Reducing the Emergence of the Gaps: Computation for Weak Emergence

by

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I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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ABSTRACT

This thesis contributes to the growing literature surrounding the importance of weak emergence by showing it can account for more phenomena than originally conceived via the use of computational reduction. Weak emergence refers to unpredictable higher-level phenomena that are reducible to lower-level phenomena. The ability of weak emergence to reduce higher-level phenomena to their lower-level constituents is useful for establishing a mechanistic explanation of emergent features. The tension between holistic higher-level phenomena and lower-level parts is a classic argument in philosophy and investigating emergent phenomena is one means of furthering the discussion. In particular I will look at theories of emergence and computational analysis related to systems biology. Systems biology uses modern computational analysis to model naturally occurring interactions of higher-level elements and, in combination with synthetic biology, can trace complex macro-level interactions back to micro-level occurrences without explanatory loss. What makes this interesting is that systems biology is able to explain and reduce phenomena that were once considered strongly emergent, therefore shrinking the number of phenomena we consider strongly emergent. Furthermore, systems biology offers a compelling milieu for philosophers to contribute to scientific discourse and vice versa. Hence, it is a worthwhile endeavor for philosophers to test their theories of emergence against actual practice as a way to inform their concepts. I will use examples traditionally considered strongly emergent (in proteomics) to show that these cases can in fact be reduced and categorized as weakly emergent because they are unpredictable but not irreducible. The reclassification of these phenomena challenges strong emergence, and reveals it to be an 'Emergence of the Gaps' whereby the number of phenomena strong emergence can describe decreases in an inversely proportional relationship to increased computational capacity.

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Teresa Branch-Smith, University of Waterloo

DEDICATION

This master's thesis is dedicated to my mentor André E. Lalonde and one of the few men I knew to be a true gentleman and scholar, Errol Hubert Branch.

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Introduction

The whole-versus-parts debate is a longstanding discussion in philosophy that continues unabated. This tension can be seen in how we conceptualize living organisms: are they a collection of cells programmed by DNA or is there something to be learnt from looking at the capacity for these cells to form organs, systems and organisms? Since the relationship between wholes and parts applies to the nature of explanation, the structure of scientific theories and so forth, it is a genre that has flourished within the philosophy of science.

One aspect of the discussion of whole-versus-parts is the concept of emergent phenomena. Emergent phenomena are events that occur at high-levels within a system and are unpredictable from the lower-level components of the system. Note that 'what constitutes a level', the 'number of levels', what is a high relative to a lower-level, are all dependent on the system. The designation of what determines a system is also context dependent and can range from atom to organism.

The relationship between high-level emergent phenomena and lower-level parts is a matter of debate that has resulted in two main categories: strong and weak emergent phenomenon. The argument between strong and weak emergence regards whether or not higher-level phenomena can be reduced to lower-level phenomena. Strongly emergent phenomena are described as being irreducible whereas weakly emergent phenomena can be reduced to lower-level components. Reduction is the defining distinction between the two emergent categories and has led to tension within the emergence literature.

Discussing and refining our definitions of emergence is something we as philosophers have struggled with for a long time. The reason we keep returning to emergence is because it offers potential to reconcile basic philosophical discrepancies between higher and lower-level parts. From an alternative perspective, contemporary theories of emergence actively critique classic reductionism but what ought to be even more compelling is how systems biologists can contribute to philosophy by providing us a means to forward our own understanding of the concept. This not only gives a novel view of the issue but acts as a way for other disciplines to connect back with philosophy.

