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Non-reductionist science: Assessing metabolism and entropy with Systems Theory and Hegelian Logic

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Abstract

This paper will offer Hegelian logic, its connection with systems theory, and how it can serve as a replacement for reductionism in the sciences. First, the connection will be made between formal logic and reductionism. Second, systems theory will be introduced as an alternative to reductionism. Third, Hegelian logic and its connection with systems theory will be demonstrated. Fourth, a non-reductionist mode of science will be offered, wherein Hegelian logic and systems theory can work alone or together, in replacement of reductionism and formal logic. Last, a brief sample of this mode of science will be shown in an examination of the relationship between metabolism and entropy.

I. Reductionism

Reductionism and formal logic are two mechanical modes of thought. The former is partly a consequence of the latter. In 1085, the first European conquest of a major Islamic city occurred, that of Alhambra (present day Toledo, Spain). In this city was a library containing more books than the entirety of Europe. Subsequent was Europe's adoption of the knowledge written in these books, including logic. This influenced Europe in a number of ways, including

- *criminal justice*: before logic, crime investigators could only take the word of a witness who saw the *entire* crime occur. With logic, however, Europeans could now gather multiple witnesses, each of whom witnessed a small selection of the crime; from this data, crime investigators could use logic to connect the various points of the crime and conclude how the crime happened (Sapolsky, 2011, 8:40).
- *theology*: Aquinas proclaimed (even) God must obey logic[1] (Sapolsky, 2011, 7:35).
- *science and technology*: measurement sought to be exact by, for example, inventing measuring tools to eliminate human variability (Sapolsky, 2011, 17:35).
- *culture*: logic pervaded European civilization, including but not limited to criminal justice systems, theology, science, and technology, which inevitably influences culture.

With logic came linear thinking, breaking wholes into parts, and reductionism. It was a daunting task to draw scientific conclusions about a complex system, but isolating parts of wholes made the system accessible to logic, for it is possible to apply logic to each part of the system. From this, additivity and extrapolation followed: once a logical truth is deduced, it can be combined with other information to find larger truths. Science now accounted for variability by regarding

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[1] “Since the principles of some sciences, as logic, geometry, and arithmetic, rest on the formal, or abstract, constituents on which the essence of a thing depends, it follows that God cannot effect anything contrary to these principles, as that genus should not be predicable of species, or that lines drawn from the centre of a circle to the circumference should not be equal” (Aquinas, 2005, 189).

it as noise and trying to avoid it. Avoiding variability, instead of embracing it, led to further reductionism, for example with the invention of the thermometer to take humans' temperatures instead of taking temperatures by hand. Thus, measurement sought to avoid variability by becoming technical, by inventing new technologies.

Reductionism can refer to different things, all of which share characteristics, such as simplifying complexity[2] and communication between levels.[3] The various forms of reductionism include

- *Ontological reductionism*: which states existence is constituted of various small parts (eg. biological systems consist of nothing but molecules and their interactions)
- *Theory reductionism*: which states higher level theories can be deduced from lower level theories
- *Methodological reductionism*: which states science can and should explain phenomena by isolating its parts, yielding conclusions about such parts, and yielding macro conclusions from these micro conclusions via upward causation.

The latter two forms of reductionism may be grouped together as "epistemic reductionism."

II. Complexity and Hegelian logic

In the 20th century, systems began to be studied *as* systems under the name "systems theory." Similar fields emerged around the same time, such as cybernetics, network theory and information theory.

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[2] For example, breaking wholes into parts.

[3] For example, lower levels of a system (eg. cells) deliver information to upper levels (eg. a brain). This can occur ontologically, wherein nervous system cells communicate via neurotransmitters to deliver information to the brain. Or, this can occur theoretically wherein a methodological reductionist reduces the brain to cells in a scientific model.

'Systems' are a collection of interacting entities that contribute to the functioning of a greater whole. Systems theory is antithetical to reductionism and determinism, as the former is a holistic approach that studies interdependent systems in their relatedness. Systems theory embraces variability, out-of-equilibrium states, continuous evolution, and unpredictability.

There are *simple systems* and *complex systems*. Simple systems, such as a car or elevator, have few components and can be easily understood, modeled and predicted. Complex systems are systems that are non-linear, dynamic, adaptive, emergent, spontaneous, self-organizing, and may contain phenomena such as chaos, feedback loops, fractality and self-similarity. Examples of complex systems include *biological systems* such as ecosystems, organisms, nervous systems, living cells or the human brain, *infrastructure systems* such as power grids, water systems, transportation systems, or telecommunications systems, *physical systems*, such as molecules in soil or in a body of water, *economic systems* such as firms, markets, or economies, *social systems* such as families, cities, societies, or nations, *financial systems* such as the system that governs how money is borrowed, lenders cooperate or compete, and the money supply changes, and miscellaneous systems such as computation, culture, languages, security systems, governmental systems, the global climate, and the cosmos. One outcome of systems theory is the implication that all systems share common behavior (since systems theory can be applied to many different fields of study).

