Kant, Heraclitus, and General Systems Theory

Philosophy, Mathematics, and the Unity of Science

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1 A Brief History of Scientific Generalism

Scientific generalism is a concept that emerges as a reaction to a culture of over-specialization in science. For most of history there was always a small number of encyclopedic knowers who knew more or less all the scientific knowledge available to their society. As Peter Burke tells us, these knowers have variously been called "renaissance men,' 'monsters of erudition,' and 'men of letters,' but altogether they may be termed 'polymaths.'[1] From the late 19th century on, though, there has been a massive "explosion of knowledge,"[2] making it virtually impossible for any one individual to carry all the scientific knowledge available to them in their mind.

In response to this explosion, a culture of specialization developed. This culture allowed students and scholars to "keep their heads above water in the flood of information,"[3] but soon this solution began to be seen as a new problem of its own. Soon the fields of mental labor began to experience the effects of the division of labor that had already plagued industrial workers for over a century. As Marx puts it

> [The division of labor] converts the worker into a crippled monstrosity by furthering his particular skill as in a forcing-house, through the suppression of a whole world of productive drives and inclinations, just as in the states of La Plata they butcher the whole beast for the sake of his hide or his tallow. Not only is the specialized work distributed

[1] Peter Burke, *The Polymath: A Cultural History from Leonardo da Vinci to Susan Sontag*, (New Haven and London: Yale University Press, 2020), vii.

[2] Ibid., 128.

[3] Ibid., 141.

> among the different individuals, but the individual himself is divided up, and transformed into the automatic motor of a detail operation, thus realizing the absurd fable of Menenius Agrippa, which presents man as a mere fragment of his own body.[4]

As the division of manual labor cripples the body, like one who overworks a single muscle and underworks all the rest, the division of mental labor cripples the mind, causing one to, for example, learn the most advanced mathematics of the day, but nothing of society, or life, or health, and vice versa.

To combat this, a call was put out for practitioners of *science* rather than practitioners of some particular science. A new generation of polymaths such as Patrick Geddes, who "specialized in omniscience,"[5] and Otto Neurath heard this call and began to seek the restoration of the unity of science. In so doing, they started to develop the field and practice of scientific generalism, which, by seeking common and general scientific ideas as well as connections from field to field, allows one to transcend the multitude of scientific subdivisions, and walk between departments. This is crucial because when normal science—to use the Kuhnian terminology—can no longer progress or resolve its anomalies, when it becomes stuck in its own theory, it is likely to be scientific generalists, or the masters of science in general, that are able to transcend the theory and devise a new, revolutionary theory. Thus, scientific generalism is revolutionary in character—

[4]Karl Marx, *Captial: A Critique of Political Economy, Volume One*, (London: Penguin Books, 1990), 483.

[5]Philip Boardman, *The Worlds of Patrick Geddes: Biologist, Town Planner, Re-Educator, Peace-Warrior*, (London: Routledge and K. Paul, 1978), 1.

not only in its resistance to the dominant culture of specialization, but also in its capacity for progression towards new and better science.

Eventually, this movement, along with other developments throughout various fields of science, led to General Systems Theory. Ludwig Von Bertalanffy, in his seminal work on the subject, summarized the situation like this

> Modern science is characterized by its ever-increasing specialization, necessiated by the enormous amount of data, the complexity of techniques and of theoretical structures within every field. Thus science is split into innumerable disciplines continually generating new subdisciplines. In consequence, the physicist, the biologist, the psychologist and the social scientist are, so to speak, encapsulated in their private universes, and it is difficult to get word from one cocoon to the other.
>
> This, however, is opposed by another remarkable aspect. Surverying the evolution of modern science, we encounter a surprising phenomenon. Independently of each other, similar problems and conceptions have evolved in widely different fields.[6]

These "similar problems and conceptions" were able to be brought together under the heading of what Bertalanffy called General Systems Theory.

General Systems Theory was furthermore a reaction to two dominant trends in science: mechanistic science and reductionism. Mechanistic science sought to

[6] Ludwig Von Bertalanffy, *General System Theory: Foundations, Development, Applications*, (New York, NY: Braziller, 1968), 30.

describe all of nature as a "scheme of isolable units acting in one-way causality."[7] Reductionism, on the other hand, was a different way to approach the unity of science, by reducing all of nature—including biology, psychology, sociology, etc.—to "the lowest level, that of the constructs and laws of physics."[8]

In the meantime, the "similar problems and conceptions" that kept appearing led scientists to become conscious of the shortcomings of these approaches. One important example is the Lotka-Volterra predator-prey equations, which describes the mechanics of population size in a simple ecosystem and helped introduce mathematics and systematic "laws" into biology. It is an interesting and important phenomena that is not practically reducible to the isolated actions of elementary particles. Moreover, it can apply to lots of different ecosystems, from cell cultures to large animals. In other words, it *emerges* from common underlying elements and interactions in these ecosystems. Thus, a science was needed that could account for such emergent and broadly applicable phenomena, and this science was General Systems Theory, which, in contrast to mechanistic science, "think[s] in terms of *systems* of elements in *mutual* interaction."[9] and their emergent organizational laws. Furthermore, systems from diverse fields can be compared on equal grounds.

Therefore, scientific generalism resulted as a reaction to a culture of specialization and isolation in science, and General Systems Theory grew out of various interdisciplinary developments in science that revealed inadequacies in the common mechanistic and reductionist worldview. Crucially, General Systems Theory

[7]Ibid., 45.
[8]Ibid., 49.
[9]Ibid., 45. Emphasis is my own.

showed itself to be the greatest hope for scientific generalism, promising to provide a way to unite all the subfields of science through the articulation and analogy of their underlying subsystems, and leading to a totally general science: a science accounting for all of nature. I claim that the congruence and incongruence of the world with systems theorization can help to illuminate the relationship between the mind and the world, something of tremendous philosophical interest. It tells us about the mind because systems theorization is an essential component of the mind's ability to understand the world, and it tells us about the world because the world has a tendency to produce systems. Thus, systems are something of an intermediate between the characters of the mind and of the world. In order to demonstrate this, we will ground systems theory in both a Kantian account of the mind and a Heraclitean account of the world.

2 The A Priori Origin of Systems

An important aspect of Systems Theory is that it is in essence a mathematical theory. In abstraction from any particular application, Systems Theory is completely free from empirical content or concepts. Thus, the significance of the application of Systems Theory to the world is tied up with the significance of the application of mathematics to the world. In fact, we will demonstrate that systems are near to the heart of mathematics.

