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Stephen Jay Kline on Systems, or Physics, Complex Systems, and the Gap Between

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Stephen Jay Kline on Systems, or Physics, Complex Systems, and the Gap Between

Philip L. Campbell¹

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Abstract

At the end of his life, Stephen Jay Kline, longtime professor of mechanical engineering at Stanford University, completed a book on how to address complex systems. The title of the book is "Conceptual Foundations of Multi-Disciplinary Thinking" (1995), but the topic of the book is systems.

Kline first establishes certain limits that are characteristic of our conscious minds. Kline then establishes a complexity measure for systems and uses that complexity measure to develop a hierarchy of systems. Kline then argues that our minds, due to their characteristic limitations, are unable to model the complex systems in that hierarchy. Computers are of no help to us here. Our attempts at modeling these complex systems are based on the way we successfully model some simple systems, in particular, "inert, naturally-occurring" objects and processes, such as what is the focus of physics. But complex systems overwhelm such attempts. As a result, the best we can do in working with these complex systems is to use a heuristic, what Kline calls the "Guideline for Complex Systems."

Kline documents the problems that have developed due to "oversimple" system models and from the inappropriate application of a system model from one domain to another. One prominent such problem is the Procrustean attempt to make the disciplines that deal with complex systems be "physics-like." Physics deals with simple systems, not complex ones, using Kline's complexity measure. The models that physics has developed are inappropriate for complex systems. Kline documents a number of the wasteful and dangerous fallacies of this type.

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1 Summary

Note: Kline shows how to address complex systems. If you would like to jump to Kline's conclusions, go now to Section 7.2 on page 35 herein.

At the end of his life, Stephen Jay Kline, longtime professor of mechanical engineering at Stanford University, completed a book on how to address complex systems. The title of the book is "Conceptual Foundations of Multi-Disciplinary Thinking" (1995), but the topic of the book is systems. The "conceptual foundation" to which the title refers is the notion of systems.

Kline's quest in this book is to establish the motivation and means for "multidisciplinary" thinking, by which Kline means building a system composed of individual disciplines (e.g., university departments).² Kline's "conceptual foundations" are the principles of systems. As a result, this book is about systems.

Unfortunately no one in the "systems" world seems to have noticed the book, not even Checkland ([6], [7], [8], [9]) who seems to reference everyone. The sole exception is Cook [11].³ But even Cook mentions Kline in a footnote only, noting that Kline "coined the term *sysrep* to describe the Checkland definition of system to distinguish it from the system of interest" ([11], page 3), as though that were the only contribution of the book. Perhaps if Kline had chosen another title for the book, such as

"System Foundations for Multidisciplinary Thinking," or

"System Foundations for Addressing Complex Systems," or

"Why Physics is Inadequate to Address Complex Systems," or

"Physics, Complex Systems, and the Gap Between,"

then perhaps the book might be receiving the attention it deserves.

The central point of Kline's book is that we have used the system concept to great advantage in science, creating productive but increasingly-narrow disciplines. However, we have not used that concept between disciplines to develop "multidisciplinary" disciplines. The result is that we have ignored a fruitful avenue and are limiting our progress. As Kline observes in the most important passage of the book:

The concept of emergent properties is far from new, and emergent properties are common in systems of many kinds we see every day. We have acted, nevertheless, as if the concept of emergent properties did not apply to the realm of ideas. We have done so even though we often have experiences in which new and improved ideas emerge from the discussion of a problem or analysis in more than one conceptual framework. The process of arguing out the U.S. Constitution plus the Bill of Rights is a notable historical example. (page 4)⁴

^{2.} This system is not a "system of systems."

^{3.} I happened on Kline's book by following one of Cook's references.

^{4.} In this report, references without a citation, such as this one, are from Kline's book [18].

The system that Kline uses for this book is the set of academic disciplines.

It would be easy to dismiss this book as little more than a squabble about different academic departments. That would be a mistake. Kline provides answers to questions of significance. As the most important example, Kline shows that for the most complex class of systems—the systems Kline calls "sociotechnical systems"⁵—the complexity is orders of magnitude beyond our capabilities to model. Our only recourse in building and maintaining such systems is what Kline calls the "Guideline for Complex Systems":

For Complex Systems:

In very complex systems,⁶ such as sociotechnical systems, we have no theory for entire systems, and must therefore create, operate, and improve such systems via feedback; that is, repeated cycles of human observations plus trials of envisaged improvements in the real systems. In such very complex systems, data from a wide variety of cases therefore become the primary basis for understanding and judgments and should take precedence over results from theory based on cuts through the hyperspace⁷ (called the "primacy of data"). (pages 62 and 312)

Corning, in a review of Kline's book (see Appendix G), describes this point in a bullet as follows:

The awesome, irreducible complexity of human systems⁸ argues for the absolute necessity of making databased, incremental changes rather than using top-down grand theories or vacuous mathematical formalizations. Kline cites some examples of how the failure to heed this dictum has led to disastrous consequences. ([12], page 493)

As Boulding puts it, "In the face of living systems we are almost helpless; we can occasionally cooperate with systems which we do not understand [such as living systems]; [but] we cannot even begin to reproduce them" [4]. For Kline, the "primary lesson of multidisciplinarity" (page 10) is that "There is no one approach, no one method, no one viewpoint⁹ that is adequate for understanding and coping with the complex systems—including humans—that play a very large role in our lives" (page 10).

Kline develops a system taxonomy based on "size and nature" (see Table 3 on page 19 herein). This taxonomy is comparable to the taxonomies developed by others, such as Checkland and Boulding (see Appendix A). Those taxonomies are interesting but little more. Kline goes further by developing a second taxonomy based on "complexity of feedback modes" (see Table 2 on page 18 herein). That table leads to a third taxonomy based on complexity (see

^{5.} See the Glossary, starting on page 54, for more information about this and other terms.

^{6.} Kline's complexity measure is presented in Chapter 4 (see Section 4.1 on page 15 herein).

^{7.} See the Glossary, starting on page 54, for more information about this term.

^{8.} See the Glossary, starting on page 54, for more information about this term.

^{9.} Except, of course for the Guideline for Complex Systems (see above), at least for the time being. Kline does not argue that there cannot be a theory of complex systems—instead of just a "guideline"—but he does argue that we do not have such a theory now, and our persistent attempts to apply to complex systems theories that have been successful for simple systems is reducing our ability not only to address those complex systems but also to find an adequate theory, if one can be found.

Table 1 on page 15 herein). This third taxonomy enables us to answer important questions, such as "Why is it that we cannot seem to 'get a handle' on sociotechnical systems?"

Kline himself describes the results of the book as "iconoclastic" (page ix).¹⁰ He notes that "a number of the conclusions that will be reached go beyond the merely controversial and directly contradict certain claims long held as typical wisdom within some disciplines" (page 11).

Kline notes that this book is a "beginning discourse that is far from complete" (page 292).

In the remainder of this report I summarize each Chapter of Kline's book.

^{10.} In this report, all parenthesized page numbers (e.g., "(page ix)") refer implicitly to Kline's book [18]. References to work other than Kline's book include an index into the references (e.g., "([12], page 493)"). References to "Sections" (such as "see Section 3.1 on page 11 herein") or tables (such as "see Table 1 on page 15 herein") point to a section or table within this report.

2 Chapter 1 Introduction

Science, namely the scientific method and the associated recursively partitioned disciplines, has provided our society with unprecedented understanding, but it has obscured the relationship of one discipline to the whole and it encourages the view of science as a "single method (usually based on physics)" (page 1). "Interdisciplinary" suggests a melding or fusion of two disciplines. "Multidisciplinary," on the other hand, suggests "overall frameworks" (page 2) that describe how multiple disciplines relate to each other. Even though we understand the importance of emergence, Kline argues that we have not applied that concept to the "realm of ideas" (page 4). That is, a multidisciplinary approach attempts to develop a *system* using the various disciplines as components and in so doing generate an intellectual boost from the resulting emergence.

A metaphor for a multidisciplinary approach could be a map of the continental United States. The disciplines describe individual states, but the continental map shows their relationships, as well as showing "the country as a whole, in one piece" (page 5).

Kline hypothesizes that there is no one approach that is sufficient:

Hypothesis III:¹¹ The Absence of Universal Approaches. There is no one view, no one methodology, no one discipline, no one set of principles, no one set of equations that provides understanding of all matters vital to human concerns. (page 6 (see also page 10))

Kline is explicit that Hypothesis III implies that science alone is insufficient for the "matters of vital concern to human beings" (page 7). The list of those matters, for the ancient Greeks, consisted of truth, beauty, happiness, and the good. Kline notes that a contemporary writer, Phenix, adds communication to the list, because it is "necessary for all the other areas of human life" (page 8), and values, as a superset of "the good." Values includes ethics and aesthetics, and Kline adds "intimate human relations" (page 10) as another item for the list. We could redefine terms and arrange the list differently, but whatever the mix and whatever the terms, Kline's point is that science alone is insufficient for us.¹²

^{11.} All of Kline's hypotheses are listed in Appendix B on page 41.

^{12.} Hayek writes something similar: "Today it is almost heresy to suggest that scientific knowledge is not the sum of all knowledge. But a little reflection will show that there is beyond question a body of very important but unorganized knowledge which cannot possibly be called scientific in the sense of knowledge of general rules: the knowledge of the particular circumstances of time and place" [17].

3 Part 1 The System Concept

3.1 Chapter 2 Systems, Domains, and Truth Assertions

The concept of "system" is the basis of our current disciplines of knowledge:

- It is the "single concept that most sharply differentiates ancient from post-Newtonian modes of science" (page 15).
- It is the "idea (not the method) that most clearly distinguishes what we call modern science in the twentieth century from older modes of modern thought" (pages 27-8).
- It is the "central concept that distinguishes ancient from twentieth-century science" (page 29).¹³

Dictionaries commonly list over a dozen definitions for "system," but, oddly enough, none of them match the definition of the word used in science. This, to Kline, is suggestive of Snow's "Culture Gap" [25].

Kline provides three definitions of "system":

- (1) **system** (shown in boldface);
- (2) sysrep; and
- (3) system.

This is the definition one of system (**system**):

"The object of study, what we want to discuss, define, analyze, think about, write about, and so forth"; I [this is Kline's voice] will call this the **system**. When I intend to denote an accurate and appropriate definition for a particular system¹⁴ (or class of systems) for a specified study, I will use the word **system** in boldface type¹⁵ as illustrated in this and the prior sentence. (page 16)

This is the definition two of system (sysrep):

A picture, equation, mental image, conceptual model, word description, etc., which represents the entity [i.e., the **system**¹⁶] we want to discuss, [define,] analyze, think about, write about, I will call the "sysrep." (page 16)¹⁷

^{13.} Elsewhere Kline notes that the "foundation stone that differentiates ancient methods from those of science since the time of Galileo" (page 169) is what he calls "traceability," meaning that the sysrep (defined below) corresponds to the world.

^{14.} I think what Kline intends here is "...for a particular object of study (or class of objects of study)..." Otherwise we have a definition-one system being used to denote a definition-three system and the taxonomy collapses.

^{15.} I follow the same format in these notes.

^{16.} or the definition-three system

^{17.} Kline notes that there are in English "more than one hundred synonyms for what we will call a 'sysrep'" (page 18). (Unfortunately Kline does not list these.) Note that "sysrep" is a portmanteau of "system" and "representation."

This is the definition three of system (system):

"...an integrated entity of heterogeneous parts which acts in a coordinated way." (page 16)

The third definition is the customary, technical definition of system and is necessary when considering the "behaviors of complete systems" (page 16).¹⁸

Kline's first definition seems superfluous. Our physical world, as well as our social and mental world, seems to be composed entirely of systems, so almost no matter what we choose as our "object of study," it will be a system. As far as usage of these three definitions goes, occasionally Kline uses **system**, such as when he mentions J. W. Gibb's **system** (see below) or when he discusses Windsor Castle (see page 25 herein) but for the most part he uses system to refer to both **system** and system, with the distinction usually discernible from the context. I follow Kline's lead.

We have complete freedom in choosing a system. For example, we could choose

an idea, a factory for making semiconductors, a range of mathematical processes, a branch of philosophy, a novel, a class of individuals who work at a given trade, a nation, a rifle, an institution, a total vacuum, or anything else we choose (page 17)

We must be precise about what we choose. To the extent that we are sloppy is the extent to which we will end in confusion. We must identify the boundaries of our system.