I support philosopher Mark Bedau's notion of computation for reduction while moving forward his claim that computation is a way to enlarge the category of weakly emergent phenomena by giving two examples of this re-categorization. There has been no work done using computation that actually takes examples proposed to be strongly emergent and has them re-categorized as weakly emergent. I perform this re-categorization in chapter three to show that weak emergence is actually able to capture more phenomena than originally credited and that the number of strongly emergent phenomena is actually a smaller set than first conceived. However contrary to Bedau, I suggest we use a more holistic approach using systems biology as opposed to synthetic biology because it might inevitably be able to shrink the number of phenomena considered strongly emergent perhaps to the point where the strong-versus-weak descriptions of phenomena are irrelevant in biology.

i) Distinguishing between Strong Emergence and Weak Emergence

An effective way to deliberate about the definition and potential of weak emergence is to consider the limitations of strong emergence. Strong emergence has four main features: unpredictability, irreducibility, supervenience and downward causation. A classic example of strong emergence is consciousness. Consciousness does not seem predictable from lower-level atomic reactions and appears to be impossible to trace back to this lower-level. Consciousness as a higher-level phenomenon emerges when a certain threshold of complexity in the lower-level is met. In the case of strong emergence, the relationship between higher-level and lower-level phenomena is not proposed to be reductive and so does not have a complete mechanistic explanation.

Under the definition of strong emergence higher-level phenomena are envisioned to be supervenient on lower-level relations and have downward causal effects on lower-level elements. Supervenience is a relationship whereby there can be no change in the lower-level without a subsequent change in the higher-level.[1] Therefore higher-level phenomena are supervenient (or reliant) on lower-level phenomena. Downwards causation is a byproduct of supervenience, it works by recognizing that higher-level phenomena can have an effect on lower-level phenomena and combined with supervenience creates a convoluted top-down and bottom-up relationship that has been repeatedly debated by philosophy scholars like Jaegwon Kim (2006), Hong Yu Wang (2010), Timothy O'Connor (2006) and Paul Humphreys (1997). In chapter one I explicitly discuss these main features of strong emergence: supervenience, downward causation, irreducibility and unpredictability. However, since there is such controversy over supervenience and downward causation, I focus on irreducibility as strong emergence's most problematic area. My conservative suggestion is that the set of phenomena considered to be strongly emergent is actually smaller than we think.

On the contrary, the defining characteristic of weak emergence is that it is reducible to lower-level elements. Classic examples of weakly emergent phenomena are the flock formation of birds and the swarming behavior of insects. These patterns are novel, but explicable. Though

[1] According to Kallestrup (2006), Kim's casual exclusion argument posits that "if all physical effects have sufficient physical causes, and no physical effects are caused twice over by distinct physical and mental causes, there cannot be any irreducible mental states." (Kallestrup, 2006, p. 459). In our interests we can broaden this so that it goes beyond emergent mental phenomena, but all strongly emergent phenomena, though consciousness is the most likely case.

these high-level phenomena are reducible to the movement of their individual parts they remain unpredictable from the starting conditions of the system. As a result of this reduction, it is possible to have a mechanistic explanation of the relationship between higher-level and lower-level phenomena. Depending on the degree of complexity of the higher-level phenomena, computational assistance in the form of mapping interactions or tracking elements may be required for the reduction. This computational requirement is not detrimental in anyway, but allows for the definition of weak emergence to account for more complex phenomena. Therefore, as the ability to recognize and compute relationships increases, so do the number of phenomena that might be explained using weak emergence.

ii) The Connection between Examples and Explanation

Explanation through reduction can offer a mechanistic account for how higher-level phenomena arise. A mechanistic account while perhaps not entirely comprehensive of all the features of the system at least can offer a plausible explanation. What is valuable about a mechanistic explanation is that is subject to empirical testing. Strong emergence cannot be reconciled with empirical investigation because the fundamental irreducible feature of strong emergence produces an explanatory gap that distorts causal relationships. The explanatory gap is the area between the higher-level emergent phenomenon and the lower-level parts of the system through which a reductive relationship cannot be constructed. For strong emergence, no matter how much additional information is acquired about the relationship between higher-level and lower-level phenomena, there is theorized to always be a gap between the lower-level phenomenon meeting the threshold of complexity and the higher-level emergent phenomenon. Therefore, strong emergence will never be reducible or accountable to empirical standards because we cannot empirically verify the casual relationship between the parts (lower-level phenomena) and the whole (higher-level phenomenon) of the system using mechanistic explanation.

To discuss the potential for enlargement of the class of phenomena that can be considered weakly emergent by shrinking the number of strongly emergent phenomena, I will look at examples in biology because biological organisms have complex top-down and bottom-up relationships many of which, like consciousness, are thought of as strongly emergent but also relate to the organism as a whole.