Key concepts of complex systems can be found in Hegel's philosophy, particularly his books "Science of Logic" (1812) and "Encyclopedia Logic" (1817). For example, a system can be thought of as a *determinate being* with its parts being in a 'unity of opposites'[4] with each

[4] 'The unity of opposites' and similar phrases (such as 'the unity and conflicts of opposites' and 'the unity and interpretation of opposites') were not used by Hegel, but by his later followers, namely, the Marxists. The phrase does not catch the specifics or subtleties of Hegel's thought, but nevertheless captures a repeating idea immanent throughout Hegel's logic and serves as a useful generalization of the dialectic.

other. Each system, which is a determinate being, can have another system and therefore another determinate being inside of it (eg. a living organism inside an ecosystem) and the laws of Hegel's logic can apply to each system independently; thus, systems (determinate beings inside another determinate being) display fractality. 'The transformation of quality into quantity and vice versa' — where, Hegel says, change in quantity results in qualitative change and vice versa[5] — is also found in complex systems in inverse relationships,[6] power laws and threshold effects.

Hegel criticizes science and logic (both formal logic and Kantian transcendental logic) for starting with definitions and presuppositions. Moreover, the content and method of science and logic are different.[7] Science and logic start with assumptions and reach their conclusions via argumentation (rather than via necessity), which makes scientific/logical conclusions at best seemingly correct opinions.[8]

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[5] Quantity's "indifferent increasing or decreasing also has a limit" (Hegel, 1991, 171). Quantity is only indifferent to quality up to a certain point, a certain threshold. "On the one hand, quantitative determinations of what is there can be altered, without its quality being affected thereby, but, on the other, this indifferent increase and decrease also has a limit, the transgression of which alters the quality" (Hegel, 1991, 171). Hegel gives the example of water (quality) and its temperature (quantity; eg. 0 degrees, 100 degrees, etc.). Cold water and warm water are of the same quality (water); but water can be brought to a temperature so cold that it goes beyond its limit and turns into ice; when water is heated to a temperature too hot, it will pass its limit and turn into steam (Hegel, 1991, 171).

[6] For example, a consequence of quantity transforming into quality and vice versa is *the inverse ratio of factors*. In this ratio, each quantum (number) is alterable and must alter in opposite directions since the product is fixed. This means, if xy=12, and if x decreases, y must increase (Hegel, 2010, 274).

[7] "In no science is the need to begin with the fact [*Sache*] itself, without preliminary reflections, felt more strongly than in the science of logic. In every other science, the matter that it treats, and the scientific method, are distinguished from each other; the content, moreover, does not make an absolute beginning but is dependent on other concepts and is connected on all sides with other material. It is therefore permitted to these sciences to speak of their ground and its context, as well of their method, in the form of lemmas; to apply presupposed forms of definitions and the like without further ado, as known and accepted; and to make use of customary ways of argumentation in order to establish their general concepts and fundamental determinations" (Hegel, 2010, 23).

[8] "There will always be the possibility that someone else will adduce a case, an instance, in which something more and different must be understood by some term or other – a term which is therefore to be defined in a narrower or broader sense and the science, too, will have to be refashioned accordingly. – Further still, definition is always a matter of argumentation as to what is to be included in it or excluded from it, within which limits and to what extent; but argumentation is open to the most manifold and various opinions, and on these a decision can finally be determined only arbitrarily. In this method of beginning science with a definition, no mention is made of the need to demonstrate the *necessity* of its *subject matter*, and hence the necessity of the science itself" (Hegel, 2010, 29).

Hegel offers a normative description of logic. Logic *should* not rest on mere presuppositions and proceed according to argumentation, but rather, the factical contents of logic must necessarily already exist within logic.[9] The truth of logic manifests in the *process* of the exposition into logic.[10] Thus, the method of logic is thinking and its contents is thinking and thus, Hegel avoids the mistake he sees in science, formal logic and transcendental logic, viz., that method and content are different. So, the normative logic that Hegel offers is the thinking of thought or the thinking of thinking.[11] He proceeds to develop a detailed logic.