Sysreps have the same opportunities and requirements as systems. Sysreps are of three types: words, pictures, and mathematics. The vital point to remember is that a sysrep is not the system! In the ideal, a sysrep is a "perfect mirror" (page 18) of the system. If the sysrep is weak (strong), then it will predict with poor (great) fidelity the behavior of the system. Sysreps are "mental tools" (page 19). The strength of the sysreps in a given field and the speed with which they can be checked against the system significantly affects how fast the field advances. For example, Max Planck's vacuum **system**, containing nothing, was important (page 22) to both the development of the theory of heat transfer and the electromagnetic propagation of energy. J. W. Gibb's **system** of chemical equilibrium provided the basis of modern chemistry and chemical engineering (page 23).

Note that a map is to a territory as a sysrep is to a system.

Each branch of science deals with only a proper subset or class of systems, not all systems, so the results of each branch are not universally applicable. Any "truth assertion" (which Kline defines as "statements that we assert (that is, claim) describe accurately some portion of physical, biological or social nature" (page 7)) has limited, not universal, applicability; it applies in some area, may or may not apply in other areas, and does not apply in all of the remaining areas. Kline refers to this as Hypothesis IV.¹⁹ The partitioning of areas should be associated

^{18.} I do not know why Kline uses the word "complete" here. If you take apart a definition-three system so that it is "incomplete," it is no longer a definition-three system.

^{19.} All of Kline's hypotheses are listed in Appendix B on page 41.

with the assertion in order to preclude misapplication.

Sometimes the disparity between a sysrep and the corresponding system blocks progress. For example, d'Alembert's Paradox describes the situation in which Euler's "ideal fluid" provided nonsensical results for airfoils. Laplace's equation (a simplification of the Navier-Stokes equations) did not work either. Prandtl corrected all of this, but Kline observes that "this sysrep problem was subtle enough that many good theoreticians failed to see the answer for more than a century" (page 25). A similar situation occurred in what Kline calls the "human sciences."²⁰ Freud's sysrep, for example, was confined to an individual, but family therapy has since expanded that sysrep to include the family, to significant effect.

As noted in Chapter 1, truth assertions do not cover all areas of human concern. And the system concept cannot solve all problems. Some proponents of "systems theory" have made "overclaims"²¹ that the use of systems and "its handmaiden, rationality" (page 28) can solve all problems. But Kline refutes this, noting (1) that truth assertions do not cover all areas of human concern and (2) that we must be able to confirm the validity of sysreps, implying that we need to know about the constituents of a **system** (we need "specific knowledge" (page 28)).

3.2 Chapter 3 Sysreps and the Human Mind

Our minds use "mental representations." Boulding calls these "images" but Kline thinks that there is more involved than implied by that word. Kline uses the word "schemata"—a proper superset of sysreps—to denote the "ideas in a person's head which are used to represent and interact with the world" (page 31). For example, one class of schemata that people use are words. Words describe generalities or classes. It appears that our knowledge involves building increasingly sophisticated schemata. Miller showed that humans can only hold seven bits of information in short-term or "working" memory at a time (page 33). To overcome this limitation humans combine a handful of such bits into "chunks" that we then index. We can process about four such chunks simultaneously, thereby increasing our working memory to 28 bits. Simon suggests that "an expert in a given professional area...will have learned from experience something like 50,000 chunks" (page 34). Building such a repertoire requires "long periods of learning" (page 32). Dennett suggests that there is a "lower level" to our minds, "not consciously accessible" (page 35), that generates "possible solutions" [32]. We have only empirical evidence of that lower level, but Miller's result, at least, has been established "beyond reasonable doubt" (page 35), and it is the "most important single constraint on the human mind in regard to how we form sysreps" (ibid.). The evidence also suggests that there are at least four categories in our long-term memory: "facts, chunks, schemata, and finally goals and long-term strategy" (page 37).

Kline argues that complex matters require schemata, not just "images." We cannot think about such things without schemata. Unfortunately we tend to adapt whatever schemata we already happen to have to new situations and the adaptation carries baggage with it, especially to the extent that (1) the new situation is different and (2) there is associated trauma associated with the pre-existing schemata.

^{20.} See the Glossary, starting on page 54, for more information about this term.

^{21.} See the Glossary, starting on page 54, for more information about this term.

Our non-conscious mind does most of the work of categorizing information and building schemata. De Groot's study of chess players suggests that it is the schemata that have been built by experience that differentiate the proficient player from the novice, not a better memory or innate intelligence or how many moves the player looks ahead (page 39). Dreyfus & Dreyfus describe four levels above the dogged use of rules, where only the highest level is true expertise (page 40). The mechanics of driving a car, for example, are simple, but to be proficient requires the establishment of a considerable repertoire of schemata.

We use our schemata to fill in details. But this is accurate only to the extent that those are the correct details! Generally we understand by subdividing into pieces, studying the pieces, and then reassembling.

A sysrep is a type of schemata. It is deliberately formed for a particular purpose. Compare, for example, the concept of "rocks" that a geologist has and the concept of "rocks" that a non-geologist has. The geologist has a sysrep; the non-geologist has a schemata that is not a sysrep. We must be able to create precise sysreps in order to generate from them truth assertions. This requires attention to detail.

4 Part 2 Complexity

4.1 Chapter 4 An Index for Complexity

Kline presents a complexity measure, C:

C = V + P + L

where

V is "the number of independent Variables needed to describe the state of the system";

P is "the number of independent *Parameters* needed to distinguish the system from other systems in the same class"; and

L is "the number of control *feedback Loops*²² both within the system and connecting the system to the surroundings" (page 49, emphasis in the original).

For example, describing the volume of a rectangular room would require three parameters: height, width, and length. Perhaps we are only interested in the temperature in the room at given times; if so, only two variables are required: time and temperature. If the room has a thermostat, then it has one feedback loop.

Kline identifies six classes of systems, based on his definition of complexity, shown in Table 1. (This is the most important table in the book.)

Class	Name	Examples	Complexity	Category ^a
А	Paradigmatic Systems of Physics, Chemistry, and Simple Engineering Anal- yses	Deflection of simple struc- tural members; the motion of pieces of matter under prescribed forces	< 5	"Simple"
В	Systems of Human Designed Hardware	Automobiles, airplanes, computers	< 10 ⁶	"Often complex"
Cb	A Single Human Being		> 10 ⁹	
D	Human Social Systems		> 10 ¹¹	
Е	Ecologies Containing Humans		> 10 ¹¹	
F	Sociotechnical Systems	Four types: (1) manufacturing, (2) use (e.g., aircraft trans- port, newspapers and TV networks), (3) distribution, and (4) research & develop- ment	> 10 ¹³	"Typically very complex"

Table 1Class Hierarchy Based on Complexity (pages 52-60)

^{22.} A "control feedback loop" consists of four steps that repeat in sequence over time: sense, transform, compare, act. A thermostat is a simple example of a control feedback loop.

a. I have added this column to the table, based on Kline's comments on page 61.

b. Kline notes that the complexity measure for Class C systems is a "significant underestimate" (page 60). However, it is "sufficient" for Kline's discussion.

Even Class A systems, with complexity, C, as low as 4, can be difficult to analyze fully. So Kline believes that we cannot hope, "(at least not in the near future)," to have "adequate theories" (i.e., sysreps) (page 66) to describe the "very complex systems." We design these latter systems based on experience via what Kline calls "human design feedback." That is, we start with an approximation and then iteratively modify it via feedback. Braybrooke & Lindblom refer to this as "disjointed incrementalism" (page 65). This approach is "not only safer than 'grand theory' but also the only pragmatic course [in complex systems] as well. Incrementalism is what policy makers therefore *actually* do, despite various so-called ideal approaches" (page 65, emphasis added).²³

Kline distinguishes four types of "information":

- 1. information in inert, naturally-occurring objects;
- 2. information in DNA;
- 3. information in brains;
- 4. information recorded by humans in or on inert matter.

Without the above distinctions, Kline claims that we have a difficult time understanding anything! (This categorization of information is used in Chapter 16 (see Section 5.10 on page 31 herein).)

4.2 Chapter 5 Thinking About Complex Systems

When the complexity of a system is greater than we can completely model, then our model provides a view of that system based on an inadequate number of variables & parameters. For example, if we attempted to model a three-dimensional space using only two dimensions, then our view of that three-dimensional space would be of a plane. Obviously this will give us misleading or incomplete answers, and we will have a difficult time distinguishing the misleading from the incomplete. We cannot completely model a human being, so we have to settle for a lower-dimensional model which can provide misleading or incomplete answers.

To constrain means to "limit to within a range of values." To determine, on the other hand, means to "limit to one value." If biological structure were fully determined, there would be only one species. The laws of physics, chemistry, and biology only constrain; they do not determine.

^{23.} For example, I believe that Braybrooke & Lindblom would agree that an example of the "ideal approach" in the determination of "risk" is the use of the equation R = T * C, where R is risk, T is the probability of the realization of a threat, C is the consequence (in dollars or deaths or some other unit as appropriate) of the effect of the realization of that threat, and a number is required for each parameter.

4.3 Chapter 6 Feedback as a Source of Complexity

Kline presents two definitions:

Entire Paradigm:²⁴ A principle that applies to every system in the class, without known exceptions.

Entire Invariant Paradigm:²⁵ A principle that predicts that all systems in the class will have the same behavior, in detail, for all times and in all places. (page 80)

Entire Invariant Paradigms exist in the class of inert, naturally-occurring objects (e.g., the focus of physics, chemistry, and other physical sciences). "We know this is so about as firmly as we know anything" (page 82). Perhaps Entire Invariant Paradigms exist in all inert, naturally-occurring objects.

Meanwhile, in the human sciences, we find Entire Paradigms but not Entire Invariant Paradigms (so far). Ethnology set out to find the universals in human behavior but found "unimaginable" variation instead.²⁶ And social behavior changes over time, such as what happened after money was invented and after the corporation was invented. Grimm's law—that "of 100 commonly used terms (like those for body parts), 86% will remain stable for 1000 years with an error [i.e., deviation] of 6.5% at the 50% confidence level" (page 85)—seems to be one of the "firmest principles in the human sciences" (page 85) but note that the expected variation is non-zero, indicating that this is not describing invariant behavior but a statistical average. The lack of invariants is a reflection of the complexity of the area. Societies even change the "rules," such as the Muslim clerics during the Middle Ages emphasizing spiritual matters over material goods. However, one Entire Paradigm about human societies is their use of sociotechnical systems: "Sociotechnical systems form the physical bases of all human societies both past and present" (page 171).

Communism is an example of what Kline calls the use of "oversimple" rules. Marx constrained society to one parameter—economics. The demise of communism was not due to argument or to the intellectual conversion of adherents on one side. We could not present sufficiently cogent arguments to convince anyone because we do not have a complete theory of society. Rather, the demise was due to the non-results in the practice of communism. Radical behaviorism, à la B. G. Skinner, is another example of oversimple rules.²⁷

Such "oversimple rules" are not only a "waste of time" but can also engender "serious negative effects" and "great harm." If anything, Kline is too mild here when one considers the known effect of communism, for example.

Kline accounts for the difference between inert, naturally-occurring objects and the objects that are the focus of human sciences by noting their differences in feedback: the former have none; the latter are composed of loosely-coupled units (people), each of which uses many feedback

^{24.} See the Glossary, starting on page 54, for more information about this term.

^{25.} See the Glossary, starting on page 54, for more information about this term.

^{26.} Kline means variation in behavior here, not variation in purpose. I believe that there is a constancy of purpose across human societies. I believe that Kline's view is a reflection of cultural anthropology and that the constancy-of-purpose view is a reflection of social anthropology—the former viewpoint emphasizing means; the latter viewpoint emphasizing ends.

^{27.} Forrester's "World Dynamics" model [16] is another example that comes to mind.

modes. Machines are one step up from inert, naturally-occurring objects, but the best the constituting parts can do to provide feedback is to stop functioning: they cannot talk back, for example, or choose goals that are independent of the machine of which they are part.

Kline describes a hierarchy of systems, shown in Table 2 below. For comparison, I have included two other system taxonomies in Appendix A on page 39.