Holism is the notion that a system should be viewed as a whole entity rather than just an amalgamation of parts. In contrast, a strict reductionist approach would be one that focuses only on the lower-level parts for explanation. A reductionist explanation of phenomena does not negate a holistic understanding of either since the reductive relationship fits within the larger schematic workings of the system. Because of the density of relevant relationships both between levels and within levels, computation has been very helpful to track these connections for use in reductive explanation. I will discuss synthetic biology to map micro-level interactions in tandem with systems biology for the macro-level phenomena and conclude that some examples are weakly as opposed to strongly emergent as is the case for the work of philosopher Bar-Yam (2004) and scientists Boogerd, Bruggeman, Richardson, Stephan and Westerhoff (2005).

iii) The Relationship of Synthetic and Systems Biology to Emergence

Synthetic biology is a tool used to describe the location of specific genes on the genome of an organism that can then be artificially manipulated by either adding or removing a fraction of the organism's DNA (e.g. sequencing the lac operon described in chapter two). Lower-level alterations to the genome such as the ones preformed in synthetic biology can influence the appearance of higher-level phenomena. Synthetic biology was developed first and systems biology followed afterwards as a branch of synthetic biology though the two work in a symbiotic relationship which I discuss further in chapter two. Systems biology investigates higher-order protein interactions. Since several proteins are able to perform multiple tasks depending on the environmental conditions of the organism, tracking their interactions can be challenging. However, computation has allowed systems biology to map and track these proteins at this higher-level as well as verify these lower-level relationships by using synthetic biology to enhance or delete certain genes to test the integrity of the system. Therefore, the higher-level systems' interactions of the proteins are reducible to the lower-level synthetic markers in the organism making this method of verification weakly emergent. What is most interesting is that scholars like Bar-Yam (2004) and Boogerd et al. (2005) have mistakenly used similar proteomic examples as strongly emergent which suggests there might be several other examples thought to be genuinely strongly emergent that can be reduced through computation and considered weakly emergent as I will show in chapter three.

Using examples of synthetic and systems biology computation, I will show that examples previously considered to be strongly emergent can actually be categorized as weakly emergent phenomena because there is a reductive relationship between higher and lower-level phenomena. Therefore I propose that the ability for weak emergence to continually be able to reduce novel higher-level phenomena to lower-level phenomena with the assistance of computation can significantly reduce the number of strongly emergent phenomena and show the category of weakly emergent phenomena to be much larger than initially believed.

In chapter one I will briefly discuss the history of emergence and the current debate within philosophy between strong and weak emergence. In chapter two, I will review the central tenents of synthetic and systems biology examining how both came into fruition and their rise in popularity within the sciences. Finally, in chapter three will discuss how computation used in synthetic and systems biology can create a mechanistic reduction between higher-level and lower-level phenomena by using two examples once thought to be strongly emergent. As a result, I conclude two main things about weak emergence. First, with computational reduction weak emergence is able to account for more phenomena than originally conceived because phenomena once considered to be strongly emergent can now be reduced and therefore be categorized as weakly emergent. Second, weak emergence is preferable to strong emergence in ontological, methodological and epistemic ways because it casts phenomena in ways that are subject to empirical investigation.

CHAPTER 1
Emergence and all its Parts

In order to contextualize current debates, in this chapter I will briefly cover the earliest uses of themes related to emergence, how the term originated, trends in emergence's popularity throughout the 18th and 19th century, and finally its reappearance in recent literature. I will then clarify my definitions for use during the rest of the paper in the framework of the present debate between strong and weak emergence as there have been several meanings for the terms. Lastly, I will offer motivation as to why philosophers should champion weak emergence as a way to engage with the scientific community and how it could aid in answering fundamental questions about the larger whole-versus-parts debate in philosophy.