Hegel must avoid starting his logic from a presupposition, so he begins from the only possible presuppositionless starting point: *being* or *pure being*.[12] Being, however, is the same as its opposite: *nothing* or *pure nothing*.[13] The unity of being and nothing is *becoming*.[14] Herein is Hegel's dialectic: being and nothing are in united opposition: they are opposites yet are in unity.[15] Being and nothing are then sublated, meaning both being and nothing cease to be yet become something new; in other words, they alter, they become something new and are not what they used to be. The result is a new determination. The sublation of being and nothing is becoming.[16] This dialectical movement pervades all of Hegel's thinking.

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[9] "Logic, on the contrary, cannot presuppose any of these forms of reflection, these rules and laws of thinking, for they are part of its content and they first have to be established within it" (Hegel, 2010, 23).
[10] " Logic, therefore, cannot say what it is in advance, rather does this knowledge of itself only emerge as the final result and completion of its whole treatment" (Hegel, 2010, 23).
[11] "This science [Hegel's normative depiction of logic] is the thinking of thinking" (Hegel, 1991, 46).
[12] "*Pure being* makes the beginning [of the logic], because it is pure thought as well as the undetermined, simple immediate, [and because] the first beginning cannot be anything mediated and further determined" (Hegel, 1991, 136).
[13] "Pure being is the *pure abstraction*, and hence it is the *absolutely negative*, which when taken immediately, is equally *nothing*" (Hegel, 1991, 139). The only difference between nothing and pure being is that with being, "something [is] merely *meant*" (Hegel, 1991, 139). The distinction between being and nothing is "a completely abstract distinction, one that is at the same time no distinction" (Hegel, 1991, 140)
[14] "This unity [of being and nothing] is *becoming*" (Hegel, 1991, 141).
[15] This principle is referred to as 'the unity of opposites' by later Hegelians, namely, the Marxists.
[16] "In becoming, being, as one with nothing, and nothing as one with being, are only vanishing [terms]; because of its contradiction becoming collapses inwardly, into the unity within which both are subltated; in this way its *result* is *being-there*" (Hegel, 1991, 145).

Hegel's logic starts with pure being and pure nothing, which are undetermined, but their result, *becoming*, *is* determined, for becoming is a something and necessarily has *quality*; in other words, a something, by definition, has content, properties, attributes. A *something* is not *pure being*, but rather *a determinate being*. A *something*, as a specific, determined thing, is distinct from what it is not, distinct from an *other*. A *something* necessarily has a *limit*[17] and an *other*.[18]

Quality is identical with being, for "something ceases to be what it is if it loses its quality" (Hegel, 1991, 136). *Quantity* is external from and indifferent to quality[19] *up to a limit*.[20] Once a threshold, a *limit* is surpassed, quality changes. Hegel gives the example of water (quality) and its temperature (quantity; eg. 0 degrees, 100 degrees, etc.). Cold water and warm water are of the same quality (water); but water can be brought to a temperature so cold that it goes beyond its limit and turns into ice; when water is heated to a temperature too hot, it will pass its limit and turn into steam (Hegel, 1991, 171). When quantity exceeds limit, quality is sublated (Hegel, 1991, 172). So, a large enough change in quantity — i.e., a change that exceeds the quantity's limit — results in a necessary and simultaneous change in quality.

Quality and quantity are not two external existents. Initially, quality and quantity are present as distinctions,[21] "but quality is indeed *in-itself* quantity, and conversely, quantity is *in-itself* quality, too" (Hegel, 1991, 173). Quality and quantity are related and united in

[17] "Something has a quality, and in this quality it is not only determined but delimited; its quality is its limit" (Hegel, 2010, 101).
[18] "Through its quality, *something* is opposed to an *other*" (Hegel, 2021, 83).
[19] Quantity "is the determination that is external to being, indifferent for it" (Hegel, 1991, 136).
[20] *Limit* is dialectical as it contains an internal contradiction: "limit constitutes the reality of being-there, and, on the other hand, it is the negation of it" (Hegel, 1991, 148).
[21] "Quality and quantity do initially confront one another in measure like something and other" (Hegel, 1991, 173).

measure.[22] Measure "is qualitative quantity" (Hegel, 1991, 136). Everything is quantitatively determined and as such has measure.

Hegel's logic proceeds to complete a metaphysical system, but the summary of his logic thus far is sufficient for the purpose of this paper.

As formal logic mirrors reductionism, Hegelian logic mirrors complexity and systems theory. Formal logic and reductionism are mechanistic world views and the latter is partly a historical consequence of the former. Systems theory and Hegelian logic, by contrast, are non-mechanistic and treat the world as if it is a set of constantly evolving complex systems and studies this complex world with appropriate tools.