Table 2	A Hierarchy of Systems	Classified by	Complexity	of Feedback Modes	(Figure
6-1, page 9	0)				

Type of System	Feedback modes and source of goals	Examples
Inert, naturally-occurring	None of any kind; no goals	Rocks, mountains, oceans, atmosphere
Human-made inert—without controls	None, but with purposes designed-in by humans	Tools, rifles, pianos, furniture
Human-made inert—with con- trols	Autonomic control mode usu- ally of a few variables; cannot by themselves change set points of variables	Air conditioner/furnace with thermostat, automobile motor, target-seeking missile, electric motor with speed con- trol
Learning	Human control mode. Human in system can learn and improve operations; systems can themselves change set points since they contain humans	Automobile with driver, chess set and players, piano with player, plane and pilot, tractor and operator, tank and driver, lathe and operator
Self-restructuring	Human design mode. Humans can look at system and decide to restructure both social and hardware elements via designs	Human social systems and human sociotechnical systems: household, rock band, symphony, manufacturing plant, corporation, army

Corning criticizes Kline's presentation shown in Table 2, pointing out that Kline did not note that the presence of feedback loops involves a "fundamental shift of system types" ([12], page 493). Such systems are "purposive." The loops are "always connected to purposes/goals/ endstates" ([12], pages 493-4). But I think that this is only a matter of terminology. Corning uses "feedback;" Kline uses "control."

5 Part 3 Structure

5.1 Chapter 7 Hierarchy as a Structural Feature

Kline argues that there is a hierarchy of systems, based on their complexity, as shown in Table 1 above, and that we humans, even with the aid of computers, are unable fully to represent systems beyond a certain level of complexity. Using the models from more than one discipline will help us here. Hence the need for what Kline calls "multidisciplinary thinking."

Kline presents what he calls "The Hierarchy of Constitution: A Taxonomy of Objects Arranged by Size and Nature" (Figure 7-1, page 107), and shown below as Table 3.

Table 3	The Hierarchy of Constitution: A Taxonomy of Objects Arranged by Size and
Nature (Fig	ure 7-1, page 107) (Sheet 1 of 2)

Arbitrary number indicating the level or size	Biological forms	Human-made objects, systems	Natural physical objects
9			Unknown
8			Universe
7		Space probes, space communications	Galaxies
6			Solar systems
5	Global ecologies	Space systems, United Nations	Stars, planets
4	Marine ecologies	Large sociotechnical systems, systems of transport, national gov- ernments	Continents, oceans
3	Local ecologies, forests	Sociotechnical systems (human-made ecolo- gies)	Geologic features (mountains, valleys, etc.)
2	Clans, herds, tribes	Large hardware (build- ings, machines)	
1	Families	Simple hardware (arti- facts, hand tools, furni- ture)	
0	Multicellular plants, animals	Materials (steel, semi- conductors, etc.)	Aggregations of atoms and molecules
-1	Unicellular plants, ani- mals		
-2	Organelles, macromole- cules, proteins	Semiconductor circuits	Individual molecules
-3			Individual atoms

Table 3The Hierarchy of Constitution: A Taxonomy of Objects Arranged by Size and
Nature (Figure 7-1, page 107) (Sheet 2 of 2)

Arbitrary number indicating the level or size	Biological forms	Human-made objects, systems	Natural physical objects	
-4			Subatomic particles	
-5			Unknown	

The numbering is arranged so that "Levels 0, 1, 2, and/or 3" are the "'classical level,' referring to classical physics" (page 107) (things of "roughly human size" (page 123)).

There are two important points about this hierarchy. First, the most complex objects, as Kline defines complexity, are in the middle of the hierarchy, not the top. Second, the hierarchy is itself a sysrep. It represents "only a small fraction of the real-world system, which is in its entirety far more complex" (page 106). As a result, it cannot provide an adequate "basis for analysis" (page 109).

5.2 Chapter 8 Interfaces of Mutual Constraint and Levels of Control: Polanyi's Principle

This Chapter, and the subsequent two, are separate arguments against the notion that everything is reducible to physics. The audience for this Chapter is biologists. The audience for Chapter 9 is "scientists, engineers, and mathematicians" (page 122). The audience for Chapter 10 is "computer scientists and individuals concerned with brain functions" (page 122).

Kline articulates two models that he calls "views":

- •top-down or "synoptic,"²⁸ and
- •bottom-up or "reductionist."

Each view, in its extreme form, "claims priority over other views and is seen as a universal overview of the world" (page 111). The synoptic view, exemplified by the Catholic Church during the Middle Ages, suggests that "the world and all forms of knowledge about the world, its surroundings in the sky, and ourselves could be understood in terms of the Christian Scriptures as interpreted by the Church" (page 110). The reductionist view, exemplified by Galileo, suggests, in Galileo's words, that "Ultimately we must understand everything in terms of the motions of matter" (page 110). Note that both views are deterministic. Although for the past three centuries the synoptic view has been waning and the reductionist view waxing, they are both incomplete: neither can provide a "complete worldview" (page 111).

In this Chapter, as in the next two Chapters, Kline demonstrates that neither the synoptic nor the reductionist view is complete. The argument that Kline uses in this Chapter is based on what he calls "interfaces of mutual constraint" (page 114) and what Polanyi²⁹ called "interfaces

^{28.} See the Glossary, starting on page 54, for more information about this term.

of dual-level control^{"30} ([1], see review of this paper in Appendix F on page 50). Kline condenses the seminal paper by Polanyi into two principles:

Polanyi's Principle, Part A. In many hierarchically structured systems, adjacent levels mutually constrain,³¹ but do not determine, each other.³² (page 115)

Polanyi's Principle, Part B. In hierarchically structured systems, the levels of control (usually upper levels) "harness" the lower levels and cause them to carry out behaviors that the lower levels, left to themselves, would not do. (page 119)

Kline notes that interfaces of mutual constraint and systems with multiple control levels are "common" (page 119). In fact, they are "nearly ubiquitous in biological systems, humandesigned systems, in communications, and thus also in sociotechnical systems" (page 119). Such structure involves more than "molecules that bump into each other in random ways" (page 120):

> How long would we have to wait for the bumping together of molecules to design the next model of a Chevrolet or a Toyota or a Mercedes well enough so it would run? (page 120)

The example that Kline uses for Part A of Polanyi's Principle—for adjacent levels that mutually constrain—is the relationship of phonemes to words: they constrain but do not determine each other. Start with the set of possible sounds and call it List A. Then take a proper subset of List A to form the set of sounds humans can both make and hear and call this second list List B. Then take a proper subset of List B to form the set of phonemes in all languages and call this third list List C. Then take a proper subset of List C to form the set of phonemes in English and call this fourth list List D. But now—and this is the important step—take a proper *superset* of List D, by creating strings of phonemes, to form the English vocabulary and call this list List E.

The set of phonemes used in English (List D) constrains but does not determine the English vocabulary (List E). Similarly, the English vocabulary (List E) constrains but does not determine the set of phonemes used in English (List D). In this way these two levels constrain but do not determine each other, as suggested in Table 4.

Constraint or Determinant	List	Size
Current and his- torical social choices	List E: Words used in one given language	(≈550,000 in English from phonemes of the lan- guage

Table 4The Relations of "Noises" to Words (Figure 8-1, page 118)^a (Sheet 1 of 2)

^{29.} Corning notes that Polanyi was a "physical chemist" ([12], page 494).

^{30.} Polanyi does not use this exact phrase. Polanyi talks of systems under "dual control."

^{31. &}quot;Constrain" and "determine" are defined in Chapter 5 (see Section 4.2 on page 16 herein).

^{32.} All of Kline's hypotheses, including these two principles that Kline attributes to Polanyi's, are listed in Appendix B on page 41.

Sociocultural his- tory	List D: Phonemes used in one given language	(≈40 in English)	
Observations of known languages	List C: All pho- nemes used in all languages	(100-200)	
Physiology of vocal chords and ears	List B: All single sounds humans can make and hear	?	
Physics of pres- sure waves of air	List A: All possi- ble sounds (an infinite list)	∞	

Table 4The Relations of "Noises" to Words (Figure 8-1, page 118)^a (Sheet 2 of 2)

a. The width of the rightmost column in this table is intended to suggest the relative sizes of the sets described in the row.

The example that Kline uses for Part B of Polanyi's Principle—for multiple levels of control—is automobile transportation. This is a social system consisting of traffic laws, rules of the road, drivers, automobiles, major assemblies such as engines which consists of component parts, and so on. Note that these are "not simply aggregations of molecules that bump into each other in random ways" (page 120); they are the results of humans harnessing lower levels to serve human purposes.

Kline argues that "interfaces of mutual constraint are both common and important" (page 117). In fact, as noted above, they are "nearly ubiquitous in biological systems, human-designed systems, in communications, and thus also in sociotechnical systems" (page 119).

Part A suggests that the Galilean, Gassendian, and Laplacean idea that because "all material objects are made up of 'particles' of matter" that we can "therefore aggregate the sysreps for particles and thereby find (or derive) all the behaviors for all systems" is "totally false" (page 113).

5.3 Chapter 9 The Theory of Dimensions

In this Chapter Kline presents a second demonstration—what he calls the "theory of dimensions"—of the insufficiency of both the synoptic view and the reductionist view. The demonstration in this Chapter is mathematical. It hinges on the notion that we move up a level in system complexity by integrating, but integrating does not add dimensions. Six dimensions are sufficient to describe "classical physical theory" (page 125), namely mass, length, time, temperature, voltage, and electric charge. But that list is insufficient to describe higher-level systems such as economics—which uses money and interest rate—or political science or communities. Similarly, we cannot get from higher-level systems, such as economics, to lower-level systems, such as physics. The items that are the focus of physics are independent of money and interest rate.

The "theory of dimensions...tells us that we cannot find out all about apples by studying

oranges" (page 139).

5.4 Chapter 10 Integrated Control Information

In this Chapter Kline presents a third and final demonstration of the insufficiency of both the synoptic view and the reductionist view. The demonstration in this Chapter is based on information. A system of "integrated control information," such as a brain, relies upon the integration of sensing and schemata, and it relies upon feedback in the form of control. (Elsewhere Kline equates "integrated control information" with "human information" (page 133) and with "skill" (page 146).) For example, driving a car requires sensing, schemata, and feedback. History is important in such systems, but history is outside the scope of inert, naturally-occurring objects such as rocks. This brings us to the conclusion that the reductionist view is insufficient. Meanwhile, values constrain but do not determine how we drive a car or carve a statue, bringing us to the conclusion that the synoptic view is also insufficient.

This leads Kline to Hypothesis V³³, Parts A and B:

The Need for at Least Three Views. Part A. At least three views are needed for a reasonably good understanding of hierarchically structured systems with interfaces of mutual constraint: (1) a synoptic overview; (2) a piecewise view of the parts [i.e., reductionist view]; and (3) a structural view of how the parts connect with each other in order to create the whole. (page 134)

The Need for at Least Three Views. Part B. Hierarchically structured systems with interfaces of mutual constraint are both common enough and significant enough so that all three views are necessary in order to understand the full range of situations and processes that are vital to humans. (page 134)

Note that while it appears that all systems exist within a hierarchy, Kline does not say that all systems have "interfaces of mutual constraint."

By "synoptic" Kline means a view that identifies the boundaries of the system, how it interacts with the environment, and what its goals are (if any).³⁴ By "piecewise" Kline means a view that understands the "smallest relevant bits" (page 134). Note that what Kline calls the "piecewise" view could also be called the "reductionist" view. And by "structural" Kline means a view that understands the connections between the pieces.

We cannot synthesize the three views in Part A above into one view because of fundamental limitations of our minds: we are unable to hold that much information in our consciousness simultaneously. As proof of this, Kline suggests the reader consider

all the details, the purposes, and the structure of any complex system familiar to you—for example, an automobile, a company, a tree, or an air

^{33.} All of Kline's hypotheses are listed in Appendix B on page 41.

^{34.} See Section 5.2 on page 20 herein.

transport system. I think you will find that even if it is possible, at a minimum it is so difficult that there is little utility in trying to think about the bits, the structure, and the system goals all at one time. (page 136)

Note that the "bits," the "structure," and the "goals" in the passage immediately above correspond to the piecewise, structural, and synoptic views, respectively of Part A further above.

5.5 Chapter 11 Disciplines at One Level: Disciplines and the Human Design Process

We are unable to deal with complex systems, such as sociotechnical systems (e.g., "economics, law, engineering, management, sociology, the humanities" (page 138)), without subdividing them: they are simply too complex. The pieces that constitute these sociotechnical systems are each the subject matter of a separate discipline and each subject matter is a slice of the space (Kline calls such a slice a "cut through the operating space" (page 73)). If the dimensions for a given pair of those disciplines are "exogenous" (i.e., disjoint), as is the case with market behavior and ecology, for example, then there is little that one discipline can do to help the other discipline. The situation is more hopeful when a pair of disciplines constrain each other, giving us a situation within one level that, in Chapter 8, we saw between levels.