1.1) History

This history is largely drawn from Peter Corning's work 'The re-emergence of "emergence": A venerable concept in search of a theory' (2002) as well as Tom De Wolf and Tom Holvert's (2004) piece 'Emergence and Self-Organization: a statement of similarities and differences' during which I highlight specific instances of where the history of emergence is of note to understand present debates between weak and strong emergence. The ongoing discussion of the relationship between parts and wholes can be explored through the emergence debate. I begin by going through a brief history of use of the term 'emergence' starting with the origins of the term, the role of emergence in the 19th century as *proto-emergentism*, through to discussions of Darwinian evolution and the rise of *emergent evolutionism*, and then transition to contemporary usage as *neo-emergentism* in order to situate the current state of the argument. The purpose of this history overview is to show how emergence as a theme is one of the oldest themes in philosophical discourse yet has been reinvented several times throughout history to describe the relationship between parts and wholes.

1.1.1) First mentions of Emergence

Emergence is the occurrence of higher-level novel structures, patterns and properties as a result of complex lower-level interactions. Consider listening to an entrancing poem with melodious cadence and an equally sophisticated vocabulary. After reading the poem it might be clear what the theme is, you can trace the grammatical structure of the phrases, decipher why the author chose the words she did, the order, and how they were spelled back down to the letter. So while you might be able to trace the theme of the poem to the words and to the letters, if I were to provide you with just the letters required to compose this poem, it would be extraordinarily unlikely that you could predict it in its exact form from these initial conditions. The poem in this case is an emergent phenomenon. The poem is not predictable from the lower-level parts of the system (the letters) but the poem as a whole and its beautiful nature are reducible to these lower-level parts.[2]

Emergence is not a new philosophical topic, however, recently more attention has been paid to exploring its explanatory potential. Corning (2002) offers that some of the earliest hints at the characteristics similar to contemporary definitions of emergence are apparent in Aristotle's Metaphysics where he speaks of the significance of wholes in the natural world "The whole is something over and above its parts, and not just the sum of them all..." (BookH, 1045:8-10). He continues to point out through the work of Tiles (1989) that this gives an explanatory precedence to the whole compared to the individual parts that make up the whole. However, for

[2] The purpose of the poem analogy here is to layout some of the most basic features of emergent phenomena and is not meant to suggest that emergent phenomena necessarily have any pre-determined goal.

contemporary notions of emergence, there is not something additional attributed to the higher-order system.[3] Hence, when emergence became a popular concept in the 19th century the ontological distinction between parts and wholes was not a new one but had to be refined from previous conceptions.

The term 'emergent' was first used by psychologist George Henry Lewes in *Problems of Life and Mind* (1879), he argued in the same vein as John Stuart Mill that certain phenomena in nature produce a 'qualitative novelty' whereby material changes cannot be expressed in simple qualitative terms.

> Every resultant is either a sum or a difference of the cooperant forces; their sum, when their directions are the same - their difference when their directions are contrary. Further, every resultant is clearly traceable in its components, because these are homogeneous and commensurable.... It is otherwise with emergents, when, instead of adding measurable motion to measurable motion, or things of one thing to other individuals of their kind, there is a cooperation of unlike kinds... The emergent is unlike its components in so far as these are incommensurable, and it cannot be reduced to their sum or their difference. (Lewes, 1879, p.413)

This passage describes an irreducible sort of emergence where the resultant phenomena are dissimilar from lower-lever properties. In a related example from 1891, Lewes distinguished between resultant and emergent products after the chemical reaction.

> ... although each effect is the resultant of its components, we cannot always trace the steps of the process, so as to see in the product the mode of operation of each factor the

[3] The emergence considered in my work has a basis in materialism and will not consider explanations which utilize vitalist forces. Vitalist forces are used to describe ontological matter whose sum is ontologically greater than its parts and is usually the result of some 'life-force'. The limitations of the vitalist explanation are detailed sufficiently in other works and so will not be entertained here (but can be found elsewhere (Allen G.E, 2005)) It should thus be noted that discussions here regarding holism or organicism refers to systems with material properties.

latter case, I propose to call the effect an emergent. It arises out of combined agencies, but in a form which does not display the agents in action... (Lewes, 1891, p.368)

The 'resultant' in this case is the emergent property coming from the initial components of the system. Note the phase 'we cannot trace' is important because sometimes emergent phenomena can be traced back to the starting conditions of the system and sometimes not. This feature is the key difference between weak and strong emergence and I will discuss it in great length when describing the two categories. Independent of the reduction, the initial components of the system (the parts) cannot predict the higher-level results (whole) of the system and all emergent phenomena have this in common. Scholarly attention to the distinction between higher-level wholes and lower-level parts would continue into the nineteenth century and become particularly popular in the biological sciences.