In order to do this, we must first determine what the heart of mathematics is, and then, if our claim is true, systems should fall right out. We will approach this from a Kantian perspective, which holds that mathematics is a natural result of the mind's form of understanding, which resides *a priori* in the mind. In particular, we claim that the heart of mathematics is “structure,” which arises from the *a priori* forms we call unity and relation. Thus, we must derive the forms of unity and relation, define structure, and then show how it constitutes the heart of mathematics. Once we have done this, we will be able to clearly see how mathematics—and, in particular, structure—is applied to the world to constitute scientific theories. Finally, using some simple empirical properties, we will be able to define a system and demonstrate what it teaches us about the mind and the world.

2.1 Introduction to the Form of the Understanding

To get a clear picture of the a priori form of the mind, we must first make a distinction between perception and what is traditionally called "the understanding." Everyone has some intuition for each of these since they are an immediate and ever-present part of our experience, and for the most part these intuitions suffice as a foundation for the rest of our analysis. If perception perceives, then naturally the understanding “understands,” but more accurately the understanding is the part of the mind responsible for *thinking*. These two faculties are especially important parts of the mind because they are the essential infrastructure in the production of knowledge.

Naturally, these faculties were the subject of much attention during the epistemological inquiries and debates of the early modern period. Empiricists had taken the position that perceptual content must be the ground of all knowledge about the external world, and so such knowledge cannot be derived purely *a priori* in the understanding, independent from perceptual evidence, as the rationalists were comfortable doing. Using an empiricist framework, David Hume was able to express serious doubts about several fundamental kinds of knowledge. For instance, we might claim that we know a cause and its effect when they are always and necessarily in sequence—or conjunction, as Hume would say—with each other. Two things may always be in sequence with each other yet not have a necessary connection between them, so we would be justified in saying that the one does not cause the other—their constant conjunction is just a coincidence. Hume demonstrated that it is impossible to find a necessary connection in pure perception, which would mean that necessary connections cannot legitimately be found in the world, and therefore he concluded that as far as we know all causation must be merely constant conjunction by coincidence. When one billiard ball strikes another, we cannot discover through perception what necessarily causes the struck ball to move. If we had not had a precedent from similar experiences, we might just as well have expected the struck ball to stand still or some other extraordinary possibility.

Hume's skeptical attack on causation is part of what drove Kant to develop the theories presented in his *Critique of Pure Reason*. Kant agreed with the empiricists that perceptual content was the ultimate ground for knowledge about the world and that the rationalists were wrong in applying pure reason to reach conclusions about the world in itself. However, he disagreed that this meant the invalidity of causation and other metaphysical concepts, which are generally said to apply to the world. Instead, Kant claimed that such concepts apply to the *world as appearance*, that is, not to the world as it is by itself but as it appears to us, which is the true subject of empirical knowledge. This is because, for Kant, these concepts, which he calls categories, constitute the necessary conditions of experience, from which all experience—and thus the world as appearance—derives its character. Causation as a necessary connection between events, for example, is a legitimate part of the world as appearance because it underlies the world as appearance as its condition: its form, like a mold which gives shape to the world as it is poured into it.

Thus, Kant is the primary framer of the theory of what I call the form of the understanding.[10] Whether Kant was successful in his development of this theory is still open to debate. Regardless, as the form of the understanding is present in all experience and thought about the world, it must be the most general and universal component of science, and hence it is the key to a totally general science. Theories from disparate areas of science are comparable because they are each shaped by the form of the understanding. Therefore, if we are to begin to grasp general science, we must endeavor to develop our own theory of the form of the understanding; however, a Kantian level of comprehensiveness is outside of our scope.

2.2 Derivation of the Form of Unity

For our purposes of grounding general science in the form of the understanding, there are exactly two aspects of this form that we need to derive: the form of unity and the form of relation. As we claim that these forms underpin all experience,

[10]However, there are hints of the embryonic form of the concept throughout philosophy before Kant.

we must derive them from absolutely general features of experience. And as experience is essentially the sum of all mental faculties—especially perception and understanding—we will derive the form of unity by taking the difference between agreeable features of experience as a whole and of perception in particular.

2.2.1 The Characterization of Perception

Perception must be understood to have the practical character of a continuous field of subjective qualities. For one, this is to say that it is not discrete. For instance, I cannot count the number of irreducible colors in my field of vision. On the other hand, if I ever try to draw a line from color to color, there must always be some color in between. This is the continuous character of perception.[11]

That the contents of perception are subjective qualities (or "qualia") like colors, sounds, smells, etc. is almost by defintion. As it stands, this premise does not need much defense because its objections are weak or ad hoc or both. The only conceivable alternatives are that the contents of perception are objects themselves or the physical causes of perception. The first alternative is easily refuted by cases of illusion.[12] In such cases, our perceptions may contradict each other and therefore the object. For instance, if I stick my finger in a glass of water, it may look bent,

[11] I say it is a practical character because the mind may be finite and therefore unable to contain true, inwardly infinite continuity—only a practical approximation. After all, there are only a finite number of neurons in the brain. On the other hand, activity inside and between neurons is analog, so the brain may have an infinite range of states. Either way, our characterization of perception is unaffected. Indeed, an approximation of true continuity does not necessarily imply the existence of atomic qualities or the ability to draw a mental line between exactly two qualities. And even if atomic qualities do exist, an intractable number of them nevertheless approximates continuity.

[12] And this is far from the only way to refute it.

but it does not feel bent. So if I am perceiving my finger itself, then my finger is both bent and not bent at the same time, which is clearly absurd.

Furthermore, the contents of perception cannot be the physical causes of perception because such contents and causes do not have the same character, which they must have if they are to be the same thing. For example, if light waves of certain frequencies are the physical cause of color, then color should have the character of such light; namely, it should be like a wave. But color is not like a wave; there are not ever-present peaks and troughs throughout my field of vision.

A better theory would claim that the contents of perception are the *immediate* physical causes of perception, such as some particular electrical activities in the brain. However, all electrical activity is the same *in itself*: it is electricity. It may be of different form—intensity, shape, adjacent neurons, etc.— but at bottom it is identical electricity, and one pattern of activity can theoretically be deconstructed and reconstructed into another, just as one clay pot may be deconstructed and reconstructed into another. On the other hand, the contents of perception can be *in themselves* quite different: blue cannot be deconstructed and reconstructed into red and vice versa; red cannot be reconstructed into the smell of a rose or a C minor 7 chord, and so on. We can imagine how such an argument could be made against all physical causes of perception. There may be analogies between them, but ultimately the physical and the subjective are not identical. So we should rest easy knowing that our characterization of perception is well justifiable.