An example of the problem and its solution is our design of automobiles. We create these complex machines by meeting criteria at multiple levels. For example, the structural design of parts involves "complex technics," but the values that constrain the design are found at higher levels. We must loop through the levels "until all the criteria are met at all the relevant levels" (page 140).

5.6 Chapter 12 Consistency as a Primary Criterion

For the purposes of this Chapter Kline presents a taxonomy of system classes that he calls "Six Major Classes of **Systems** of Human Concern" (Figure 12-1, page 144), reproduced in Table 5.

Class	Class Name	Examples
1	Inert, Naturally-Occurring	Rocks, air, oceans, weather, atoms, molecules
2	Artifactual	Tools, machines, structures, synthetic materials, sociotechnical systems
3	Biological	Organisms, ecologies
4	Human Systems	Social, political, economic, aesthetic, affectional
5	Values	(None provided)
6	Communications	(None provided)

Table 5Six Major Classes of Systems of Human Concern (Figure 12-1, page 144)

Note that the label for the column at the left in the Table above is a "class," not a "level,"

suggesting a lack of hierarchy.

Kline argues that the reductionist view works superbly for class 1, the class for which it was designed, but it is insufficient for classes 2, 3, 4, and 6, and it tells us "essentially nothing" (page 144) about class 5. This is not to denigrate physics:

Indeed, physics seems to be the only discipline that has something, nearly always something important, to say about every level in the hierarchy of constitution. Physics just doesn't tell us all the important things we need to know except in the domain of physics itself. (page 145)

Kline believes that heterogeneity is necessary for biological systems. Physics deals with homogeneity exclusively.

The applicability of the synoptic view is the obverse of the reductionist view: the synoptic view is "sometimes sufficient" for class 5 (the complexity of class 5 systems limits the synoptic view from being always sufficient), but it is insufficient for classes 2, 3, 4, and 6, and it tells us "essentially nothing" (page 146) about class 1, as shown in Table 6 below.

Class	Reductionist View	Synoptic View
1	works superbly	tells us essentially nothing
2	insufficient	
3		
4		
5	tells us essentially nothing	sometimes sufficient
6	insufficient	

Table 6Reductionist and Synoptic View of Value for Table 5 Classes

For systems with hierarchical structure, the reductionist and synoptic views, even together, are insufficient. We need structural views, as noted in Hypothesis V (see page 23 herein). We need to use the human design process that Kline describes in Chapter 11 (see Section 5.5 on page 24 herein). That process considers all of the levels of concern. Kline considers, as an example, the **system** of Windsor Castle in 1100 A.D. To understand this system we need to understand the "social structure, values, and communications systems of the people who lived in the castle in 1100 A.D." (page 148). That is, we need to consider all classes of concern.

One class need not be derived from another level. It only has to be consistent, as the name of this Chapter implies, and all of the "principles and data in all the relevant fields of knowledge" (page 149) for the classes must be satisfied in order to have a solution. Attempting to apply a principle that has been developed for one class to a different class without confirming that the application is appropriate is problematic. Kline considers positivist philosophy, out of which grew behaviorism, to be an example of the inappropriate application of principles developed in one class to another class. A second example is social Darwinism, which may be a contributory cause of World War I.

We have a difficult time learning about things that are outside of our sense experience and require instruments. For example, microbes are outside of our sense experience so it has been

difficult to develop a theory of diseases based on microbes. The reason it has been difficult is because we cannot learn about these systems "by direct observation" (page 154).

5.7 Chapter 13 Operational Procedures in Forming Sysreps for Complex Systems

Kline suggests six questions to guide us in determining the validity of real world models (i.e., sysreps), in particular with (hierarchical) systems that have interfaces of mutual constraint:

- 1. How many levels are there in the system structure?
- 2. How many total degrees of freedom are there on each level?
- 3. Of these total degrees of freedom, on each level, how many are constrained by the levels below and the levels above in the system of concern? Or, to put this the other way around, how many degrees of freedom are left open for independent action, thoughts, choices, and/ or design options in a given level?
- 4. Which are the levels of control?
- 5. Are the feedback loops autonomic, or do they involve human-control or human-design feedback modes?
- 6. Do the controls at higher levels have "jumpers"³⁵ directly to lower levels? (pages 158-9)

The first three questions are sufficient for increasing our understanding of "ancient unresolved questions" (page 158). The last three questions are important in "many cases" (page 159). Structure is generated by the lower levels and values are generated by the higher levels. For example, the question of free will vs. determinism is similar to asking what the temperature is for an automobile. There are different temperatures because an automobile has different parts, just as there are different answers about free will in humans because humans have different parts. The following are Kline's answers to the first three questions above, as applied to the question of free will & determinism:

Question 1: Humans have "five physical levels and three levels of control in the brain" (page 160).

- **Question 2:** We have so many degrees of freedom we cannot count them.
- **Question 3:** Only a "handful" of those degrees of freedom are constrained by physics; though many more are constrained by biology, many additional degrees of freedom are not constrained by a lower level: how else can we account for the "unimaginable variation" (page 161) of human cultures, languages, values, religions, artifacts, music, economics, sports, and beliefs about science? Granted, we "cannot make *any* possible choice, but within limits we can make a wide variety of choices" (page 163, emphasis added).

Finally, if humans were determined, then "all humans would think and act alike" (page 161), something that even the most casual of observers would be able to conclude is incorrect.

^{35.} An example of a "jumper" is "management by walking around" by higher-level managers: those managers "jump" to a lower level by talking directly to staff instead of going through lower-level management. This term and its use appear to be particular to Kline.

As another example, Kline shows that religion and science can co-exist if each stops overclaiming. Neither societies that are run by clergy nor societies that are explicitly godless (e.g., communism) have ever developed a "society of abundance" (page 165), meaning a society where at least 90% of the people are at least at level 2 in Maslow's hierarchy of needs (economic needs are met). Wisdom and compassion cannot help us with system classes that deal with mass and length; yet we cannot get from what is to what should be without values, and living without spiritual values is, as Jung put it, a "hard way to live," a concept with which Kline agrees. In the practicality of our everyday lives we generally do not overclaim in this area.

5.8 Chapter 14 Examples of Multidisciplinary Analysis

This Chapter presents three examples of the value of multidisciplinary analysis:

- 1. the source of the distinction between humans and animals;
- 2. the nature of innovation; and
- 3. nature vs. nurture.

The first example Kline presents is the distinction between human and animals. For this example we first need to study "sociotechnical systems" a bit.

A "sociotechnical system" is a system that "links people with human-made hardware to perform tasks that humans want done" (page 171). All human societies have used sociotechnical systems. The purpose of such systems is to "extend human powers" (page 172) and thereby "reduce the amount of hard and unappealing labor that humans must do to survive" (page 172). The rate of increase in such powers over the last 100,000 years is "astounding" (page 173), reaching over a billion times what we can do unaided by such systems.

Kline calls the development of sociotechnical systems the "basic pattern" (page 174) of human societal development. Such systems interacted with evolutionary forces to increase our brain size and vocal abilities as well as our manual dexterity. But note that the power generated by our sociotechnical systems is an attribute of human communities, not human individuals.³⁶ Humans are separated from animals by our ability to innovate. Our "human-made" systems now "proceed at roughly one million times the rate of evolutionary change" (page 176).

However, Cassirer in his 1969 book, *An Essay on Man* [5], attributed the difference between humans and animals not to our use of sociotechnical systems, which he did not even consider, but to our use of "symbolic forms" and our ability to delay gratification. Cassirer is not alone here in not noticing sociotechnical systems; he is joined by "many able and thorough scholars" (page 177). Our sociotechnical systems are as omnipresent and as invisible to us as water is to a fish.³⁷

The second example that Kline presents is innovation. Innovation is increasingly important economically, yet there is disagreement on fundamental questions, such as what it is and how it

^{36.} A discussion in Cox's book on the production system that generates and distributes pencils is an illuminating example of a system that was created and is maintained by humans but is beyond our individual capacity to understand [13].

proceeds. A common definition is the following: "An innovation is the introduction into the market of a new product" (page 179). But that definition is too narrow because it only considers hardware and not the changes to sociotechnical systems that are independent of hardware.

Kline reviews the six innovation models that Constant describes in *The Origins of the Turbojet Revolution* [10]. Constant discounts as "simply wrong" (page 180) the models for political science, sociology, and ethnology (labeled models 1, 2, and 3, respectively). The economics model (model 4), which is almost a "non-model" it is so simple, is a black box: innovation happens in the box and that is that. This is an example of a "cut through the *hyperspace*."³⁸ This is not wrong so much as it is incomplete, and if it is presumed to be complete, then the answers it provides are misleading or wrong. Neither model 4 nor model 5 considers the system as a whole. The engineering model (model 5) focuses on developing hardware and is too narrow. The science model (model 6), also known as the "linear model," presumes that innovation begins with research, proceeds to development, enters production, and then completes in marketing, as shown in Figure 1.



Figure 1 The Science (Linear) Model of Innovation (Figure 14-4, page 182)

This model discounts skills and crafts. Kline argues that "most innovations come from human designs, not from science" (page 183). Kline's model of innovation—based on personal

^{37.} This invisibility might be necessary: "As Alfred Whitehead has said in another connection, 'It is a profoundly erroneous truism, repeated by all copy-books and by eminent people when they are making speeches, that we should cultivate the habit of thinking what we are doing. The precise opposite is the case. Civilization advances by extending the number of important operations which we can perform without thinking about them.' This is of profound significance in the social field. We make constant use of formulas, symbols, and rules whose meaning we do not understand and through the use of which we avail ourselves of the assistance of knowledge which individually we do not possess. We have developed these practices and institutions by building upon the habits and institutions which have proved successful in their own sphere and which have in turn become the foundation of the civilization we have built up" [17]. (See also Sowell's essay "Are Jews Generic?" in his collection [26] for a discussion on the value that middle men provide, in all parts of the world, and the hostility that they engender, on the grounds that they are parasites, precisely because their work is invisible.)

^{38.} The word "hyperspace" is in italics to indicate that a definition for it appears in the Glossary, starting on page 54.

experience and the "multidisciplinary position for thinking" (page 183)—is the "chain-linked model" which looks somewhat like a chain-link fence due to the connections between its seven parts (I have not included the diagram for this model).

The third example Kline presents is nature vs. nurture. E.O. Wilson's "sociobiology" model [31] theorized that there is a biological basis for all social behavior. Note the word "all." Wilson means that biology determines social behavior. This is the same argument that a "leading economist" to which Kline refers uses to support the view that all of sociology can be derived from economics. Wilson's is one voice among many in the nature vs. nurture debate. Unfortunately Wilson fails to address the question of how biological changes are able to control sociotechnical systems that are changing one million times faster than biological changes can control. As Kline notes, this would be like "driving a car down a twisting mountain road at 30 miles per hour [but you can] turn the [steering] wheel only once per minute" (page 188). Surely your trip will end up in disaster. The "impermeability of disciplinary boundaries" (page 189), which is the opposite of multidisciplinary thinking, inspires such theories, leading to "prolonged sterile debate and thus much wasted effort of many able scholars" (page 189). Kline proceeds to show how there are readily available counterexamples for *any* one position in the spectrum between nature and nurture. Progress on this issue requires an "eclectic—that is, multidisciplinary—position" (page 192).

5.9 Chapter 15 The Evolution of Disciplines, 1500-1900

During the Middle Ages the Catholic Church provided a unified view of the world but this was broken up by the Reformation. The Renaissance re-introduced Greek notions of logic and rationality, based on discussion (what Kline calls "dialectic") as opposed to empiricism. "Natural philosophy" was the name for the non-theological body of belief generated by the dialectic. Bacon encouraged empiricism but it was slow in spreading. Galileo was the "turning point." Disciplines broke off from natural philosophy, and then those disciplines splintered from there, leaving us with "some hundreds of 'pieces'" (page 197). The members of the disciplines formed "invisible colleges." The members gave (and give) more allegiance to these invisible colleges than to the institutions that pay their salaries. The disciplines are based on empiricism and the system concept.

Kline notes that Gutenberg's movable type enabled a qualitative change in the speed, accuracy, and cost of printing. This was requisite for the rise of science. Gutenberg's was a development in a sociotechnical system, and "Innovations [such as Gutenberg's] in sociotechnical systems have been a primary engine of change in both economies and cultures (including values)" (page 197).

