, F. (1853). *Traité de chimie anatomique et physiologique normale et pathologique.* Paris: Baillière.

Robinson, G. (1982). Acidents and Sociotechnical Systems: Principles for Design. *Accident Analysis & Prevention, Vol. 14, No. 2*, 121-130.

Rocha, L. (1998). Syntactic Autonomy. *Proceedings of the Joint Conference on the Science and Technology of Intelligent Systems* (pp. 706-711). Gaithersburg, MD: IEEE Press.

Rochlin, G., La Porte, T., & Roberts, K. (1987). The Self-Designing High-Reliability Organization: Aircraft Carrier Flight Operations at Sea. *Naval War College Review, Vol. 40, No. 4*, 76-90.

Rolleston, H. (1933). A Paper on Changes in the Character of Diseases. *The British Medical Journal, Vol. 1, No. 3768*, 499-500.

Rosenbleuth, A., Wiener, N., & Bigelow, J. (1943). Behavior, Purpose and Teleology. *Philosophy of Science, Vol. 10*, 18-24.

Rosenblueth, A., & Wiener, N. (1950). Purposeful and non-purposeful behavior. *Philosophy of Science, Vol. 17, No. 4*, 318-326.

Roux, W. (1914). *Die Selbstregulation, Ein Charakteristisches und Nicht Notwendig Vitalistisches Vermögen aller Lebewesen (The Self-Regulation, a Characteristic and Not Necessarily Vitalistic Capacity of All Organisms).* Berlin: Halle Karras.

Rumbaugh, J., Blaha, M., Premerlani, W., Eddy, F., & Lorensen, W. (1991). *Object Oriented Modeling and Design.* Upper Saddle River: Prentice-Hall.

Rumbaugh, J., Jacobson, I., & Booch, G. (1999). *The Unified Modeling Language Reference Manual.* Reading, Mass: Addison-Wesley.

Ryan, T., & Mothibi, J. (2000). Towards a Systemic Framework for Understanding Science and Technology Policy Formulation Problems for Devloping Countries. *Systems Research and Behavioral Science, Vol. 17*, 375-381.

Sato, T., Yasuda, Y., Kido, A., Arakawa, A., Mizoguchi, A., & Valsiner, J. (2007). Sampling Reconsidered. In J. Valsiner, & A. Rosa (Eds.), *The Cambridge Handbook of Sociocultural Psychology* (pp. 82-108). Cambridge: Cambridge University Press.

Schrodinger, E. (1946). *What is life? The physical aspect of the living cell.* New York: The Macmillan Company.

Schwartz, B., Ward, A., Monterosso, J., Lyubomirsky, S., White, K., & Lehman, D. R. (2002). Maximizing Versus Satisficing: Happiness Is a Matter of Choice. *Journal of Personality and Social Psychology, Vol. 83, No. 5*, 1178-1197.

Schwartz, L. (1966). Communication and the Computing Machine. In A. M. Hilton (Ed.), *The evolving society: The proceedings of the first annual Conference on the Cybercultural Revolution--Cybernetics and Automation.* New York: Institute for Cybercultural Research.

Scott, H. (2009). *Grounded theory online*. Retrieved June 7, 2014, from Grounded theory online: http://www.groundedtheoryonline.com

Segel, L. (1980). *Mathematical Models in Molecular and Cellular Biology.* Cambridge: Cambridge University Press Archive.

Seidl, D. (2004). *Luhmann's Theory of Autopoietic Social Systems.* Retrieved January 15, 2015, from Ludwig-Maximillians Universitat Munchen: http://www.zfog.bwl.uni-muenchen.de/files/mitarbeiter/paper2004_2.pdf

Sellars, R. W. (1927). Why Naturalism and Not Materialism. (W. P. Warren, Ed.) *Philosophical Review, Vol. 36*, 216-225.

Selye, H. (1973). Homeostasis and Heterostasis. *Perspectives in Biology and Medicine, Vol. 16, No. 3*, 441-445.

Senge, P. (1990). *The Fifth Discipline: The Art and Practice of the Learning Organization.* New York: Doubleday/Currency.

Senge, P. (1990). *The Fifth Discipline: The Art and Practice of the Learning Organization.* New York: Doubleday.

Serugendo, G., Gleizes, M., & Karageorgos, A. (2011). Self-organising Systems. In G. Serugendo (Ed.), *Self-organising Software* (pp. 7-32). Berline: Springer-Verlag.

Shannon, C. (1948). A Mathematical Theory of Communication. *The Bell System Technical Journal, Vol. 27*, 379-423,623-656.

Shannon, C. (1949). Communication in the Presence of Noise. *Proc. Institute of Radio Engineers, Vol. 37, No. 1*, 10-21.

Shannon, C., & Weaver, W. (1949). A Mathematical Theory of Communications, Part 1. *Bell System Technical Journal, Vol. 27, Iss. 3*, 379-423.