2.2.2 The Characterization of Experience

Having characterized perception, we must now characterize experience as a whole. The relevant aspect of experience is that our experience of the world is an experience of a world of objects: a bottle of wine on the table, a red stain on the carpet, a dog on the couch, etc. This should be taken at face value, and so it does not need much defense. It is just the way we interpret our experience. By an object, in this context, we generally mean something discrete, whole, and one: one dog which is completely separate from its surroundings but completely connected in itself. Theoretically, I could count the number of objects in a room.[13]

2.2.3 Conclusion

Thus, we have our desired characterizations of experience and perception, and the difference between them follows straightforwardly. On the one hand we have perception as a continuous field of subjective qualities, and on the other we have the experience of the world as the experience of a world of discrete and unitary objects. Therefore, there must be some faculty of conscious experience other than perception that takes the continuous totality of perception and carves it up into a world of discrete, unitary objects. The form of this faculty I call the form of unity. We have not determined that the form of unity resides in the understanding in particular, only that it does not reside in perception; however, as we will see, the role of the form of unity is largely to help understand the world, and so it is best

[13]There may be some challenges in counting, owing to ambiguity in the precise definition of object, but this is not relevant to our argument, as we do not seek this level of precision. Notably, for any precise defintion of object, it should still be possible to count the number of objects in a room.

considered to be a part of the form of the understanding.

2.3 The Form of Unity in the Understanding

We have derived the form of unity from its simple action of dividing perception into a world of objects; however, when we experience an object, we do not simply experience it as an object in general, but as a particular object, like a dog or a candle. Thus, not only does the understanding divide up the field of perception into objects, but it also imbues these objects with additional meaning. In fact, this additional meaning is a necessary prerequisite for a perception to be interpreted as an object. This is because an object is not merely a discrete region of perception, but extends beyond perception. My interpretation of an object as a dog means that it can be pet, a candle that it can be lit, etc. even though I am not actually perceiving any of those possibilities. When a perception is interpreted as an object by the form of unity, these various unperceived meanings must somehow be united and made available to experience.

But being available to experience means being available to be manifested in consciousness as subjective qualities.[14] After all, perception is also made available to experience by its manifestation as subjective qualities. Since these unperceived subjective qualities are not given to us in perception, but are brought to experience by us, we will say that they reside in a different faculty than perception. In particular,

[14]This is essentially by definition.

we will call this faculty the imagination.[15] Additionally, hallucinations provide evidence that the imagination is largely continuous with perception.

Thus, these subjective qualities in the imagination are being united with the subjective qualities in perception in much the same way that subjective qualities in perception are united with each other. Therefore, it is reasonable to say that this activity is also made possible by the form of unity, or at least the form of understanding.

Furthermore, the activity of uniting together a variety of subjective qualities in the imagination, which would be made available in the presence of an object, is also possible in the absence of an object. Indeed, this activity may be called thinking about an object, and the subjective phenomena available in the thinking of an object will be called the concept of that object. Therefore, the form of unity constitutes the form of concepts. And, as the imagination plays a principal role in thinking, it should be considered to be a subfaculty of the understanding, and so concepts are the content of the understanding.

2.4 The Form of Relation

We have, then, the form of unity, and have seen how it gives rise to objects and concepts, so all that remains, as stated, is the form of relation. Fortunately, the form of relation follows almost immediately from the form of unity. Once we have a way of bringing a continuum into a discrete unity, we merely need a way of

[15]To see that meanings are brought by us to experience, it is instructive to look at the well-known duck-rabbit illusion, famously used by Thomas Kuhn in *The Structure of Scientific Revolutions*. It is clear that we can bring different meanings to this image virtually at will.

bringing together several discrete unities under some singular unity, which is called a relation. Thus, the form of relation is merely that form which enables the unity of unities. To clarify, relating is a unifying activity bringing together a plurality of unities into a single greater unity, called a relation, and the form of relation is the *a priori* form that enables this activity and its resulting unity.

For instance, if we relate two events as cause and effect with respect to each other, then we conceive of the two events as parts of a single process. Similarly, when we interpret a part of perception as a tree, and a part of that same part of perception as a leaf, then we may bring the tree and the leaf into a relation with each other, in particular, the relation of a part to a whole.

2.4.1 An Objection to Relations

Now that we have an account of relations,[16] we should be able to respond to conflicting accounts. In particular, we are now able to respond to a simple version of what is called "Bradley's regress." F.H. Bradley, in various works,[17] has claimed to the effect that in order for a relationship R to relate relata A and B, there must furthermore be a relation R' relating A to R, and similarly for B and R. Then, similarly, there must be another relation between A and R', and so on infintely. This is a vicious regress, so, by this argument, relating is impossible.

However, with our account of relations as the result of a uniting activity, we

[16]Note well that we speak here only of *subjective* relations—that is, relations applicable only to subjective experience, either in perception or in the understanding—and so all of our following responses apply only to a subset of possible entities that may be called relations.

[17]such as Francis Herbert Bradley, *Appearance and Reality: A Metaphysical Essay*, (Abingdon: Routledge, 2002), 33-34.

can see two different possible responses to this, either of which is sufficient. For one, we can see that not everything which *can* be related *is*. In order for things to be related, the activity of relating must have been applied to them. Thus, there may *potentially* be a relation R' between a relation R and one of its relata A, but it need not necessarily exist, which avoids the vicious regress.

Secondly, we can see that, as the relata are brought together under the relation, the relation itself has also already been brought together with its relata by the same action. Hence there is no need for an additional act of relating to bring them together. To actualize the secondary relation R' between the primary relation R and its relata would merely be to formalize a preexisting state of affiars, and hence introduce nothing actually new, which also avoids the regress. So we can see that Bradley's problem of how relations relate is easily solved by our account, giving it much further justification.

2.5 Conclusion

In sum, we have derived the form of unity and the form of relation from completely general facts of experience. They are the forms of consciousness that enable the experience of discrete objects out of a continuous perceptual field, and the understanding of higher unities out of other preexisting discrete unities. The form of unity functions not only by separating the significant elements of an object from the insignificant remainder of the perceptual field, but also by synthesizing these significant elements with further experience, as provided by the imagination, which is significant of the full potential of the object. And the general set of this additional imagined experience, as abstracted from an actual object in perception, is what we call a concept. Thus, we have all the elements we need to define the concept of structure, which is the subject of the next section.