Typically, disciplines develop in a "matrix-like" progression of activities,³⁹ such as

- 1. selecting a class of systems,
- 2. developing "words and concepts" to describe that class,
- 3. organizing the area taxonomically,

^{39.} Kline calls these activities "steps," but then he argues that they are not followed necessarily linearly in time. I call them "activities" to avoid the confusion.

- 4. inductively developing rules that describe the phenomena associated with the systems,
- 5. testing the rules,
- 6. improving the rules and adjusting the class of systems,
- 7. converging, sometimes, on Entire Invariant Paradigms, and
- 8. computationally simulating sysreps.

In order for the "rules" to be mathematical, we must be able to make measurements. We can do this with the concept "length," for example, but not with "beauty" or "love." This does not mean that the latter are "less important." It only means that they are different.

Taxonomies enable an "understandable structure, or order" (page 202). For example, Newton's "laws," Linnaeus' tree, Mendeleyev's table are each a "fundamental picture of nature disclosed by human investigation" (page 202).

Logic systems do not follow the activities described above. These are "formal systems," deductively developed based on axioms. But these systems "do not necessarily apply to the world as it exists, since the world of material entities and living creatures is not composed of human-made formal systems" (page 203).

When we can express rules in mathematics, we associate the phenomena to variables. The set of variables implicitly delimit the sysrep, because what the variables cannot express, is excluded from the sysrep. However, we can iterate between "Baconian empiricism" and "Cartesian axiomatization." Kline believes this to be "the most powerful method we know for adding to the existing body of what we call science" (page 204). Classical mechanics and gravity were the first disciplines to complete the first four activities described above. Those rules were for inert, naturally-occurring objects with low complexity, yet it took three centuries ("from Copernicus through Kepler and Galileo to Newton" (page 205)) to complete those activities. These rules appear to be Entire Invariant Paradigms; they use simple mathematics with only a few variables. But those rules are not universal, as we will see when we consider the human sciences in the material below.

Kline notes that developments in nineteenth-century Europe led people to believe (1) in continuous progress in the sciences, meaning that all the sciences would all develop as physics had, and (2) in the continuous improvement of humans. Anthropology, sociology, and psychology developed in this atmosphere. Comte's positivist philosophy is at their roots and Mill encouraged this process. Comte suggested a hierarchy of disciplines, with disciplines higher in the hierarchy building on the results of disciplines lower in the hierarchy: mathematics is at the foundation, upon which is built, in sequence, "astronomy, physics, chemistry, biology (including physiology), [and] sociology" (page 208). ⁴⁰ Kline calls this "snobbish hierarchy" Comte's "pecking order" (page 208). It confused levels of constitution. It confused systems, such as physical and biological systems. As a result, it is "not possible of achievement" (page 208). Thomas Kuhn carried on the same tradition by labeling some disciplines "mature" (i.e., physics-like (they "create 'iron laws' stating simple principles in terms of a small number of 'hard' variables" (page 209)) and labeling other disciplines as "immature." Freud explicitly strove to develop a physics-like "science."⁴¹ This is not to

denigrate physics. Rather it is a function of the "unimaginably successful" (page 209) nature of the field of the physics; it is an instance of "success overrunning itself" (page 209).

But science is only three centuries old, and humans have been innovating for millennia, suggesting that we do not yet understand the relation between science and areas such as "medicine, engineering, agriculture, and psychotherapy" (page 210). Those "Working areas [i.e., areas of professional employment] often deal with complete sociotechnical systems. Sciences are typically cuts through a hyperspace of such systems and are therefore not sufficient for all problems within the systems" (page 211). Those areas play a "symbiotic" (page 211) role with science. They are not "merely applied science" (page 210). De Solla Price argues that technology—tools, skills, manufacturing capability—has contributed more to science than science has to technology.

5.10 Chapter 16 Relations Among the Disciplines in the Twentieth Century: Similarities and Differences

During the Twentieth Century scholarly communities grew and their standards rose. The emigration of eminent, European scholars to the United States contributed to those trends. However, depth of expertise has increased at the expense of breadth. Of the six human sciences, only history has avoided the urge to be more "physics-like"; the reason for this is that history deals with "complete human systems" (page 214). Meanwhile, the physics community changed their model from the Newtonian-Galilean view to quantum mechanics. But physicists continued to presume that their model, now "randomly probabilistic" (page 216), was a model for a worldview. This is a

...serious overclaim. It is serious because it has distorted worldviews and confused understanding of the relationships between the disciplines for many of us for a century or more."⁴² (page 217)

Yet, Kline notes, physicists have cautioned that the world of quantum mechanics does not apply to the world of classical objects!

Quantum mechanics is not suitable for a worldview because (1) the characteristics of the

mathematics, philosophy (there is a hierarchy within philosophy: phenomenology, the "normative sciences" (there is a hierarchy within the normative sciences, namely esthetics, ethics, and then logic), metaphysics), and then

the "special sciences" (e.g., psychology, anthropology, linguistics, history, in no particular order).

41. A kind of physics-envy perhaps.

^{40.} C. S. Peirce (1839-1914) espoused the same notion. Pierce's hierarchy is as follows, starting with mathematics at the foundation and building from there:

^{42.} Hayek provides an example of this type of overclaim in the following passage: "It seems to me that many of the current disputes with regard to both economic theory and economic policy have their common origin in a misconception about the nature of the economic problem of society. This misconception in turn is due to an erroneous transfer to social phenomena of the habits of thought we have developed in dealing with the phenomena of nature [i.e., physics]" [17].

quantum world are not those of higher systems, (2) emergent properties arise from heterogeneity, feedback loops, and hierarchical systems with interfaces of mutual constraint not found at the quantum level, and (3) the generation of the laws of thermodynamics from quantum mechanics, apparently considered a first step in showing the suitability of quantum mechanics, has not been done. Quantum mechanics does not eliminate Newton's laws. We have confidence in those laws "with as much assurance as anything humans know about the world" (page 220). They are the basis of engineering, for example. So we seem to have three different kinds of systems in inert, naturally-occurring objects: deterministic; random probabilistic; and chaotic. For each, a different kind of sysrep is required.

The problem here is the extension of models from a domain for which the models were developed to some other domain, without examining empirically the suitability of the extension. In particular, physics is limited to systems that do not have "human information" (page 225) (see page 16 above).

It would help us if we were to distinguish between three types of rules (see Section 4.3 on page 17 herein):

1. Entire Invariant Paradigms.

These are rules that predict with certainly a behavior of all systems in a domain "for all times and in all places" (page 80).

2. Entire Paradigms.

These are characteristics that apply to all systems in a domain. For example, two Entire Paradigms about groups of people is that they have a religion and they use the family as "the primary social unit" (page 82).

3. guidelines.

These are "useful but not always correct in terms of predictions" (page 226).

Philosophy, far from providing an evaluation of physics-as-worldview, seems to have adopted it via positivism.⁴³ Philosophy has undertaken the task to "interpret" physics, i.e., show how it applies to the rest of the world, somewhat the way Christian apologists interpreted the Scriptures during the Middle Ages. Philosophy does not seem to recognize the importance of "domains" in determining applicability of "laws" such as those developed by physicists. In addition, philosophy uses dialectical discussion, which is subject to swings in thought, instead of empiricism, which displays incremental progression. Kline considers the failure of philosophy to help here "one of the most perplexing issues that this volume treats" (page 226).

Within universities, interdisciplinary programs have increased in number but multidisciplinary ones have not. Departments control the curricula. Since 1900 a number of disciplines have arisen that focus on information. Kline notes that "human information is not and should not be described by the equations of physics" (page 230). He also notes that there are "qualitatively different kinds of information and feedback modes" (page 230).

^{43.} See the Glossary, starting on page 54, for more information about this term.

6 Part 4 Fallacies of Projection

6.1 Chapter 17 Fallacies of Projection: Illustrations

"Projection" is the psychological term that describes a human tendency to "believe that others know what we know, think in the way we do, and have the same feelings we do about a given situation" (page 44). The mathematical analogue is "extrapolation." A "fallacy of projection" is Kline's term for "projections of 'ideas' that are appropriate in one domain into another domain in which the same 'ideas' are less appropriate or even totally erroneous" (page 235). The inappropriateness arises if the sysrep is smaller than the domain (that is, the sysrep cannot model the entire domain) or if the sysrep is made to extend beyond the domain. Fallacies of projection "are usually not entirely wrong, but usually are seriously incomplete" (page 235).

Kline lists 28 fallacies (see Appendix C). The list is not exhaustive. Rather, the list represents "only some of the examples" (page 240) that Kline has collected "as they came to [his] attention." Kline observes that over half of the fallacies are due to "attempts to make principles physics-like" (page 241), suggesting that we have thought too highly of the success of physics. Pre-literate societies attributed human qualities to rocks; our society has done the opposite by attributing the qualities of rocks to humans. Kline remarks that these fallacies support the notion that the "human mind seems to have a natural tendency to accept simple sysreps about complex systems" (page 241).

Fallacies are eventually discarded if they are subject to a community of scholars, such as exists within a discipline. This is the case with logical positivism, logical empiricism, radical behaviorism, and social Darwinism, for example. At least for positivism and social Darwinism, for example, Kline notes that both are "now known as important scholarly aberrations" (page 151). But because there is no multidisciplinary activity, fallacies that are outside of disciplines—such as physics-as-worldview or the reductionist/synoptic argument—tend to persist. This is one of the reasons Kline advocates multidisciplinary activity.

6.2 Chapter 18 Fallacies of Projection: Possible Sources

There have been two tendencies of importance. (1) We have blindly applied sysreps from one domain to another. (2) We have used "oversimple" sysreps for complex systems.

These two tendencies are due to six sources:

- 1. Our minds are limited. We can only hold seven bits of information in our attention.
- 2. The world is complex. Complex systems require three views—"piecewise, structural, and synoptic" (page 245) (see Section 5.4 on page 23 herein). The only universal principle appears to be that all other principles are not universal but are confined to domains.
- 3. We want to understand ("epistemic hunger," Dennett calls it). Note how eagerly children learn language and the propensity with which they ask "Why?"
- 4. There is no multidisciplinary discourse. There has been no "outside view" (page 251) and little opportunity to understand the context of a given discipline.

- 5. Disciplines are independent of each other and sometimes independent of "empirical grounding" (page 247) as well. Without feedback, disciplines have drifted, sometimes into "mass illusions" (page 247)—exemplified by phlogiston, caloric and ether—reminiscent of the earth-fire-water-air theory of the elements. We no longer create myths but we do lapse into "incompletely or inappropriately projected schemata" (page 247).
- 6. Disciplines are sub-cultures, complete with creation myths, rites of passage, social structure, vocabulary ("semiotically encoded words (jargon)" (page 251)) and taboos. These subcultures provide "distorting filters" (page 258). In addition, members of these disciplines work so consistently on a particular subset of problems that it is easy for them to presume that this particular subset is the full set.⁴⁴ As a result, disciplines present some imperviousness to the outside world and have inadequate checks against overclaims.

The "history and sociology of science" (page 252) has provided some insight. But some of that insight has been obscured by Kuhn's notion of "mature" sciences being those that are like physics, as noted above. The philosophy of science, on the other hand, should have helped here but it has not. In fact, philosophy has supported the overclaim of physics as a worldview. It has ignored the following:

- the necessity of empiricism,
- the differences in methods (Baconian empiricism, Cartesian axiomatization, and Popperian falsification) and the differences in views (Comtian realism, quantum instrumentalism, Feyerabendian⁴⁵ relativism) in the scientific disciplines, under the presumption that there is only one method and one view (which leads to "non-closing arguments over several non-answers" (page 255)),
- the system concept, and
- the value of taxonomies and hierarchies ("hierarchy is an invention of the Western mind" (page 256)).

Tarnas [29], in a "survey of the Western mind" (page 257), suggests that the paradigms of Western science have come from our "collective unconscious," which Kline considers preposterous, as though Newton's calculus or the Navier-Stokes equations could have that as their source. Kline thinks that Feyerabend and Tarnas, both philosophers, have projected the "Hegelian swings" so typical of philosophy on to science.

^{44.} This is similar to the notion that the mind presumes that what it sees is normal. So if what the mind sees is skewed, say by a preponderance of TV, then the mind considers the world of TV to be the normal world.

^{45.} Kline notes that Feyerabend was a "nihilist" who assumed that there is "no basis for deciding what are appropriate versus inappropriate sysreps" (page 257).