1.1.2) Emergence and Evolution

Lewes' work published in 1875, according to De Wolf and Holvert (2004), would go on to influence later work in the early 1900s called emergent evolutionism (or proto-emergentism). In these instances, emergence was used broadly as an alternative to reductionism.

Emergent evolutionism was developed by Victorian theorists who framed the parts and wholes relationship within an evolutionary context to account for biological complexity. The movement attempted to show how novel traits could arise in a population. Darwinian evolution was considered by some as problematic and thought to negate the possibility of radically new phenomena (like developmental consciousness for example).[4] Emergent evolution offered to

[4] Darwin's resistance to sharp discontinuities in nature is evident through his repeated use of the phrase *natura non facit saltum* (nature does not make jumps) that he uses multiple times in the Origin of Species. Instead he favoured laws of continuity and incremental change. With reference to the consciousness example of strong

reconcile Darwin's gradualism and the appearance of 'novel qualities' by allowing features like consciousness to be the result of sufficient complexity. To do so, evolutionary emergentists used Lamarckian notions of inherent energy driven evolution as seen in the work of biologist and sociologist Herbet Spencer (See First Principles, 1904).

Corning (2002) points out that besides Spencer, emergent evolution amassed several devotees such as Samuel Alexander (1966) and his 'natural piety', Roy Wood Sellars' *Evolutionary Naturalism*, C.D. Broad's *The Mind and its Place in Nature* (1925), Jan Smuts' *Holism and Evolution* (1926), Arthur Lovejoy's *The meaning of Emergence and its modes* (1927) and W.M. Wheeler's *Evolution and the Social* (1926). These theorists came from diverse backgrounds and provided thematically varied emergence related contributions. For example, comparative theorist Conwy Lloyd Morgan, would go on to publish three volumes: Emergent Evolution (1923), Life, Spirit and Mind (1926) and The Emergence of Novelty (1933) that would heavily influence later writers.[5] To show another early link between biology and philosophy of emergence I point to Morgan and others who would go on to influence concepts like David Sloan Wilson's 'trait group selection', John Maynard Smith's 'synergistic selection' and Corning's Synergism Hypothesis using emergent evolution.

As a result of the rise in genetics during the 1920s and 1930s there was a decrease in interest towards emergence after the Darwinian evolution (McLaughlin, 1992). This occurred in part because of the epistemological potential of genetics and the microscopic experimental

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emergence, the laws of Darwinian evolution propose that features like consciousness are the result of 'descent with modification' thus permitting novelty to retain a traceable source. In the Descent of Man, Darwin spoke of mind (and consciousness) as the defining characteristic between humans and animals, but this was envisioned to be a difference in degree not of kind (I, p.70, 6) because biological phenomena like consciousness were theorized to occur incrementally as opposed to abruptly (Corning, 2002). This calls into question whether or not phenomena like consciousness are strongly emergent; however, because strong emergence necessitates a gap, once the threshold of complexity is met it does not appear reconcilable with a difference in kind.

[5] Morgan's paradigm had a holistic angle because of his belief that quantitative incremental changes eventually lead to qualitative changes that are different from, yet reducible to, their parts within the larger framework of the organism. The qualitative features of the wholes are therefore believed to be irreducible to their parts.

approach rising in popularity throughout biology that focused almost exclusively on reductive methodologies. At its most extreme, reductionism dominated knowledge claims and was challenged by the possibility of evolution by Natural Selection. According to Corning (2002), critics like philosopher Stephen Pepper, computer engineer Charles Baylis, psychologist William McDougall and more famously logical positivist Rudolph Carnap, as well as analytical philosopher Bertrand Russell, all examined emergence skeptically. Russell in particular claimed that emergent phenomenon were just epiphenomena with no scientific significance and favored a new methodology in philosophy with a more rigorous empirical/logic based approach instead. He argued that analytics "enables us to arrive at a structure such that the properties of the complex can be inferred from those parts" (Corning 2002, pp.285-286, p.11). The idea was that in time science would develop a mechanistic and causal account for all seemingly emergent phenomena and a need for emergent theories in explanation would wane.