3 Structure and Mathematics

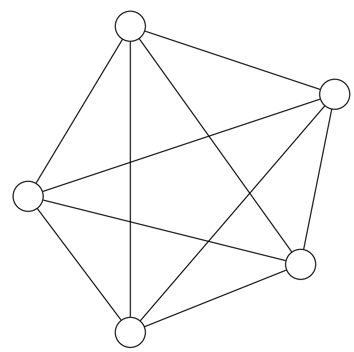

Figure 1: An abstract representation of a structure with elements (circles) and relations (lines)

We define a structure to be a unity of related unities (or elements). The concept of an element is essentially the conceptualization of the form of unity, and can be described as the general, abstract form of an object or concept. Similarly, the concept of a relation arises from the form of relation, as it simply brings multiple unities under some single relation. Note that a structure could theoretically be divided into two parts: the set of its elements and the set of its relations. From this, we can see that our definition of structure is essentially equivalent to the definition of the mathematical concept called a graph.[18] The concept of structure is the cornerstone of the form of the understanding and therefore of the science of theory.

As the cornerstone of the form of the understanding, structure plays a role in all our thinking. To elucidate this point, we will introduce the idea of a *conceptual structure*. A conceptual structure is a structure whose elements are concepts. It is less obvious what the relations of a conceptual structure are, but we will postulate that they are either concepts themselves or something consequent to the form of concepts as determined by the form of the understanding. Likely relations in a conceptual structure are things like inclusion and opposition. Some examples of simple conceptual structures are "Many tables are wooden" and "energy is proportional to mass." Both examples contain two concepts and a relation. We will call a conceptual structure a *theory*—especially when the conceptual structure attains a certain degree of complexity. It is easy to see that all scientific theories are conceptual structures. For example, the science of physics is a conceptual structure seeking to provide precise relations between physical concepts such as mass, energy, space, time, temperature, velocity, momentum, etc.

Thus, structure as applied to the world constitutes the form of the theories of

[18]"***Definition 5.*** A graph is an object consisting of two sets called its vertex set [the set of elements] and its edge set [the set of relations]. The vertex set is a finite nonempty set. The edge set may be empty, but otherwise its elements are two-element subsets of the vertex set." Richard Trudeau, *Introduction to Graph Theory*, 2nd ed. (New York, NY: Dover Publications, 1994). A graph, as we can see, is particularly composed of two-element relations. We don't need to go into such specificity with respect to the nature of relations, as that would require a much more complex deduction, but we will note that two-element relations seem clearly to be the most important and fundamental kind of relation.

the various empirical sciences. The study of structure itself, though, independent of particular empirical content, is known as mathematics. Philosophers have long accepted that mathematics is a science as free of empirical content as possible. If it is to be done entirely in thought and free of empirical content, then it can only take the a priori structures of the mind as its content. Otherwise, it would have to reach out to the world or some speculative supernatural realm for its content. That mathematics is the science of structure can be further realized when we compare structure to the usual foundations of mathematics.

Before, we compared structure to the graph of discrete mathematics, but the graph is hardly recognized as a part of the foundations of math. If we look closely, though, we can see that both sets and categories, two of the biggest contenders for math's foundations, are in fact special graphs—or, more accurately, structures.

Sets are hard to define without relegating to some kind of circularity—such as defining a set to be a "collection" of elements, where 'collection' may as well be replaced with 'set'—and so most authors will either hedge it or embrace (or ignore) the circularity.[19] The problem is that the way of unifying the elements must be made explicit, and that is where relations come into play. In other words, the elements of a set cannot just *be* by themselves, they must somehow be brought together into a set, i.e. related. Therefore, a set is a structure where the relations between elements

[19] "A set is a collection of things (called its members or elements), the collection being regarded as a single object." Herbert B. Enderton, *Elements of Set Theory*, 1st ed. (New York, NY: Academic Press, 1977), 1.

are arbitrary.[20] In this way, the relations generally become irrelevant, and we are left with a structure only significant of its elements, which is what a set is usually taken to mean. For example, the elements of a set may all be related because they are even numbers or simply because they were stipulated to be related, e.g. the set {goose, Denver, 22}. This is similar to ideas in constructive set theory, wherein the notion of how a set was "constructed" must be viewed, in some sense, as a part of the set.[21]

The last prospective mathematical foundation we will discuss is the category. Roughly speaking, a category is composed of three main parts: a set of objects, a set of "morphisms" from one object to another, and a composition operation between morphisms satisfying some particular rules.[22] Understanding the details of the rules of composition or what a morphism is is not important for us because, from this informal definition, the correspondance with our definition of structure is already clear. Taking a category to be a structure in our sense, its elements are called 'objects,' and its relations are called 'morphisms.' The third part of the definition could potentially be interpreted in a number of ways, but one formal way is that it defines another structure that takes the relations (morphisms) of

[20]We are in direct opposition to something Michael Potter says in *Set Theory and Its Philosophy*: "One way of thinking of a structure is as a certain sort of set. So when we discuss the properties of structures satisfying the axioms of set theory, we seem already to be presupposing the notion of set." Michael Potter, *Set Theory and Its Philosophy: A Critical Introduction*, (Oxford: Oxford University Press, 2004), 9. We, on the other hand, think of a set as a certain sort of structure, and so a set already presupposes the notion of structure.

[21]This account allows us to consider interesting, novel accounts of several things in foundational mathematics. For instance, perhaps the empty set can be considered to be something like the form of relation conceptualized by itself, without any relata.

[22]c.f. Serge Lang, *Algebra*, Revised Third Edition, (New York, NY: Springer-Verlag, 2002), 53.

the category as its elements and provides relations between these relations called their composition.[23] Categories emphasize an important aspect of the science of structure: their mappings, transformations, and equivalences, which will be the topic of the next section.

Not only do math's foundations fit the concept of structure, but every mathematical object fits as well. For example, one way to define a *space* is as a structure whose elements are points related by some number of orderings. In fact, the field of math is commonly—albeit roughly—divided into two subfields: algebra and analysis. By our account, we can see that algebra may be simply characterized as the study of discrete structures, and analysis as the study of continuous structures, which may in many cases be called spaces.

So we have defined the concept of structure, derived it from the general nature of experience in order to ground it as an essential component of the form of the mind's understanding, and reviewed its role in application to science and math. In particular, it is used to construct conceptual structures, both empirical and *a priori*. Furthermore, this should make obvious the answer to the common question of why mathematics happens to be so applicable to describing the natural world. Namely, mathematics *just is* the underlying foundation of how we understand the world in terms of the application of structure to the world and the fitting of the world into our structures.

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[23] Our parallel between categories and graphs is further justified by one of the founders of the subject of category theory, who, in one of his foremost works on the subject, introduces categories through a concept he calls the 'metagraph,' which is essentially the same as a regular graph. Saunders MacLane, *Categories for the Working Mathematician*, Second Edition, (New York, NY: Springer-Verlag, 1978) 1.