7 Part Five: Conclusions

7.1 Chapter 19 What Have We Learned? A Summary of Results and Conclusions

The two "central questions" (page 263) of this book are "(1) What are the appropriate relationships among the disciplines? and (2) What are the appropriate relationships between a discipline and overviews of the intellectual terrain or truth assertions?" (page 263). Kline has presented the system concept, system complexity, and hierarchical systems with interfaces of mutual constraint to help us address these questions. Our arrangement of intellectual disciplines is new and valuable but suffers from projections and incomplete sysreps. Kline argues that "no one method, no one set of principles, no one viewpoint, no one set of equations, no one discipline…is sufficient to understand all matters vital to human concern" (page 264).

Kline presents the results in five sections, named as follows (a summary of the results are shown in Appendix D):

- A. Systems and Their Mental Representations
- B. Complexity and Its Implications
- C. The Structure of Systems
- D. Differences and Similarities Among Disciplines
- E. Other Results Concerning Multidisciplinarity

7.2 Chapter 20 What Have We Learned? Implications and Inferences

Kline presents seven sections in this final Chapter.

7.2.1 Lack of a Universal Approach

Kline argues that if a theory were available for such highly complex systems as "the nature of life, the origin of complexity, the conditions needed for stable fair governments" (page 277), then it would be incomprehensible to us. We do not have the capacity.

7.2.2 Implications of Complexity

The significance of complexity is "seriously underestimated" (page 278). We are not capable of understanding complete systems when they are complex. So, out of necessity, we use "cuts." Those cuts are, necessarily, incomplete and thus are not perfectly predictive. Our recourse is incremental improvement based on experience.

7.2.3 Interfaces of Mutual Constraint

Polanyi's principle of mutual constraint has not been assimilated. However, from it we can understand that "physics and biology constrain but do not determine social and sociotechnical systems" (page 278). The rules change from level to level "in many instances" (page 147). We

would like a "single theory of everything" (page 279) but such a theory does not fit the "messy, complex world we see around us" (page 279).

7.2.4 Limits of the Mind

Our minds are at the "cutting edge of consciousness on the planet" (page 279) and also an "evolutionary 'kludge' with severe limitations." We are limited in the number of items we can retain in short-term memory. Because we have an urge to understand, we project when we have no ready-at-hand schemata with sufficient explanatory power. It is as though we collectively agree that being somewhat wrong is better than having no idea what is going on.

7.2.5 The Mismatch of Mind and Complexity of Systems

We think we can understand anything, but the complexity of systems around us is beyond our powers of rapid comprehension. We have no choice but to move slowly, to build piece upon piece, all the while checking to make sure our model matches the real thing.

7.2.6 The System/Sysrep Apparatus

There is an "iterative loop between system⁴⁶ and sysrep" (page 281) that can be improved by "the implications of complexity, hierarchical structure, the theory of dimensions, feedback control, and related ideas" (page 281) presented in this book. These iterations can help between disciplines and within disciplines. In the former arena, the iterations help identify the "rules" of multidisciplinarity; in the latter arena, the iterations provide "traceability," ensuring that the sysreps represent reality.

7.2.7 Is Multidisciplinary Discourse Important?

Disciplinary experts are limited by their schemata. Those schemata serve well within the discipline but not out of it. The disciplines have a responsibility to the larger community. We can look to experience in government (i.e., the U.S. Constitution) and industry (i.e., Japanese techniques for consensus) to guide us here. We can use the map metaphor, where the map is a multidisciplinary view and the blocks of land on the map are individual disciplines. We can use the loop-through-lower-and-higher-levels approach, as described in Chapter 11. We will need at least three views: piecewise, synoptic, and structural. Ethnology presents a pattern to follow. The variation in culture required both an insider's view ("emic") and an outsider's view ("etic"). These names come from "phonemic," relating to the sounds in all human languages, and "phonetic," relating to the sounds in just one human language. The emic view strives for consistency within a discipline; the etic view strives for consistency between disciplines; together they strive for consistency in our world view.

Multidisciplinary discourse is important for a number of reasons.

1. We need at least three views to understand a complex system.

^{46.} I think that this instance of "system" should appear in bold (see Section 3.1 on page 11 herein) but Kline disagrees.

- 2. The results of this book suggest the value of that discourse.
- 3. The tools developed via this book are important within disciplines.
- 4. We commonly make projection fallacies.
- 5. With the proper structure and process we can enhance disciplines by learning from other disciplines.
- 6. Many concepts in this book are the result of multidisciplinary thinking.
- 7. We need multidisciplinary capabilities to deal with our increasingly complex systems.
- 8. We are obliged to train the next generation properly.

Our various, separate disciplines have been "successful far beyond anyone's imagination two centuries ago" (page 290). But they are fragmented. Without a multidisciplinary view, we will miss

- 1. accuracy at the highest level,
- 2. a reasonable "umpire" for funding allocations,
- 3. a perspective from which curricula can be designed,
- 4. a way to engage multiple disciplines on a problem,
- 5. an inter-discipline communication channel,
- 6. a community concerned with the whole of intellectual knowledge, and
- 7. a way to learn from the set of disciplines, the way we have learned about what it means to be human from the set of 2,000 tribes that ethnology has studied.

8 Concluding Material

The concluding material for this book consists of two Appendices.

In Appendix A Kline presents some "implications for education" (page 295) based on the results of the book. None of those "implications" are included in this report.

In Appendix B, Kline makes two "standing bets" that "dispute overclaims" (page 301) of what two particular disciplines can do. These two particular disciplines are chosen because they have had "more effects in the twentieth-century world than those of other disciplines" (page 301). In "Bet A," Kline challenges any physicist to "provide a logically correct derivation of the second law of thermodynamics from statistical mechanics" (page 302). In "Bet B," Kline challenges any economist to describe, using economic theory, the "actual steps that were needed to create [any of ten] innovation[s]" (page 308) namely radio, turbojet, transistor, personal computer, telephone, automatic transmission for automobiles, the FAX machine, nylon, penicillin, and the steam turbine.

Appendix A Other System Taxonomies

For comparison with Kline's system taxonomy, presented in Table 2 on page 18 herein and Table 3 on page 19 herein, I have included here the system taxonomies of Checkland and Boulding.

Checkland's system taxonomy contains "at least" four types:

- 1. natural systems (e.g., physics, chemistry, biological systems),
- designed physical systems (e.g., bridges, engines),
- 3. designed abstract systems (e.g., mathematics, poetry, this category of systems), and
- 4. human activity systems (e.g., football teams, corporations, political parties, social systems) [6].

Boulding's system taxonomy contains concentric systems starting with the "smallest" system:

1. framework

This type of system includes "the geography and anatomy of the universe" ([4], page 10), such as electrons around a nucleus. These frameworks are the "beginning of organized knowledge in almost any field" ([4], page 11). The Copernican revolution was a framework change, though on a different scale.

2. clockworks

This type of system includes the solar system, the "great clock of the universe" ([4], page 11). This is the level of "classical' natural science" (page [4], 13).

3. thermostats

This type of system encompasses the "whole empirical world of the biologist and the social scientist" ([4], page 11).

4. cells

This type of system includes open systems or "self-maintaining structures" ([4], page 11) and structures that can "both reproduce themselves and maintain themselves in the midst of a throughput of material and energy" ([4], page 12) and thus qualify to be called "life."

5. plants

This type of system exploits division of labor among cells.

6. animals

This type of system is characterized by "increased mobility, teleological behavior, and self-awareness" ([4], page 12), requiring "an enormous increase in the intake of information" (ibid.). Behavior here is the result in part on the animal's "image" of the world. This image requires a structure independent of the input, though it is formed by that input and changed by it in non-linear ways.

7. humans

This type of system is characterized by self-awareness, the use of symbols, and the concept of time and relationships.

8. social organizations

This type of system use "roles" connected by "channels of communication" ([4], page 13), along with the meaning of messages. These systems are difficult to separate from humans because humans spend almost all of their lives in social organizations: "a truly isolated man would not be 'human' in the usually accepted sense" (ibid.).

9. transcendental systems

This type of system includes "inescapable unknowables" ([4], page 13).

Appendix B Kline's Hypotheses

Kline presents several hypotheses in various places in his book, all of which are in an Appendix (along with "Guidelines" and "Dicta and Queries"). Only three of these items are shown in the body of this report. Because the hypotheses are numbered, it is disconcerting for the reader not to have access to the missing hypotheses, so all of Kline's hypotheses, as well as a couple of corollaries, as they appear in Kline's Appendix, are shown below.

Hypothesis I: The Possibility of Multidisciplinary Discourse.

Meaningful multidisciplinary discourse is possible. (page 311)

Hypothesis II: Honor All Credible Data.

In multidisciplinary work, we need to honor all credible data from wherever they arise. (This includes not only data from various disciplines and from our laboratories, but also from the world itself, since we have no labs from which we can obtain data for many important purposes.) (ibid.)

Hypothesis III: The Absence of Universal Approaches.⁴⁷

There is no one view, no one methodology, no one discipline, no one set of principles, no one set of equations that provides understanding of all matters vital to human concerns. (ibid.)

Hypothesis IV: The Necessity of System Definition.⁴⁸

Each particular truth assertion about nature applies only to some **systems** (and not to all). (ibid.)

Hypothesis IV, Corollary A.

No truth assertion about nature is complete without a statement of the domain of applicability. (ibid.)

Hypothesis V: The Need for at Least Three Views.⁴⁹

Part A. At least three views are needed for a reasonably good understanding of hierarchically structured systems with interfaces of mutual constraint: synoptic, piecewise, and structural. (ibid.)

Part B. Hierarchically structured systems with interfaces of mutual constraint are both common enough and significant enough so that all three views are necessary in order to understand the full range of situations and processes that are vital to humans. (ibid.)

^{47.} This hypothesis is shown on page 10 of this report.

^{48.} This hypothesis is shown on page 12 of this report.

^{49.} This hypothesis is shown on page 23 of this report.

Polanyi's Hypothesis, Part A.

In many hierarchically structured systems, adjacent levels mutually constrain, but do not determine, each other. (page 312)

Polanyi's Hypothesis, Part B.

In hierarchically structured systems, the levels of control (usually upper levels) "harness" the lower levels and cause them to carry out behaviors that the lower levels, left to themselves, would not do. (page 312)

Hypothesis VI: Empiricism in Heretical Structures.

In order to provide an adequate empirical base, we must make observations at all levels of concern for the class of systems under study. (ibid.)

Hypothesis VII: The Principle of Consistency.

In systems with hierarchical structure and levels that mutually constrain one another, solutions must satisfy the principles and the data in all the relevant levels and fields of knowledge. The same is true for systems studied by more than one field when the dimensions of the various fields are exogenous to each other. (ibid.)

Hypothesis VII, Corollary A.

When solutions from more than one level in a hierarchical structure with interfaces of mutual constraint provide results for a given behavior in the same system, then the results must be consistent where they overlap. If the results are not consistent, then we must seek the source of the error, and not argue that one level or one discipline governs (or has priority over) the other. The same remark applies when two disciplines give overlapping results and have some primary dimensions exogenous to each other (ibid.)

Durham's Hypothesis:

Genetic information and cultural information are two separate, interacting sources of human information; each evolves over time, but at different rates of change.

Addition [to Durham's Hypothesis] (by author [i.e., Kline]):

Human skills form a third type of human information which interacts with the other two. Skills are necessary for maintenance of human societies over time. Skills are socially transmitted and evolve. (ibid.)

Appendix C Fallacies

In Chapter 17 Kline lists 28 fallacies in two general categories, fallacies of "projection" and fallacies due to "difficulties of incompleteness." A fallacy of projection involves applying a principle in one domain to another, inappropriate domain. For example, social Darwinism (Fallacy I-a) is the application of evolution in biology to human social groups. A fallacy due to difficulties of incompleteness involves applying a principle in one domain to a superset domain. For example, physics-as-worldview (Fallacy II-a) suggests that we can solve "macroscopic problems" based on "principles and methods of physics."

Kline also includes what he calls "inverse" fallacies. An inverse fallacy is the belief that a principle does not apply. For example, entropy does in fact apply to biological systems (Fallacy I-h). Entropy is a constraint on matter but not on information.

For each fallacy Kline provides a few sentences of explanation which, for brevity, I do not include.