Shermer, M. (1995). Exorcising Laplace's Demon. *Hisory and Theory, Vol. 34, No. 1*, 59-83.

Silverman, D. (1993). *Interpretting qualitative data.* London: Sage Publications.

Simon, H. A. (1956). Rational choice and the structure of the environment. *Psychological Review, Vol. 63, No. 2*, 129-138.

Simon, H. A. (1956). Rational Choice and the Structure of the Environment. *Psychological Review, Vol. 63, No. 2*, 129-138.

Simon, H. A. (1962). The Architecture of Complexity. *Proceedings of the American Philosophical Society, Vol. 106, No. 6*, 467-482.

Simon, H. A. (1974). How Big is a Chunk. *Science, Vol. 183, No. 4124*, 482-488.

Simon, H. A. (1976). *Administrative Behavior.* New York: Free Press.

Skyttner, L. (2005). *General Systems Theory: Problems, Perspective, Practice.* New Jersey: World Scientific.

Slaymaker, O. (2004). Equifinality. In A. Goudie (Ed.), *Encyclopedia of Geomorphology* (pp. 321-323). Routledge.

Smith, M. (1987). *Descartes's Theory of Light and Refraction: A Discourse on Method.* Philadelphia: The American Philosophical Society.

Smuts, J. (1926). *Holism and Evolution.* New York: J.J. Little and Ives Company.

Snowden, D., & Boone, M. (2007, November). A Leader's Framework for Decision Making. *Harvard Business Review*.

Srinivasan, C. (1974). Goal-Directed Organizational Behavior: An Informational Viewpoint. *Management International Review,Vol. 14, No. 2/3*, 101-116.

Stagner, R. (1961). Homeostasis, Need Reduction, and Motivation. *Merrill-Palmer Quarterly of Behavior and Development, Vol. 7, No. 1*, 49-68.

Stebbing, T. (2010). *A Cybernetic View of Biological Growth: The Maia Hypothesis.* Cambridge: Cambridge University Press.

Stephan, A. (1999). *Emergenz: von der Unvorhersagbarkeit zur.* Dresden: Dresden University Press.

Strauss, A., & Corbin, J. (1998). *Qualitative research: techniques and procedures for developing grounded theory.* London: Sage Publications.

Streeter, C. (1992). Redundancy of Organizational Systems. *Social Service Review, Vol. 66, No. 1*, 97-111.

Susman, G. (1976). *Autonomy at Work: A Socio-Technical Analysis of Participative Management.* New York: Praeger.

Sweller, J. (2011). Cognitive Load Theory. In B. Ross (Ed.), *The Psychology of Learning and Motivation* (pp. 38-74). San Diego: Academic Press.

Tada, T. (2004). Toward the Philosophy of CAM: Super-System and Epimedical. *Evidence-Based Complementary and Alternative Medicine, Vol. 1, No. 1*, 5-8.

Tallarida, R., & Murray, R. (1987). Dissociation Constant III: Perturbation Methods (Rate Constants in the Drug-Receptor Reaction). In *Manual of Pharmacologic Calculations* (pp. 50-53). New York: Springer-Verlag.

Thorn, C., & Welford, M. (1994). The Equilibrium Concept in Geomorphology. *Annals of the Association of American Geographers, Vol. 84, No. 4*, 666-696.

Travis, J., & Ryan, R. (1981). *The Wellness Workbook.* Berkeley, CA: Ted Speed Press.

Tricarico, E., & Gherardi, F. (2006). Shell acquisition by hermit crabs: which tactic is more efficient? *Behavioral Ecology and Sociolobiology, Vol. 60, No. 4*, 492-500.

Trist, E., & Bamforth, K. (1951). Some Social and Psychological Consequences of the Longwall Method of Goal Getting. *Human Relations, Vol. 4, No. 1*, 3-38.

Ulrich, W. (1981). A critique of pure cybernetic reason: the Chilean experience with cybernetics. *Journal of Applied Systems Analysis, Vol. 8*, 33-59.

Underwood, K. (1969). *The Church, the University, and Social Policy.* Middletown, CT: Wesleyan University Press.

Van Gigch, J. (1991). *System Design Modeling and Meatmodeling.* New York: Plenum Press.

Varela, F. (1979). *Principles of Biological Autonomy.* New York: North Holland/Elsevier.

Varela, F. (2000). *El fen´omeno de la vida.* Santiago: Ensayo.

Varela, F., Maturana, H., & Uribe, R. (1991). Autopoiesis: The Organization of Living Systems, Its Characterization and a Model. In G. Klir (Ed.), *Facets of Systems Science* (pp. 559-569). Springer.

Verveen, A. A. (1971). In Search of Processes: The Early History of Cybernetics. *Mathematical Biosciences, Vol. 11*, 5-29.