Newton's first law of motion states bodies at rest remain at rest and bodies in motion remain in motion. In mainstream economics, economic or financial crises are seen as anomalies. Reductionism treats stasis and equilibrium as the normal and desired state and treats out-of-equilibrium states as anomalies and disasters. In systems theory, however, such anomalies or "disasters" are seen as naturally occurring phenomena that are systemic or cyclical by nature. In Hegelian logic, stability is seen as opposing forces temporarily in balance. Thus, for reductionism, change is an anomaly in a static world. For systems theory and Hegelian logic, antithetically, stability is a special and temporary case in a constantly changing and random world.

III. Non-reductionism: systems theory versus Hegelian logic

The world view in the West, toward the sciences otherwise, was mechanistic with formal logic and reductionism until logic was revolutionized by Hegel and science and its methods were

[22] The unity and truth of quality and quantity is "qualitative quantity or *measure*" (Hegel, 1991, 169).

revolutionized by complexity and the methods of studying complexity, namely, systems theory, cybernetics, network theory and information theory.

Hegelian logic is partly compatible with systems theory. They both study complexity and can account for things such as contingency, constant evolution, inverse relations, power laws, threshold effects, and fractality. Hegelian logic and systems theory can both be used to do science. They can be employed simultaneously.

Hegelian logic and systems theory are not fully compatible, though. They each have their strengths. Systems theory's strength is its mathematical apparatus. Systems theory tenets certain equations are, within limits, adequate to address systems. Mathematical systems theory will define a set of variables and interrelations and, from given initial conditions, predict future behavior of the variables. If variables transcend boundaries, this can mean either there is a shock disrupting the system or the equations are no longer valid. Thus, systems theory cannot account for models' variables qualitatively changing (as Hegelian logic can). Hegelian logic has its strong suits in its ability to account for a number of things — necessity,[23] negation/contradiction/opposition, sublation and transformation, and arguably other concepts[24] — in a way systems theory does not. Consequently, Hegelian logic is more adequate to account for systems' whole-part relations for two reasons:

1) Hegelian logic accounts for both wholes and their parts, but does not privilege the parts, as reductionism is guilty of, nor privileges the wholes, as holism might; and

[23] Necessity is a key concept for Hegel as he thinks his logic is based on necessity and not, as is the case of science or formal logic, based on argumentation from presuppositions. Systems theory does not account for necessity in this way; it has no explicit treatment of the concept of necessity.

[24] The Hegelian (Marxist) biologist Mary Boger says, albeit systems theory is concerned with process, complexity, and interconnection, it cannot account for dialectical contingency, historicity, mediation or contradiction (Levins, 1998, 376). Although she is correct Hegel explicitly accounts for these concepts in a unique and subtly rich manner, I do not see in a direct or practical way how Hegel's account of contingency and historicity is opposed to and superior to systems theory in conducting science.

2) Hegelian logic can account for change with respect to other change, for example, an organism's change in response to environmental change, and, *simultaneously*, vice versa.

IV. Hegelian logic on the whole-part dialectic

Engles, a Hegelian philosopher, knew that nature has no "hard and fast lines" and "either-or" is inadequate in science. In nature "all differences become merged in intermediate steps, and all opposites pass into one another through intermediate links, the old metaphysical method of [non-dialectical] thought no longer suffices" (Engles, 1987, 493). Opposites are unified and pass into one another in nature: excitatory and inhibitory neurons, reaction-diffusion systems, sympathetic and parasympathetic stimulation in the nervous system, and more. Unified opposites exist purely logically, too, for example, in categories such as cause and effect,[25] necessity and chance,[26] and identify and difference.[27] The existence of the unity of opposites is what logically follows from the Hegelian maxim spouted in the opening of both logical texts: 'being and nothing are the same'. The 'unity of opposites' is a more developed form of 'being and nothing are the same'; the former takes the same form of the latter, but it is more general and encompasses anything with the form of unified opposites (and not only the specific example of being and nothing).

The unity of opposites is embodied in systems, wherein systems are composed of parts and wholes and these parts and wholes are in unified opposition, meaning they necessarily exist in unity, yet they are opposites of one another. Hegel explicitly cites whole-part relations in *Encyclopedia Logic*:

[25] In cause and effect, the cause is also an effect of a previous cause and an effect is a cause for a future effect.
[26] It is necessary that contingency exists.
[27] For example, Hegel says the unity of opposites in identity and difference exists in every sentence wherein the subject is the different than the predicate yet says identity; the sentence "the rose is red," says identity yet identifies two different things ('rose' and 'red') (Engles, 1987, 495).