Before moving on to the next piece, we will provide an important remark about the concept of structure. That is, 'structure' is essentially synonymous with both 'object' and 'whole.' An object is especially a spatial structure, but it is also used in reference to more abstract structures such as those of mathematics. For instance, a mathematical group is often called an object. A whole is also a structure, and its elements and substructures are its parts. This fact makes clear the answer to how a whole is more than the sum of its parts: a whole is the sum of its parts *and their relations*. The particular interrelatedness of a whole's parts can lead to emergent properties not found in the parts themselves.

3.1 Analogy and Morphism

One of the central ideas of a completely general science is that all of nature can and should be organized into one vast conceptual structure and to discover general concepts that can be applied to concepts all throughout the structure. Thus, it would be useful if we could find a general method for discovering such concepts. One such method is to make use of *analogies*.

If many pieces of theory can be brought into analogy with each other, that is good evidence that they are instances of some general structural phenomenon. For instance, very many things in the world seem to take on the form of a tree: trees, rivers, lightning, nervous and cardiovascular systems, dendritic copper crystals, etc. Some of these are the result of organic growth, and some are the result of purely physical phenomena. It is likely, though, that all of them are subject to the same or similar conditions in their process of formation, so these conditions result in a highly general class of objects prevalent throughout many diverse areas of science, and thus these conditions are something of a general feature of nature.

To make the idea of analogy more rigorous, we can borrow the concepts of isomorphism and homomorphism from mathematics. In particular, we already have the concept of structure in a somewhat precise mathematical form, and isomorphism and homomorphism are what are described as "structure-preserving maps." A map is some way to send or transform the elements of one structure to those of another, and structure-preserving means that the a relation between elements in the original structure has a corresponding relation between corresponding elements in the mapped structure. In general, an isomorphism preserves the whole structure, while a homomorphism preserves some substructure. It is especially helpful when a complex structure is completely determined by a simple rule; the map merely has to preserve the rule.

Therefore, if we can rigorously describe a science in terms of its concepts and their relations, we can begin to tie the complex conceptual structure of the whole of nature closer together by relating its substructures through isomorphism and homomorphism. Additionally, each isomorphism class—that is, the set of structures that are isomorphic to each other—defines a general structure that may be applicable to the whole of nature.

Such an activity would help us determine the most relevant concepts and relations in any science, and furthermore the hypothesization that one structure is isomorphic to another structure can be highly productive towards discovery. In fact, I speculate that this is how much of science is already implicity done. For example, early in its discovery, the atom was theorized to be analogous to the solar system, and this turned out to be quite productive in discovering and explaining certain properties of atoms. Moreover, this analogy served as a foundation for elaborating misanalogy, further elucidating the true, more unique structure of the atom. An apparent analogy serves as a good indication of some similar underlying structure waiting to be articulated.

4 From Structure to System

Having established the idea of a conceptual structure and how it may be solidified by analogy, we should attempt to propose some common analogical structures to be found in the conceptual structure of nature. These structures are generally found by induction, by examining a wide swath of nature and its conceptual structure and noticing the inherent patterns. Covering all such structures, or even the most important ones, would be beyond the scope of this paper. However, examining only a few crucial structures is sufficient to give us a remarkably practical definition of system that is largely compatible with systems theory as it stands.

4.1 Change and Rest

When it comes to fundamental principles of nature, it is no mistake that virtually all cultures have identified *change* as the foremost. Change manifests itself throughout all of nature in the form of the processes of growth and decay, generation and degeneration, formation and dissolution, etc. As Heraclitus said, "it is impossible to step in the same river twice," for by the time you go to step again, the river as it was has already passed away.[24] In his *Physics*, Aristotle defines nature itself as a "principle of motion and change."[25] The Buddhists identify *anicca*, or impermanence, as one of the three marks of existence. The Aztecs note that all nature is identical to Teotl, and Teotl is in a constant motion of self-generation and regeneration.[26] Although we have, in many ways, superior science to the ancients, there is no reason we should deny them general knowledge of nature's most fundamental principles, which are available to everyone's intuition. They were, after all, in many ways much closer to nature than we are—living in societies that increasingly separate us from nature.

As our empirical and theoretical evidence, we may take the phenomenon of zero-point energy. Zero-point energy is, roughly, the energy of a quantum system at its lowest energy state. As a result of the uncertainty principle, even when all quantum fields are in their lowest energy state, i.e. the vacuum state, there must still be some nonzero zero-point energy, which is tantamount to the presence or potential for change, often manifesting as the appearance and disappearance of virtual particles.[27] Therefore, if there is motion even in the most static states possible, naturally there must be a great deal of motion in the average, everyday

[24]Parmenides may have contradicted him, but it is worth noting that Parmenides arrived at this idea through reason. Observation tells us in its own language that everything changes.

[25]Book III part 1, c.f. Book II part 1.

[26]James Maffie, "Aztec Philosophy," Internet Encyclopedia of Philosophy, n.d., https://iep.utm.edu/aztec/.

[27]Dennis Sciama, "The Physical Significance of the Vacuum State of a Quantum Field," in *The Philosophy of Vacuum*, ed. Simon Saunders and Harvey Brown (Oxford: Clarendon Press, 2002), 137.

state. In fact, if everything is always moving, we would expect for rest to be an absolute impossibility. As a second piece of evidence, we may take the current theory of fundamental forces, which are always acting on matter. For instance, "the weak interaction operates between all particles"[28], and so all matter may be said to be actively being changed by the weak interaction.

However, we know that there must be rest. A rock may find its balance on another rock, a mountain may remain unmoved for millions of years, and the meditator may find peace for half an hour. Furthermore, our knowledge of the world requires it to rest. It is difficult to get to know something when it passes away in a moment. All things are changing, but we tend to conceive of them as they are. Therefore, there must be some rest, some resistance to motion, something that allows the mountain its leisure and for us to conceive of it.

Thus, we have a contradiction. Everything is moving and yet there is rest. This contradiction can only be resolved by the notion of *contrary* motions. Everything is moving (or being moved), but as long as it is being moved in opposite directions simultaneously, it can stay still for a while. Gravity may want to collapse the pillar to the ground, but as long as the internal matter of the pillar is moved in the opposite direction by the mutual repulsion of its particles, the pillar may stand tall. This is balance and equilibrium, which, as it gives rise to all complex structures in the world, is as much of a fundamental principle of nature as change is. However, just as there are no perfect geometrical shapes in nature, there is hardly a perfect

[28]Walter Greiner and Berndt Müller, *Gauge Theory of Weak Interactions*, 4th ed. (New York, NY: Springer-Verlag, 2009), 2.

equilibrium, and so eventually the pillar will collapse, the mountain will erode, and ultimately even the sun and the stars will pass away.