In the years following the rise of analytic micro-science based in the laboratory there was very little discussion about emergence.[6] However, there were still faint trends that had emergent themes. For example, embryologist Joseph Needham put forward the idea of “'integrative levels' throughout nature and the existence of (different) levels of organization in the universe, successive forms of order in a scale of complexity and organization (p.234, 12)” (Corning, 2002, p.20). In this same vein, biologist Julian Huxley, forefather of the 'modern synthesis' in evolutionary biology, asserted that not only were there various levels of complexity within

[6] It should be noted that while an interest in genetics and the biochemistry as a subdiscipline may have rejected emergentisim in favour of explicit reductionism, other sub-fields such as ecology were on a much different trajectory. Ecologists were keen on the idea of holism and the notion of higher order levels having a relationship with lower-level phenomena mixing degrees of reductionism and holism.[6] The holistic approach mentioned is more favourable now in systems biology which I will suggest as the optimal way to engage with weak emergence in chapters two and three.

systems but that there was also a potential for the rapid development of new properties.[7] And so, early work on proto-emergentism led to the establishment of emergent evolutionism. This emergent evolutionism provides a conceptual framework for our understanding of wholes and parts, which continues to help researchers develop new techniques to investigate biological phenomena today.

1.1.3) Contemporary Emergence

After the Victorian era there was a lull in scholarly discourse about emergence until the mid-twentieth century. The next wave of emergence that inspired contemporary debate is known as neo-emergence and began germinating due to an interest in 'systems theory' that focused on elucidating principles that could be applied across multiple disciplines. Inspired by biologist Ludwig von Bertalanffy, this research had strong interdisciplinary roots and interested not just scientists and philosophers, but engineers and computer scientists as well.

Following this neo-emergentism, complexity theory became established with a strong mathematical and scientific basis, where complexity theory refers to the study of densely interrelated elements of systems or series of systems usually by computational analysis. Complex Systems include the idea of emergence in terms of the scale of complexity and self-organization over time.[8]

[7] See Alex B. Novikoff's defense of emergence and levels of reality in his 1981 article "The Concept of Integrative :Levels in Biology."
[8] Sub-disciplines of complexity theory include: Systems theory, Nonlinear Dynamics, Pattern formation, Evolution & Adaption, Networks, Collective Behaviour and Game Theory.

The wide array of applications that complexity and emergence enjoy in science today arises from neo-emergence. Areas such as cybernetics, solid state/condensed matter physics, evolutionary biology, artificial intelligence and near-living architecture all share a complexity basis founded in emergence discourse. Chaos theory and dynamical systems theory allow science to model interactions within the system and lend mathematical legitimacy to the notion of systems with many parts that can be deterministic yet unpredictable. The 'system with many parts' idea is echoed in the notion that there are historical reasons as to why the system is constrained yet still retains unpredictable features. For example, physicist and founder of synergetics, Herman Haken’s cooperative phenomena have contributed to a large body of literature in holistic theory that relies on the multiple parts.[9]

In summary, from the discussion of parts and wholes to the more complex cross-disciplinary role emergence is able to adopt, the definitions and applications of this concept continue to change. Throughout the rest of my work I attempt to establish a case for what I hope will be the next major view of emergence: that the set of strongly emergent phenomena is actually much smaller than originally conceived because some examples of strongly emergence are actually weakly emergent. To better comprehend this definition of emergence, let me look briefly at the complexity required for emergent phenomena to occur.