> The *immediate* relationship is that of the whole and *the parts*; the content is the whole and *consists* of its opposite, i.e., of the parts (of the form). The parts are diverse from each other and they are what is independent. But they are parts only in their identical relation to each other, or insofar as, taken together, they constitute the whole. But *the ensemble* is the opposite and negation of the part (Hegel, 1991, 204).

In the same text he states such a whole-part relationship regarding organic life. 'An animal may, of course, be said to "consist of" bones, muscles, nerves, etc. … [however] the various parts and members of the organic body have their substance only in their union, and cease to exist as such if they are separated from one another' (Hegel, 1991, 196). In the Science of Logic he restates the whole-part dialectic more clearly:

> *the whole is equal to the parts and the parts are equal to the whole*… But further, the whole is equal to the parts but not to *them* as parts… The whole is not equal to them as this self-subsistent diversity but to them *together*. But this, their "together," is nothing else but their unity, the whole as such" (Hegel, 2010, 452).

In other words, the whole is equal to the parts in their (the parts) relatedness to all other parts of the whole and wholes and their parts are in a unity of opposites.

V. Whole-part dialectic: metabolism and environmental entropy

This section will provide a sample of how Hegelian logic can substantiate a theory of changing entropy and metabolism in far-from-equilibrium states in open systems. The history of biology has not addressed the relationship between organisms and environment in a dynamic way. Pre-evolutionary biology treated the environment mostly as a place of resources (food, shelter, etc.) for organisms, organisms which have structures to obtain these resources. After the theory of natural selection, the environment was viewed as an insecurity to organisms (since, when confronted with scarce resources, predation, infection, etc., adapted organisms will survive and reproduce while non-adapted organisms will not), organisms that must survive the environment (Levins, 1985, 51). Both paradigms treat the organism as something active and changing, while the environment "is passive, delineated superficially, and treated as fixed in principle" (Levins, 1985, 52).

According to Denbeigh and Prigogine, who independently formulated entropy relationships in dissipative systems, total entropy change is the sum of the change in the internal production of entropy in the system (i.e., metabolism) and the change in environmental entropy in the system (Toussaint and Schneider, 1998, 4):

$$dS=dS_i+dS_e$$

So, total entropy, a 'whole', is necessarily related to metabolism and environmental entropy, which are its composed 'parts', taking the form of the unity of opposites, thus demonstrating the evolving and adaptive character of living subjects (parts), the environment (the whole), *and* their *relationship*. To view one of the formula's three components alone is impossible because each component is definitively composed of the other two. To show mathematically, merely rearrange the equation:

$$dS=dS_i+dS_e \equiv dS_i=dS_e-dS \equiv dS_e=dS_i-dS$$

The outcome of this relationship is also Hegelian. Entropy increases with aging and maximum entropy occurs with death, which exhibits the maxim Hegel spouted in both of his logical texts that 'life bears the germ of death' (Hegel, 2010, 60).

VI. Conclusion

Reductionism and formal logic not only share characteristics, but the former is partly a historical consequence of the latter as Europe's re-discovery of logic led to reductionist thinking in academia and everyday life. Breaking wholes into parts, treating parts in isolation, analyzing parts with logic, and disregarding variability made it feasible to study complex phenomena in criminal justice, theology, nature, technology and elsewhere.

The 20th century brought opposition to reductionism with systems theory and related fields, which take a holistic approach to studying systems *as* systems of interrelated parts functioning at local levels to yield a macro outcome. Complex systems theory embraces variability, out-of-equilibrium and far-from-equilibrium states, dynamism, constant evolution, adaptivity, non-linearity, and unpredictability. Complex systems theory shares similar characteristics with Hegelian logic, which is a metaphysical system that serves as an alternative to formal logic. Analogous to systems theory challenging reductionist thinking is Hegelian logic challenging formal logic. A typology follows that science can be done with reductionism and formal logic, or systems theory and Hegelian logic.[28]

To show an application of Hegelian logic and systems theory in biology, consider the relationship between metabolism and environmental entropy. Metabolism is a 'part' and environmental entropy is a 'whole', each one on their own is evolving and adapting, and their relationship itself, which is realized in total entropy, is dynamic and, like all whole-part relationships, necessarily consisting of unified opposites. Accordingly, a systems theory informed with the subtleties of Hegelian logic can push science past standstills and into regions reductionism will not.

[28] This typology does not intend to imply formal logic and systems theory can never mix.

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