Again, it is equilibrium, not absolute rest or the absence of motion, that gives rise to the stable forms we observe around us in the world. The fundamental natural processes of generation and degeneration, birth and death, are actually just the motions into and out of an equilibrium. As these two concepts—change and equilibrium—permeate all of nature, general science must be, in part, a theory of change and equilibrium.

Out of this simple consideration, we are now ready to give a definition of system. A structure, as a unity of related elements, is generally taken to be something static—the elements and relations are fixed and unchanging. If we want structures that are capable of describing the constantly changing natural world, though, we must combine structure with change, and out of this arises systems. There are two valid ways to achieve this. One way is to say that a system is a strucure in which the principal relations become *interactions*, as Bertalanffy described them, and the elements have certain quantitative and qualitative properties that may be affected by them. For instance, there may be a system of three electrons and their mutual interactions. Another, more general way, is to say that a system does not necessarily describe any particular structure, but rather defines a number of valid elements and the valid ways they may be related and interact. In other words, a system defines a number of potential structures and how they may change into one another. In this sense, the standard model is a system—it is a system of fundamental particles. This is opposed to the former sense, in which the system included particular, actual elements and interactions *from* the standard model. Before considering some of the further implications of our theory, we should ground one more common feature of systems and then give an example of a significant type of system.

4.2 The Continuous and the Discrete

We note with curiosity that in many ways the character of perception seems to reflect the character of the world. In particular, just as perception is practically continuous, so is the world. That is to say, we are not trying to settle the long-standing philosophical and scientific debate of whether or not the world is, at bottom, continuous or discrete, but merely that the world has the *practical* character of continuity at virtually every scale insofar as everywhere it is composed of an intractable quantity of parts. This often presents a significant challenge for science, which—owing to the form of unity—likes to work with things that are discrete.

4.2.1 Problems of Classification

There are countless examples of this problem, but we will take three excellent examples from the sciences of linguistics, history, and biology. Since their similarities are so palpable, it is worth going into in some detail. In linguistics, there is the well-known problem of determining whether two different forms of speech represent two different languages or two different dialects of the same language, and similarly whether two relatively similar speech forms represent two different dialects or not. This is of course because, in reality, both dialects and languages are composed of innumerable *idiolects*—or the speech forms of individuals—which can all be more or less distinct from each other and from their parent language. Inevitably, some idiolects are going to fall on the border between any two dialects or languages, giving rise to the more accurate conception of a *dialect continuum*. For example, the Arabic language exhibits a dialect continuum stretching between Persia and Morocco, the two ends of which are not mutually intelligible, and so by all accounts must represent different dialects, yet where to make the division between them is not as easily discernable, and so must generally be done heuristically and subjectively.

Similarly, historians want to divide up history into discrete eras. This is known as periodization. But of course history, like time, is practically continuous—even when reduced down into a series of discrete events, the events are nevertheless too intractably numerous to include all of them in a reasonable account of an interval of history. As such, there are countless debates about when each period "really" begins and ends, usually hallmarked by some important event. Really, all historical borders are fuzzy, and every moment in history should probably be conceived simultaneously as part of its own period, part of the transition period out of the previous period, and part of the transition period into the next period.

Finally, in the case of biology, we have the problem of distinguishing taxons—in some sense the paradigmatic example of this problem. Just as the linguistic problem of distinguishing languages and dialects has the useful property of mutual intelligibility, so the problem of distinguishing species has the property of mutual reproducibility. That is, two organisms are of different species if they cannot produce a fertile offspring together, otherwise known as reproductive isolation.

However, even these properties do not solve all problems of continuity. For example, if a species is in the process of *becoming* reproductively isolated, it is likely that some members of the species can reproduce with both the newly reproductively isolated members of the species as well as with the former species. In other words, reproductive isolation probably does not happen all at once, and there can be a gray area between two different species. Regardless, even if biologists land on an objective, unambiguous definition of species, the problem still hopelessly remains for the other taxa of genus, family, order, etc.

A solution to all these problems lies in coming to terms with continuity. In particular, if a continuum of change—such as between dialects, eras, or genera—must be divided into discrete pieces, we can take recourse to *statistically significant rates of change*. That is, rather than being objective divisions between discrete groups of objects, they are statistical divisions of a continuum of objects. In order to do this, a concept of distance must be divised for each class of continua, for instance one which counts the number of common elements and relations between objects on the continuum. Then, this distance between objects can be seen as a function of some independent variable(s)—for instance, time when working with history, or longitude when working with the Arabic dialect continuum. As this independent variable changes, a conceptual division can be made on the continuum whenever a significantly strong change in distance between objects occurs over a similar change in the variable. In other words, a division can be made whenever there is a statistically significant deviation in the derivative along the function—the more significant the deviation, the higher the order of the division, e.g. a genus rather than a species, or an eon rather than an era. This works well for almost everything in nature, as there is almost always some significant natural cause that would lead to such a significant deviation in derivative, such as a geological boundary leading to a difference in dialect. However, if the distance function had a relatively constant derivative, a different approach would be required.

4.2.2 Partial Wholes

All of the above problems of continuity are problems of classification, which are clearly largely artificial, and so it is natural that there would be some problems of subjectivity. However, problems of continuity apply not only to classification, but to all of nature's objects. For example, I think of my body as a discrete, natural object; however, I am constantly taking in and giving off matter, so it is not clear when this matter becomes or ceases to be a part of me. For instance, it is not clear whether the food in my stomach is part of me, especially when it is dissolved and absorbed but not yet metabolized. Similarly, it is not clear whether the air I breath is part of me. On a smaller scale, the cells of my skin are constantly dying off, but to my eye everything looks normal. It is not clear whether these cells are a part of me. If they are not part of me because they are dead, then my hair should also not be a part of me. Smaller still, the atoms of my skin are constantly exchanging electrons and whatever else with the adjacent air. It is not clear whether these electrons are part of me. So we can see that there must be some continuity between my body and the world. Indeed, all natural objects are constantly giving off and taking in matter in some way, so there is a continuous change between everything.

Therefore, nothing is a fully separate from everything else in nature.

As before we saw that the understanding divides up the continuous whole of perception, so now we see that it does the same to the continuous whole of nature. Indeed, all objects are to a large degree artificial conceptual constructs. However, just as nature has a way of bringing things to rest so that we can understand them, it undoubtedly seems to have a way of making things *practically* discrete so that we can understand them as well. Many things seem to congregate together into solids or otherwise form a boundary that—for the most part—separates themselves from the rest of nature, like a city wall or a cell wall. Thus, they make themselves more suitable to our form of understanding, and such things are certainly easier to conceptualize than others. Indeed, much of science seems to be the process of taking continuous and ever-changing nature and turning it into something discrete and stable that we can grasp with our understanding. We may wonder, therefore, by way of hypothetical analogy, that if the external world's character of a continuous and ever-changing totality is reflected in the character of perception, then perhaps the character of discrete and stable unity provided by the form of unity in our understanding somehow reflects the character of what Kant would call our transcendental selves. I think Plato would certainly be sympathetic to this characterization.