Here is Kline's list:

Type I: Projective Errors

- Fallacy I-a: Survival of the fittest applies to human social groups within given institutions (social Darwinism).
- Fallacy I-b: We are in danger of [imminent] "heat death" as a result of the entropy principle.
- Fallacy I-c: The Heisenberg Uncertainty Principle explains why life is uncertain.
- Fallacy I-d: Entropy as defined in the technical world applies to social systems.
- Fallacy I-e: All systems, including social systems and biological systems, tend toward (and not away from) disorder because of the entropy principle.
- Fallacy I-f: "It is a general rule of logic that 'principles' are not to be multiplied beyond the necessary. Therefore, since interpretation in terms of energy has proved a general principle in the physical sciences, we must limit ourselves to it in psychology also" (Carl Jung, *Autobiography*). (But physical energy is not psychic "energy." Even "great" men can lapse into fallacies.)
- Fallacy I-g: The principles of the physical sciences are not invariant; they are only relative, since they are created by human consensus.

Inverse Fallacy, Type I

Fallacy I-h: The entropy concept does not apply to living systems (organisms).

Type II: Difficulties of Incompleteness

- Fallacy II-a: "In principle," one can do [i.e., address] all the macroscopic problems of the world starting from the principles and methods of physics. [This is what Kline calls "physics-as-worldview."]
- Fallacy II-b: Neoclassic economics is a sufficient basis for erecting a theory of innovation and hence for the growth of economic productivity.
- Fallacy II-c: Truth assertions are a sufficient basis for all human values. [Kline calls this a "hard way to live."]

- Fallacy II-d: The human brain can be fully simulated by a "rule-bound" computer or by any simple set of fixed "rules."
- Fallacy II-e: The implied assertion in radical sociobiology that ultimately all human cultures and human behaviors are controlled by genetics.
- Fallacy II-f: All systems should be described in terms that are probabilistic and uncertain—as in quantum mechanics.
- Fallacy II-g: Engineering is merely applied science.
- Fallacy II-h: Medicine is merely applied biology.
- Fallacy II-i: Agriculture is merely applied agronomy.
- Fallacy II-j: Psychotherapy is merely applied experimental psychology.
- Fallacy II-k: A top-down (synoptic) view is sufficient by itself to understand all the problems of vital concern to humans.
- Fallacy II-l: A bottom-up (piecewise) view is sufficient by itself to understand all the problems of vital concern to humans.
- Fallacy II-m: Godel's Theorem tells us that we cannot fully understand nature.
- Fallacy II-n: The household thermostat air-conditioner system is a good model for feedback in human communication systems.
- Inverse Fallacies, Type II
- Fallacy II-o: The idea that the newer human sciences ought to adopt the methods and viewpoints of classical (more specifically, Newtonian) physics.
- Fallacy II-p: Logical positivism and logical empiricism.
- Fallacy II-q: Disciplines that have not produced Entire Invariant Paradigms are "immature."
- Fallacy II-r: Data from [the] study of non-human animals in environments controlled by the human experimenter are a sufficient basis for a complete human psychology. (pages 236-9)
- Kline adds a projective fallacy that some "pre-literate societies" (page 240) believe:
 - Fallacy I-i: Forests, lakes, mountains, and/or features of inert physical nature can and do understand human actions and can reward or punish human actions. (page 240)

The following additional projective fallacy has been suggested by "some interdisciplinary workers" (page 240):

Fallacy I-j: The total flow of energy per person through a society is a good measure of the advancement of society. (page 240)

As an example of one of Kline's comments about the fallacies, Kline comments as follows on Fallacy I-j:

Energy is a reasonable rough measure of the state of production of goods, but it tells us nothing about the state of social fairness, the spiritual health, or the political health of a society. Nazi Germany had a relatively high flow of energy per person. (page 240)

Appendix D Results

In Chapter 20 Kline lists 36 "results," in five sections, of the book. I have listed all 36 below, in my own words, occasionally quoting Kline. Kline notes that there is redundancy and overlap in the set because the "terrain is complex and interconnected" (page 264).

A. Systems and Their Mental Representations

- A1. Truth assertions require context (i.e., for what domains are they relevant?)
- A2. Confusing a sysrep with a system, in itself leads to confusion.
- A3. By default we use current schemata to explain new phenomena.
- A4. Inert, naturally-occurring systems require deterministic, probabilistic, and chaotic sysreps.
- A5. Non-technical people need to learn the system/sysrep apparatus, and technical people need to learn that rationality is insufficient for "all problems of vital concerns to humans" (page 266).
- A6. Reductionism⁵⁰ is necessary but not sufficient.
- A7. All human societies use sociotechnical systems.
- A8. Sociotechnical systems distinguish humans from animals; they provide a model of innovation; and they clarify the nature/nurture issue.
- B. Complexity and Its Implications
 - B1. Complex systems are beyond analysis or even modeling and our only hope in dealing with them is by using the "human-design feedback mode" (page 267).
 - B2. Sociotechnical system models are necessarily incomplete.
 - B3. Experience precedes (i.e., is more important than) theory for complex systems.
 - B4. A sysrep is incomplete unless it includes all relevant variables.
- C. The Structure of Systems
 - C1. Complex systems generally require three views: synoptic, piecewise, and structural.
 - C2. Neither reductionism nor synopticism⁵¹ is sufficient.
 - C3. Consistency, not derivation, is all we can expect across hierarchical interfaces.
 - C4. Humans have capabilities—such as self-reference, imagination, and the ability to pass on culture and skills—that "qualitatively transcend" animals.
 - C5. Human systems evolve. (The "rules" evolve as well.)
 - C6. There do not seem to be Entire Invariant Paradigms in the human sciences.
 - C7. Hierarchy is necessary for many systems.
 - C8. Taxonomies are necessary for the development of many disciplines.
 - C9. "Variables, parameters, behaviors, and the appropriate 'rules' all typically vary between one level and others in hierarchical structures" (page 270).

^{50.} See the Glossary, starting on page 54, for more information about this term.

^{51.} See the Glossary, starting on page 54, for more information about this term.

- D. Differences and Similarities Among Disciplines
 - D1. Human sciences are "significantly different" (page 270) from physical sciences because the former have open degrees of freedom.⁵²
 - D2. Humans must make choices. (These choices can be based on "spiritual, utilitarian, pragmatic, economic, affectional" (page 271) values.)
 - D3. "There seem to be no Entire Invariant Paradigms in the social or behavior sciences (unlike the physical sciences)" (page 271).
 - D4. "Neither genetics nor culture nor the principles governing subatomic particles determine all human behavior" (page 271).
 - D5. Separate disciplines is a new phenomenon. It has been valuable but there are problems, suggesting the need for multidisciplinarity.
 - D6. Disciplines for simple systems developed first, followed in time by disciplines for complex systems.
 - D7. The differences between the human and physical sciences has been "underappreciated and understated for a century or more" (page 272).
- E. Other Results Concerning Multidisciplinarity
 - E1. Science is the best generator for truth about nature that we have, but it is insufficient to deal with "all the problems of vital concern to humans" (page 272).
 - E2. Some problems require more than one discipline.
 - E3. No physical science paradigm, such as those developed for physics, can be a worldview.
 - E4. Human sciences are currently insufficient for all human systems.
 - E5. Multidisciplinary tools are available.
 - E6. "Rules" can be at least "principles, laws, paradigms, guidelines, and so forth" (page 274).
 - E7. Multidisciplinarity is of value.
 - E8. Maps of the "intellectual terrain" (page 275) are valuable.

^{52.} See the Glossary, starting on page 54, for more information about this term.

Appendix E Biography

The following is an except from Kline's obituary that appeared in the Stanford News [19] *on November 28, 1997:*

Even in a community of over-achievers Kline stood out, according to his colleagues. "Steve was a very remarkable person with a broad range of interests. He had exceptional drive, personality and originality," said Walter Vincenti,⁵³ professor emeritus of aeronautics and astronautics, a longtime friend. "He had a very striking personality. He was very convinced of the validity of his own ideas, and very strong in presenting them."

Kline was born and grew up in Los Angeles. He earned a bachelor of science degree in mechanical engineering from Stanford in 1943. After graduating, he went to work for the U.S. Army in the Office of the Chief of Ordnance for three years before taking a job as a research analyst at North American Aviation (now Rocketdyne). He returned to Stanford and obtained his master of science degree in mechanical engineering in 1949. He earned a doctorate in 1952 from Massachusetts Institute of Technology, where he studied thermodynamics, fluid mechanics and heat transfer. He joined the Stanford faculty immediately thereafter and served until he retired in 1992.

"Since I was very young I have had two characteristics which pushed me toward and helped me in a career in science and engineering," Kline once wrote. "I have an intense curiosity about how things work, and I want to understand them in a direct, visual physical way. I am primarily interested in problems which are largely unsolved and important to humans and to the advancement of science and technology."

In the 1940s and 1950s, the nature of turbulence was considered one of the most important unsolved problems in fluid mechanics, so Kline was drawn to it. He developed methods of scientific visualization that allowed him to take the first detailed look at the layers of turbulent air that surround moving objects. These turbulent flows are responsible for 50 percent of an aircraft's "drag," the aerodynamical force that opposes its motion.

In 1968, Kline organized a unique conference on turbulent boundary layer prediction that was held at Stanford. According to the American Society of Mechanical Engineers International, this conference was "a landmark in the development of boundary layer technology."

"His work led to a whole field of research, both experimental studies and the development of computer simulations, that has greatly influenced the design of modern airplanes," said Peter Bradshaw, professor emeritus of mechanical engineering and one of Kline's friends and colleagues.

Kline published 150 technical papers and three books, primarily in the fluid mechanics field. His research won him scientific medals in six countries. In 1981, he was inducted into the National Academy of Engineering — the highest honor that a U.S. engineer can receive.

^{53.} Kline writes in the Preface that he and Vincenti divided up the initial work in the "Program in Science, Technology and Society" (STS) as follows: Vincenti would produce case studies and Kline would "work on foundation concepts" (page xv).

He also did extensive consulting with industry. He worked with a number of companies, including Ingersoll Rand, General Electric, E. I. du Pont de Nemours and Co., General Motors Research Laboratories and United Technology Corp.

"His only hobby was his work. He liked nothing better," said Dr. Naomi Jeffries Kline, his wife of 20 years and a practicing psychotherapist.

Behind Kline's hard-charging engineer's demeanor lurked a rich vein of kindness, say friends and colleagues. When he became concerned that the university environment did not provide adequate emotional support for its people, for example, he helped launch a local chapter of the Support Group Network, a non-profit group with the goal of helping individuals provide each other with mutual support and encouragement.

Kline was so immersed in the culture of engineering that he had a habit of sprinkling his speech with mechanical metaphors, like "chugging along," recalled Robert McGinn, chairman of the Science, Technology and Society program. Nevertheless, Kline's broad interests increasingly carried him beyond the boundaries of his discipline.

In the late 1960s, Kline became concerned that a significant intellectual gap existed in the curricula at Stanford and other major U.S. universities. He realized that studies of the ways that science and technology affect and are affected by social institutions and human values were virtually nonexistent, despite the importance of the subject. Long discussions in 1970 with Vincenti and two other professors led the four to create the Stanford Program in Values, Technology and Society (now Science, Technology and Society, or STS) devoted to understanding the nature and significance of technology and science in modern, industrial society. According to Vincenti, Kline was the driving force in the group.

"One of Steve's most admirable qualities," McGinn notes, "is that while continuing to do research in mechanical engineering, he also read widely in the humanities and social sciences and made important contributions in the STS field. Indeed, of the many scholars in the STS field around the world, Steve Kline was one of the very few who had profound, firsthand knowledge of engineering practice and brought that understanding to bear fruitfully on his STS scholarship. In so doing, he helped to establish engineering as a new area of STS studies."

Kline's most important single contribution, McGinn said, is his model for technological innovation. Kline felt that the dominant linear or "assembly line" model for research and development, with its assumption that investment in basic research will automatically be transformed into new technology, was not only simplistic, but actually harmful. So he developed what he called the "chain-link" model of innovation, which has been widely adopted in a number of disciplines both in the United States and abroad.

In 1985 Kline and economics Professor Nathan Rosenberg presented this model as part of an overview prepared for a national symposium on innovation sponsored by Stanford and the National Academy of Engineering. Contrary to popular wisdom, innovation is "inherently uncertain, somewhat disorderly, involves some of the most complex systems known, and may consist of changes of many sorts at many different places within the innovating organization," they wrote.

Kline also was concerned that the current approach toward higher education, one combining in-

depth work in the student's major with assorted required courses in other subjects, was not adequate to provide an intellectual framework that students can use to embed the specialized information and theories that they learn. So in his final book *Conceptual Foundations for Multidisciplinary Thinking* (Stanford University Press, 1995), which he completed after becoming ill, Kline explored the relationships and conflicts among different disciplines and called for the development of an integrated conceptual framework that can link the specialist's expertise to the overall intellectual enterprise.