Vitt, L., & Caldwell, J. (2014). *Herpetology: An Introductory Biology of Amphibians and Reptiles, Fourth Edition.* London: Academic Press/Elsevier.

Von Bertalanffy, L. (1932). *Theoretische Biologie: Band 1: Allgemeine Theorie, Physikochemie, Aufbau und Entwicklung des Organismus.* Berlin: Gebrüder Borntraeger.

Von Bertalanffy, L. (1950). An Outline of General Systems Theory. *The British Journal for the Philosophy of Science, Vol. 1, No. 2*, 134-165.

Von Bertalanffy, L. (1950). The Theory of Open Systems in Physics and Biology. *Science, Vol. 111, No. 2872*, 23-29.

Von Bertalanffy, L. (1950). The Theory of Open Systems in Physics and Biology. *Science, Vol. 111*, 23-29.

Von Bertalanffy, L. (1951). Towards a Physical Theory of Organic Teleology: Feedback and Dynamics. *HUman Biology, Vol. 23, No. 4*, 346-361.

Von Bertalanffy, L. (1952). *Problems of Life: An Evaluation of Modern Biological Thought.* New York: Wiley.

Von Bertalanffy, L. (1968). *General Systems Theory.* New York: GEORGE BRAZILLER.

Von Bertalanffy, L. (1968). *General Systems Theory: Foundations, Development, Applications.* New York: Braziller.

Von Foerster, H. (1974). Cybernetics of Epistemology. In W. Keidel, W. Handler, & M. Spring (Eds.), *Kybernetic und Bionik* (pp. 27-46). Munich: Oldenburg.

Von Foerster, H. (1993). For Niklas Luhmann: "How Recursive is Communication". *Teoria Soziobiologica, Vol. 2, No. 93*, 61-88.

Von Foerster, H. (2003). Ethics and Second Order Cybernetics. In H. Von Foerster, *Understanding Understanding: Essays on Cybernetics and Cognition* (pp. 287-304). New York: Springer-Verlag.

Von Humboldt, W. (1836). *On Language: The Diversity of Human Language-Structure and its Influence on the Mental Development of Mankind.* Cambridge: Cambridge University Press.

Von Neumann, J., & Morgenstern, O. (1944). *Theory of Games and Economic Behavior.* Princeton, NJ: Princeton University Press.

Waddington, C. (1940). *Organisers and genes.* Cambridge: Cambridge University Press.

Waddington, C. (1942). Canalization of development and the inheritance of acquired characters. *Nature, Vol. 150, No. 3811*, 563–565.

Waddington, C. (1953). Assimilation of an Acquired Character. *Evolution, Vol. 7, No. 2*, 118-126.

Waddington, C. (1957). *The Strategy of the Genes.* London: George Allen & Unwin.

Waddington, C. (1968). *The Origin of Life.* Piscataway, NJ: Aldine Publishing Company.

Waddington, C. (1968). *Toward a theoretical biology.* Edinburgh University Press: Edinburgh.

Walter, D. O. (1971). Alternatives to Continuity, Observability, and Passivity in Biological Modeling: A Tribute to McCulloch. *Mathematical Biosciences, Vol. 11, No. 1-2*, 85-94.

Warfield, J. (1973). Participative Methodology for Public System Planning. *Computers and Electrical Engineering, Vol. 1, No. 2*, 187-210.

Warfield, J. (1990). Generic Planning: Research Results and Applications. *Knowledge in Society, Vol. 3, No. 4*.

Warfield, J. (1993). Structural Thinking: Producing Effective Organizational Change. *15th Annual Meeting of the Association for Integrative Studies.* Detroit.

Warfield, J. (1995). *Mentomology: The Identification and Classification of MindBugs*. Retrieved March 6, 2015, from http://www.gmu.edu/depts/t-iasis/paper/p4.htm

Warfield, J. (1999). Twenty Laws of Complexity: Science Applicable in Organizations. *Systems Research and Behavioral Science, Vol. 16*, 3-40.

Wayne, R. (2009). *Light and Video Microscopy.* Amsterdam: Academic Press/Elsevier.

Weaver, W. (1948). Science and Complexity. *American Scientist, Vol. 36*, 536-544.

Weber, A., & Varela, F. (2002). Life after Kant: Natural purposes and the autopoietic foundations of. *Phenomenology and the Cognitive Sciences, Vol. 1*, 97-125.

Wegner, D., & Bargh, J. (1998). Control and Automaticity in Social Life. In *The Handbook of Social Psychology, Vols. 1 and 2* (pp. 446-496). New York: McGraw-Hill.

Weiner, N. (1948). *Cybernetics: Or Control and Communication in the Animal and the Machine.* Cambridge: MIT Press.