4.2.3 Conclusion

This final consideration on the continuous character of nature leads us to an important concept within systems theory known as open systems. In an open system, there may be interaction between what is "internal" to the system—i.e. within the system boundary, like a cell wall—and what is "external." Bertalanffy gives a common example: "Every living organism is essentially an open system. it maintains itself in a continuous inflow and outflow, a building up and breaking down of components..."[29] In fact, the theory of open systems was the answer to the contradiction between the second law of thermodynamics, i.e. the law of increasing entropy or disorder, and the apparent decrease in entropy or tendency to higher stages of order in living organisms. That is to say, the earth, for example, as an open system, may experience decreases in entropy, but this is only because the earth experiences a vast influx of energy from the sun, and the (approximately) closed system including the Earth and the Sun does only increase in entropy. The continuity of nature implies that everything in nature can be considered to be more or less an open system. This idea again affirms one of Heraclitus's famous principles, i.e. that "all is one."

4.3 Flow

Lastly, to demonstrate the power and universality of systems, we will discuss a special phenomenon of systems that I call "flow." In order to work our way up to a definition of flow, it is perhaps best to start with a paradigm example. For this, I will take a ripple on the surface of a pond. The essential thing to notice about the ripple is the way that each continuous region—or, alternatively, each discrete part, e.g. a water molecule—interacts with its neighbors. In particular,

[29] Bertalanffy, *General System Theory*, 39.

the change of one region of the pond, such as its rising or falling a certain height, causes a similar change in all of its neighboring regions: they rise or fall in turn. The result of all these interactions is the appearance of a different form of motion, i.e. an outwardly expanding circle of rising water. Thus, we might describe flow in general as the emergent motion resulting from many mutually constraining and interacting independent motions. In our example, the emergent motion is the outwardly expanding circle of water, the independent motions are the rising and falling individual particles or regions of water, and the mutual constraint is the attraction of nearby particles to each other.

One crucial feature that this defintion reveals is the importance of the mutual constraint. If the mutual constraint is too strong, then the emergent motion will be identical to the individual motions, as in a solid; on the other hand, if the mutual constraint is too weak, one individual motion may have no effect on nearby parts, and so no emergent motion will result, as can happen in a gas. Therefore, in order to achieve flow, the mutual constraint must have an intermediate level of strength.

We don't need to reach very far to come up with more examples of flow. An example always worth mentioning is the spectacle of a murmuration of starlings. Furthermore, every physicist intuitively knows how fundamental flow is to nature. The waves found in a guitar string, a drum skin, or the gravity waves moving through spacetime itself are all examples of flow. In particular, they are examples of unconstrained flow, which generally propogate as an expanding n-sphere, but fundamentally they propogate *isotropically*. We can get interesting, non-isotropic kinds of flow if we add various kinds of external constraints. For instance, if the flow is constrained by a kind of channel, or if the flowing parts are directed towards some end, then the flow takes on a *linear* rather than isotropic character, which I call a directed flow. The river is a paradigm example of a directed flow, but examples from all domains abound. Traffic is a great example of a directed flow; the road acts as a channel, and the individual vehicles are directed towards some end. Another good example is a battalion rushing towards an enemy.[30] Directed flows will follow whatever channel they are placed in and smoothly move around obstacles.

Almost all directed flows exhibit another important property: branching. Branching can occur in many ways; it might occur if the flowing parts become attracted to more than one end, or if there is some impenetrable obstacle in the middle of the flow. Each branch will only have a fraction of the flowing parts of its source, and so its flow will have less overall force or motion. For this reason, branches are almost always smaller in size than their source. Trees and lightning are both examples of branching, directed flows. For lightning, the resistance in the air forms a kind of channel so that the lightning will tend to flow through the path of least resistance. On the other hand, a tree grows in a medium with a nonuniform distribution of desirable qualities, such as available lighting, so it will tend to direct the material flowing through its existing body to accumulate on its ends in the direction of optimal desirable qualities, emergently following the path of most optimal quality. Other significant examples of directed flows with branches include

[30] "The onrush of a conquering force is like the bursting of pent-up waters into a chasm a thousand fathoms deep." Sun Tzu, *The Art of War*, chapter four, verse 20.

electronic circuits and factory assembly lines. In the latter case, material flows down the various paths of assembly, being continuously transformed at each step until it becomes a finished product. Notably, as material moves down parallel lines of identical assembly steps or through a series of operations, the speed at which the material flows will follow similar laws as charge moving through a circuit with parallel paths or resistors in series. This reveals that the concepts of resistance in parallel and in series are essential to the theory of flow.

Thus, we have illuminated the ways that diverse phenomena such as rivers, trees, traffic, and lightning are related: they are all examples of flow. Crucially, the theoretical descriptions of these phenomena will all be very similar, down to the mathematics. Indeed, there is a well-known analogy between the laws of an electronic circuit and of systems of water pipes known as the electronic-hydraulic analogy. This analogy is very close to being developed into a full isomorphism and reveals many of the most essential elements of a theory of flow. In fact, the theory of flow just is the theory of the underlying substructure common to all of these phenomena. It would be of tremendous utility if students could equally be taught the theory of flow and then go on to become traffic engineers, factory designers, or electrical engineers with little additional education. This is what Bertalanffy calls "the production of scientific generalists."[31] Lastly, when we reflect on the near universality of flow—even solids flow, although at a much slower rate—we affirm another famous Heraclitean principle, namely "πάντα ρεί," everything flows.

[31] Bertalanffy, *General System Theory*, 49.

5 A Couple of Objections

Having given a Kantian account of mathematics, we might quickly respond to the major alternative accounts. Three major schools in the philosophy of mathematics are often taken to be Intuitionusm, Platonism, and Formalism. Intuitionism, though differing in specifics, is also grounded in something of a Kantian account, so it would likely be most sympathetic to our account, and we will not respond to it at the moment.

Platonism, on the other hand, rather than holding that the objects of mathematics are concepts constructed out of the *a priori* forms of the mind, holds that they are something like "abstract ideas," existing independently of both the world and the mind, which we perceive through an intellectual perception analogous to our sensory perception. Disproving this account is a lot like trying to disprove that magic fairies control the weather. It supposes a supernatural class of objects, which it may be difficult or impossible to *disprove* the existence of, but a similar challenge holds for proving their existence. Furthermore, it is not reasonable or necessary to assume the existence of this class of objects as a prerequisite for the existence of mathematics since mathematics can already be fully explained by an existing class of objects—i.e., mental concepts, forms, content, and activities—just as it is not reasonable to assume the existence of a supernatural class of objects to explain the weather since natural objects and forces are already completely sufficient to do so.