In 1996 the American Society of Mechanical Engineers International bestowed its highest honor on Kline. The citation provides a capsule summary of Kline's professional life. It read: "For a lifetime of contributions to the engineering science of turbulent flows, for seminal contributions to the understanding of the fundamental structure of turbulent layers, and for leadership in articulation of the conceptual foundations of multidisciplinary thinking."

Appendix F Review of Polanyi [22]

Note: This paper by Polanyi is part of the foundation of Kline's argument in Chapter 8 (see Section 5.2 on page 20 herein).

In this paper Polanyi develops what he calls the "theory of boundary conditions" ([22], page 1310). This theory postulates that the "higher levels of life" form a hierarchy and that the same type of condition exists at the boundary of each system in this hierarchy, namely that "the principles of...a lower level leave indeterminate conditions to be controlled by a higher principle" ([22], page 1311) and "the operations of a higher level cannot be accounted for by the laws governing its particulars on the next-lower level" (ibid.). As Polanyi explains,

Each level relies for its operations on all the levels below it. Each reduces the scope of the one immediately below it by imposing on it a boundary that harnesses it to the service of the next-higher level, and this control is transmitted stage by stage, down to the basic inanimate level. ([22], page 1311)

As an example, Polanyi considers the five levels of a "spoken literary composition" are as follows:

- 1. a voice (i.e., noise or, more precisely, "phonemes"),
- 2. words,
- 3. sentences,
- 4. a style, and finally
- 5. a composition ([22], page 1311).

Phonemes are arranged into words by a vocabulary. The only possible constituting pieces for words are phonemes, but which phonemes are actually combined cannot be determined at the phoneme level. In a similar manner, the words are arranged into a vocabulary by a grammar, a vocabulary is arranged into sentences by a style, and sentences are arranged into a style by the ideas of a composition.

As a second example, Polanyi considers the set of living beings to consist of the following hierarchy:

- 1. "the forces of inanimate nature,"
- 2. vegetative life,
- 3. muscular action,
- 4. "the integration of such action to patterns of behavior,
- 5. intelligence,
- 6. "still higher principles of a responsible choice" ([22], page 1311).

As a third example, the mind "includes an ascending sequence of principles" ([22], page 1312). The lower levels involve "appetite" and "intellectual workings," which give rise to "principles

of responsibility" at the higher levels.

We make a machine by "harnessing":

In constructing a machine and supplying it with power, we harness the laws of nature at work in its material and in its driving force and make them serve our purposes. ([22], page 1308).

But note that machines are not determined by the "laws of nature." Machines, and many other systems, are systems under "dual control." In the same way, an upper level of a system hierarchy harnesses principles at work at a lower level to make something do what the principles at the upper level want done.

We can descend a hierarchy by using analysis. For example, if we repetitively say a word, concentrating on the sound, we can drain the word of its meaning. At that point we have only phonemes. But we can immediately return to the word level by using the word in a context. However, at any given level there is no suggestion of a higher level, just as "traces of prehistoric sites" may be visible from an airplane but "over the centuries, have been unnoticed by people walking over them" ([22], page 1312). That is, analysis—moving down the hierarchy—is straightforward but integration—moving up the hierarchy—"may be beyond our powers" ([22], page 1311).

When we consider a text in a language that we do not understand, we see only the text. We do not see the meaning. We only have "from" knowledge, as Polanyi describes it. However, when we consider a text in a language that we *do* understand, then we see the text on our way to seeing the meaning. We look from the text "at" its meaning: we have "from-at" knowledge. As with the repetition of a word, if we can concentrate fully on the shape of the letters constituting the text, then we (temporarily) no longer see the meaning, in the same way that repeating a word drains it of meaning.

Galileo and Gassendi argued that "all manner of things must ultimately be understood in terms of matter in motion" ([22], page 1312). But "matter in motion" is "almost empty of meaning" (ibid.). Polanyi considers that the theory of boundary conditions, as he presents them in this paper, refutes Galileo's and Gassendi's argument. And Laplace's similar argument is similarly refuted: the velocities and forces of "atomic particles" has "hardly any knowledge that is of interest."

The linear sequence of the four DNA bases is not controlled by potential energy. One sequence of bases is just as chemically stable as any another sequence. There is no suggestion that DNA serves some higher level. But it can serve some higher level precisely because any base may follow any other base. That is, the sequence is not determined at the chemical level. This is unlike the structure of an "ordinary" molecule that has an orderly structure determined by minimum potential energy. A crystal is an example of high order with little information.

Polanyi concludes that "both machines and living mechanisms are irreducible to the laws of physics and chemistry" ([22], page 1310)—this is life's "irreducible structure"—and from this Polanyi notes the "impossibility of understanding living things in terms of physics and chemistry" ([22], page 1312).

Note:

In a separate paper Polanyi provides another description of boundary conditions:

Thus the boundary conditions of the laws of mechanics may be controlled by the operational principles which define a machine; the boundary conditions of muscular action may be controlled by a pattern of purposive behavior, like that of going for a walk; the boundary conditions of a vocabulary are usually controlled by the rules of grammar, and the conditions left open by the rules of chess are controlled by the stratagems of the players. And so we find that machines, purposive actions, grammatical sentences, and games of chess, are all entities subject to *dual control*. ([23], page 4, emphasis in the original)

In similar fashion (and in that same paper), Polanyi notes that

The actual working of behaviorism [à la B.F. Skinner et al.] therefore confirms my conclusion that strictly isolated pieces of behavior are meaningless fragments, not identifiable as parts of behavior. ([23], page 4)

Appendix G Corning's Book Review

Peter Corning published a glowing review [12] shortly after Kline's book was published. The review begins as follows:

This unpretentious book—plainly written, packaged with a straightforward descriptive title and published by Stanford University Press with little fanfare—should be required reading for every college student and their professors. It is that important. Unfortunately, such an eventuality is extremely unlikely, not least because this book is deeply subversive to "business as usual" in the academic world. (page 491)

Corning describes Kline's thesis as the argument that neither the reductionist nor the synoptic view is sufficient. Corning notes the hierarchical nature of systems and their "interfaces of mutual constraint." Others have argued similarly—Corning provides six references, not including Polanyi ([1], [21], [27], [28], [30], [33])—but Kline's presentation, in Corning's opinion, has "greater depth" and is presented "more compellingly than I have seen anywhere else" (page 491). (Corning also notes that the "founding fathers of the systems sciences" were Bertalanffy [3], Boulding [4], Rapoport [24], and Miller [20]. According to Davidson [14], the four that founded the Society for General Systems Research were the first three on Corning's list, along with Gerard.)

Corning also notes that Kline argues that we cannot understand complex systems, which is almost everything around us, because of the gap between their complexity and our abilities.

Corning describes, along the way, some of the "many insights, hypotheses, propositions" that Kline presents.

Although there are "very few things to criticize in this profoundly important volume" (page 493), Corning does have three criticisms. The first is minor—a discrepancy between the text and two figures. The second criticism is more substantive—Kline does not appreciate the qualitative difference that feedback-control gives a system. Feedback-control introduces purposiveness. These systems are qualitatively different than inert, naturally-occurring objects and processes because they are purposive. The third criticism is that Kline is biased toward physical systems, befitting a mechanical engineer, and shies from biological systems.

Note: Corning is the author of <u>The Synergism Hypothesis</u> (McGraw-Hill, New York, NY, 1983), a book that Kline references at least five times and which Kline describes as an "excellent" discussion (page 93). Corning is currently director of the Institute for the Study of Complex Systems (http://www.complexsystems.org/) in Palo Alto, California.

Glossary

Entire Invariant Paradigm

...a paradigm that predicts that all systems in the class will have the same behavior, in detail, for all times and in all places... (page 80)

For the two major classes of systems Newton studied, his principles have over time been shown to be Entire Invariant Paradigms. By this I imply, as before, that we now have an uncountable number of observations in many qualitatively distinct situations in which Newton's 'laws' have been used to make predictions that were later verified empirically with results as accurate as the uncertainty in the measurements allow. (page 205)

Kline considers the "Navier-Stokes equations for viscous compressible fluid motions" (page 257) to be an example of an Entire Invariant Paradigm.

In sum, there are strong reasons for believing that Entire Invariant Paradigms exist for many (perhaps all) systems consisting of inert, naturally-occurring objects and processes. We know this is so about as firmly as we know anything. (page 82)

Entire Paradigm

...a principle that applies to every system in the class, without known exceptions" (page 80)

Entire Paradigms can change over time and place, which sets them apart from Entire Invariant Paradigms.

Human Sciences

Six disciplines consisting of three "newer human sciences" (anthropology, sociology, and psychology) and three "older human sciences" (economics, political science, and history). Also included are "related professional practices" such as "psychotherapy and policy studies." These disciplines "focus on human behaviors and human-made systems." (page 26)

There are no known Entire Invariant Paradigms for the human sciences (page 83).

Those who would denigrate the human sciences because they do not produce "hard results" in terms of "hard variables" are, in my own view, not only displaying ignorance about the relative complexity of systems, but also coupling that ignorance with an appeal to intellectual snobbery. (page 86)

Human Systems

Human systems include humans' mental, social, cultural, and sociotechnical systems.

Hyperspace

...I will use the words 'complete hyperspace' to denote 'the metaphorically extended idea of the "space" of all the appropriate

variables and parameters, regardless of the number of variables and parameters or their types.' (page 70)

The "complete hyperspace" is the union of the "operating space," which is the set of variables, and the "design space," which is the set of parameters (page 70).

In practice, Kline seems to equate "complete hyperspace" with "hyperspace."

Open Degrees of Freedom

The dimensionality of a system (page 77) that is not determined by a system that is lower or higher in the hierarchy of constitution (page 116).

Overclaim (verb, intransitive)

A Klinean term referring to the act of arguing that the principles, methods, sysreps, or results of a given discipline apply to another discipline, possibly to all disciplines.

Positivism

philosophical system of thought which denies any validity to speculation or metaphysics. It maintains that knowledge is founded exclusively on experience and the positive sciences. The term is applied specifically to the system of Auguste Comte, who developed the coherent doctrine and named it, but it includes in general all views of like nature. Positivistic tendencies appeared in Epicurus and other ancients; they influenced medieval thought and were certainly strong in the early exponents of the scientific method. Hume gave the basic ideas of positivism status in modern philosophy, influencing the general trend of recent pragmatic and instrumentalist thinking. (Columbia Encyclopedia)

Kline notes that positivism is "now known" as an "aberration" (page 151).

Reductionism

The philosophy that we can learn about systems by studying their constituting pieces. (cf. Synopticism)

Sociotechnical Systems

The term 'sociotechnical systems' is used to denote complete systems of coupled social and technical parts which humans erect and operate primarily to control our environment and perform tasks we cannot do without such systems...Four types of sociotechnical systems are common: manufacturing enterprises (Boeing, General Electric, Sony, Rolls Royce), systems of use (aircraft transport, newspapers and TV networks, households, orchestras and bands, armies), systems of distribution (Sears, Takashima, Harrods), and systems of research and development for creating new or modified sociotechnical systems. (page 60)

A sociotechnical system "link[s] people with human-made hardware to perform tasks that humans want done" (page 171).

The primary purpose of sociotechnical systems is to extend human powers both quantitatively and qualitatively. A secondary purpose is to reduce the amount of hard and unappealing labor that humans must do to survive. We use sociotechnical systems to extend our muscle powers, thinking powers, sensing powers, transport powers, and many other human capacities. (page 172)

Other animals use sociotechnical systems, but they do not purposefully innovate in those systems, as far as we have been able to observe. Beavers create beaver dams and ponds. Ants create anthills, bees create beehives, and so on. However, in each species except for humans, the sociotechnical system look the same, generation after generation, for as long as we have records. If changes occur in the systems, they occur at the very slow pace allowed by biological evolution. (page 176)

Some examples that Kline gives of "large" such system are "economics, law, engineering, management, sociology, the humanities" (page 138).

Synoptic

holistic

1 : affording a general view of a whole 2 : manifesting or characterized by comprehensiveness or breadth of view 3 : presenting or taking the same or common view; specif., often cap. : of or relating to the first three Gospels of the New Testament 4 : relating to or displaying atmospheric and weather conditions as they exist simultaneously over a broad area (Webster's Seventh New Collegiate Dictionary)

Synopticism

The philosophy that we can learn about systems by imposing upon them a worldview. (cf. Reductionism)

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