West, B. (2013). Mathematical Principle: Tales of Tails. In J. P. Sturmberg, & C. Martin, *Handbook of Systems and Complexity in Health* (pp. 63-81). New York: Springer.

White, R. K. (1959). Motivation Reconsidered: The Concept of Competence. *Psychological Review, Vol. 66, No. 5*, 297-333.

White, R. K. (2012, April 11). *Yerkes-Dodson Law*. Retrieved March 8, 2015, from Heterostasis: http://heterostasis1.com/2012/04/11/yerkes-dodson-law/

Wiener, N. (1949). *The extrapolation, interpolation and smoothing of staionary time series.* New York: John Wiley & Sons.

Wiener, N. (1954). *The Human Use of Human Beings: Cybernetics and Society.* Boston: Houghton Mifflin.

Wilden, A. (1980). *System and Structure: Essays in Communication and Exchange.* London: Tavistock Press.

Williams, J., & Colomb, G. (2006). *The Craft of Argument (3rd Ed.).* New York: Longman.

Willmer, P., Stone, G., & Johnston, I. (1999). *Environmental Physiology of Animals, 2nd Ed.* Malden, MA: Blackwell Science.

Wilson, A. (1951). Two Contrasted Mining Systems. In F. Emery (Ed.), *The Emergence of a New Paradigm of Work.* Canberra: Australian National University.

Wingfield, J. (2005). The Concept of Allostasis: Coping with a Capricious Environment. *Journal of Mammalogy, Vol. 86, No. 2*, 248-254.

Winn, P. (1995). The Lateral Hypothalamus and Motivated Behavior. *Current Directions in Psychological Science, Vol. 4, No. 6*, 182-187.

Witherington, D. C. (2011). Taking Emergence Seriously: The Centrality of Circular Causality for Dynamics Systems Approaches to Development. *Human Development, Vol. 54*, 66-92.

Wright, S. (1921). Correlation and Causation. *Journal of Agricultural Research, Vol. 20*, 557-585.

Yerkes, R., & Dodson, J. (1908). The Relation of Strength of Stimulus to Rapidity of Habit-Formation. *Journal of Comparative Neurology and Psychology, Vol. 18*, 459-482.

Yin, R. (2014). *Case Study Research: Design and Methods, 5th Ed.* Thousand Oaks, CA: Sage .

Yoffey, J. (1958). *Homeostatic Mechanisms.* Brookhaven: Brookhaven National Laboratory, Biology Department.

Yolles, M. (2006). *Organizations as Complex Systems: An Introduction to Knowledge Cybernetics.* Charlotte, NC: Information Age Publishing.

Zadeh, L. (1953). Theory of Filtering. *Journal of the Society for Industrial and Applied Mathematics, Vol. 1, No. 1*, 35-51.

Zeleny, M. (1981). What is Autopoiesis. In M. Zeleny (Ed.), *Autopoiesis: A Theory of Living Organization* (pp. 4-17). New York: Elsevier North Holland.

VITA

Walt Akers
2101 Engineering Systems Building
Norfolk, Virginia 23529

EDUCATION

2011 – 2015	**Doctor of Philosophy, Systems Engineering**	*Old Dominion University*
2008 – 2010	**Master of Project Management**	*Western Carolina University*
2007	**Bachelor of Science, Computer Science**	*Park University*

PROFESSIONAL EXPERIENCE

Thomas Jefferson National Accelerator Facility — *Newport News, VA*

2011 – Present	Technical Interface for Experimental Nuclear Physics
2005 – 2011	Computing Infrastructure Manager
1999 – 2005	Computer Scientist – High Performance Computing
1995 – 1999	Accelerator Controls Scientist

Science Applications International Corporation — *Bothell, WA*

1988 – 1995	Computer Scientist

United States Air Force — *Pentagon, Washington, DC*

1984 – 1988	Computer/Communications Operator

VOLUNTEER EXPERIENCE

2008 – Present	Founder/Executive Director	*The Twisted Oaks Foundation*
2007 – Present	Director	*The Yorktown Foundation*
2014 – Present	Chairman	*York County Civic and Cultural Grants Advisory Committee*
2008 – Present	Committee Member	*York County Historical Committee*
2008 – 2009	Director	*The Watermen's Museum*
2000 – 2008	President/Corps Commander	*The Fifes and Drums of York Town*

HONORS AND AWARDS

2014	**Bronze Medal for Citizenship** *National Society of the Sons of the American Revolution*	*Washington, DC*
2012	**Outstanding Citizen Award** *Yorktown Rotary Club*	*Yorktown, VA*
2006	**National Award for Community Service** *National Society of the Daughters of the American Revolution*	*Washington, DC*
2006	**Virginia Award for Community Service** *Virginia Daughters of the American Revolution*	*Richmond, VA*
2004	**ALLI Award for Community Service** *Cultural Alliance of Hampton Roads*	*Norfolk, VA*