As for formalism, I take this account to be a merely practical one. It holds that higher mathematics is just the rule-following manipulation of meaningless symbols, and the objects of elementary arithmetic are abstract objects.[32] Thus, as we have already critiqued abstract objects, we have also critiqued this view. However, there is more to say. Mathematics certainly *can* be done as the mere rule-following manipulation of symbols on a page; however, this is not an accurate expression of how mathematics *is* done. Generally, the understanding of a solution precedes its representation as symbolic manipulation, and understanding is generally seen to be the true treasure of mathematics.[33] As Gauss famously said, "I have had my results for a long time, but I do not yet know how I am to arrive at them." This is because the "results" are mental phenomena, so any philosophy of mathematics that does not include an account of mental phenomena must be incomplete. From a mathematician's point of view, any symbols that do not represent his or her mental phenomena are practically worthless.

The surprising result of the formalist perspective, then, is that virtually all mathematical mental phenomena can be represented by symbols. Thus, it can be a practical shorthand to say that mathematics merely works with symbols. But perhaps not all symbols necessarily represent mental phenomena. Take paradoxes for instance. In order to really understand what is going on with a paradox as written, it would be most instructive to examine the mental phenomena it is supposed to represent. Perhaps it cannot represent valid mental phenomena, hence its paradoxicality. On the other hand, if it can represent mental phenomena, we

[32]Leon Horsten, "Philosophy of Mathematics," *The Stanford Encyclopedia of Philosophy*, Spring 2022, https://plato.stanford.edu/entries/philosophy-mathematics/.

[33]For instance, symbolic manipulations that do not engender understanding, such as perhaps those performed by a computer, are often seen as less valuable.

are sure to learn something, rather than being stuck on its surface representation. I would conjecture that *all* mental phenomena can be symbolized, due to some aspect of the nature of the form of the mind and its linguistic expression; however, this is beyond the scope of this paper.

Finally, a sophisticated objection might hold that structures, like objective space, can be an objective feature of the world, so mathematics deals not just with mental structure, but structure in general. We accept the possibility of nonmental structure, but two main points suffice to defend our account as given. For one, even if mathematical theorization does represent some objective structure, it is often done in isolation from this structure, and so cannot validly be said to be working with or referring to this structure, and must therefore work with something actually available, i.e. mental content. For instance, non-euclidean geometry was discovered in isolation from knowledge about the apparent curvature of spacetime, and so cannot be said to be principally a theory of spacetime.

The second point is that, as suggested above, if there is any objective, natural structure it is most likely the structure of the continuum. However, we know that mathematics also deals with discrete structures. Thus, the origin of discrete structure must be independent of the world. That is to say, if someone were to suggest that ‘two’ must be an objective structure because there are two stars independent of any mind, we would reply that the determination of each star as a discrete object is done by the mental application of the form of unity, and is not an independent feature of the world. Moreover, tying back to the first point, the structure of the continuum is also readily available mentally in the form of perception.

6 Concluding Remarks

In review, we have established both an *a priori* and *a posteriori* ground for the concept of a system, which means that a system combines fundamental aspects of both the mind and the world. In other words, the concept of system necessarily consitutes something of a “root metaphor” for all our knowledge about the natural world, and hence nature as we know it, as well as any of its parts, may be validly characterized as a system of systems. Moreover, nature as a whole could be seen as the one true closed system.[34]

Our *a priori* ground is the concept of a structure, which is derived in a Kantian manner from the *a priori* forms of the understanding. In particular, structure results from the conceptualization of the forms of unity and relation, which are the conditions for the mind’s formation and interpretation of discrete objects out of the continuous field of perception. On the other hand, we have shown that certain important features of contemporary systems theory, dynamics and open systems, are reflections of general features of nature, in particular change and continuity. The conceptualization of these general features can also be traced back to Heraclitus in antiquity, along with many other civilizations not mentioned, demonstrating the ubiquity of human wisdom throughout history.

[34] I take this to be similar to the general approach taken by Platonic and Neo-Platonic philosophy. Specifically, for Plato, the cosmos is likened to an organism that does not need to consume or expel anything else. In Neo-Platonism, the concepts of “the all” and “the one” are explored, which are similar to the idea of the whole universe as a unity and the form of unity itself, respectively.

Thus, we may call the *a priori* half of our theorization Kantian, and the *a posteriori* half Heraclitean. In fact, the same conceptions that are attributed to Heraclitus are often taken up by dialectical philosophers following Hegel, so our *a posteriori* half may also be called dialectical. Furthermore, the fact that systems theory has evolved independently[35] as an accepted theory of science and converged on much of the same conclusions as dialectical philosophy demonstrates the credibility of the dialectical perspective. Systems theory can be seen as a contemporary expression of the dialectical philosophy which traces its presence back thousands of years and all across the globe.

Furthermore, the incongruity between the characters of the static, discrete *a priori* half expressed by structure and the ever-changing, continuous *a posteriori* half expressed by nature shows that both nature and the mind must somehow approximate each other in order for the mind to understand nature. That is, they both must approximate systems as a medium between them. Otherwise, the form of unity would have nothing to discriminate, and anything it did would pass away before it could be comprehended. The mind approximates systems by conceptualizing and incorporating change and continuity into its conceptual structures. On the other hand, we can see that nature approximates systems by approximating stasis through equilibrium and discreteness through natural composition and boundary formation. This is the essence of what systems theory and our account teaches us about nature.

One final lesson can be glimpsed from our account: the possibility of *a priori*

[35] Although, Marx's dialectical philosophy can certainly be seen as a precursor and influence to systems theory.

knowledge about the world. There are a few ways this could be approached. First, if the *a posteriori* features used in our theory, such as change and continuity as well as the approximation of nature to systems, can be derived from *a priori* features of the mind in the same way as structure, then systems theory, as a theory about the world, could be completely *a priori*. More promising than this, perhaps, is that *some* aspects of nature could be demonstrated to necessarily fit the definition of structure. In particular, the whole of nature—i.e. the universe, taken to mean all of existence—could be argued to be a necessary unity, and so any facts about unity knowable *a priori* must also apply to nature as a whole *a priori*, thus constituting *a priori* knowledge of the world.[36] However, the form of unity in itself may be so simple that few interesting things could be derived from it. All in all, it seems there is little hope for interesting, purely *a priori* knowledge about the world.

[36]Similar considerations could apply to any atomic parts of the universe; although, if the universe is continuous in the proper sense, then it has no smallest parts.