1.2) Complexity

Complexity is a key feature in the discussion of emergence because it is what allows emergent phenomena to appear. As a necessary requirement, complexity is used in descriptions

[9] Further proof of this is seen in the work of Gregoire Nicolis and Ilya Prigogine (1977). Their work focused on non-equilibrium thermodynamics, and the concept of 'dissipative structures' added to the interest in complexity theories not just from physics but also biology.

of both weak and strongly emergent phenomena. I will include a definition of complexity I will use for my investigation into computation and weak emergence but first begin by going back to my simple example from earlier.

Recall my poem example from before where the letters, words, phrases, paragraphs and themes all make up respective levels of the poem. What constitutes a level is entirely subjective to the phenomena being discussed but what is more important is that these levels are interrelated. Consider the twenty-six letters in the English alphabet, entirely quantifiable but with notable rules for how they can be ordered to make coherent words (ex: 'i' before 'e' except after 'c'). These letter-order rules are necessary for the next level up, the word level. But, the rules regarding the correct spelling of words have a downward effect on the ordering of letters in a bidirectional relationship. At this stage, additional rules like word order also come into effect. The interrelated relationship between lower and higher-levels contribute to the complexity of the poem helping to develop the theme as well as the effect it has on the audience.

Taking the poem analogy further, imagine a bland style of writing. Depending on word choice, a work might not be interesting or well composed enough to be truly poetic. In which case, a threshold of complexity (prose) must therefore be met in the relationships between the lower-levels of the system in order for the higher-level thematic (poetic) features to occur. The same happens when discussing emergent phenomena: the system can usually be divided into levels, each with their own set of rules, able to influence and interact with higher and lower-levels; however, there is a determining factor in the threshold of complexity that allows for higher-level emergent phenomena to occur. I will use the following working definition:

Complexity: A complex system is one in which the elements of the system have a degree of connectedness in terms of their relationships to one another but is considered sufficiently dense by virtue of some threshold (be it number of connections, the appearance of an emergent phenomena etc).

Emergence is believed to be a phenomenon that results from a threshold of complexity being met, but how exactly to describe emergent phenomena and their properties are contested.

1.3) Defining Emergence

This section will examine the current debate in the philosophy of science noting prominent thinkers who support either strong or weak emergence. By familiarizing ourselves with the literature my reason for supporting weak emergence will be apparent especially due to the problematic conceptions of strong emergence.

In the poem analogy recall that there are certain themes that might only become apparent at the highest level of the work, not the level of the letter or words but after reading the whole piece. Let us say that the poem's theme is one of admiration. Once we know the theme of the work is admiration, we can look specifically at which verses suggest this, the words used and even the letters (A-D-M-I-R-E) to figure out how we arrived at this thematic conclusion. The tracing from the higher-level theme to the lower-level letters is an example of a reductive relationship and is a core feature of weak emergence. But what if after knowing the theme, we look at the verses, words and letters but cannot quite explain why we think admiration is the theme? This would represent an irreducible relationship between higher-level thematic features of the piece and the lower-level components. This is irreducibility which is a defining feature of strong emergence.

Not all scholars make the distinction between the two common types of emergence, strong and weak. The main difference between strong and weak emergence is that the higher-level phenomena in strong emergence are thought to be irreducible to the micro-level phenomena irrespective of how much information about the system is gathered. Weak emergence has higher-level properties that are reducible to lower-level phenomena. Strong and weak emergence also differ in the amount of regulatory power the higher-level emergent phenomena have over lower-level phenomena. As defined, strong emergence is regulatory whereas weak emergence is just influential. However, both strong and weakly emergent phenomena are unpredictable from micro-level phenomena. The ontological and epistemological merits of weak emergence will be investigated more thoroughly in the next sections to show its superiority over strong emergence in terms of usefulness for empirical investigation.

1.3.1) Strong Emergence

Though my argument focuses on showing the shrinking number of strongly emergent phenomena, it is most easily understood in comparison to strong emergence. I will go through strong emergence first, highlighting its weaknesses and its critics as a way to lead into weak emergence. Generally, strong emergence is what authors refer to when they discuss emergence because they mean for emergence to entail a mechanistically irreducible relationship between higher and lower-level phenomena. In the literature, definitions of strong emergence are noted to be "…not deducible even in principle" (Chalmers, 2006) or "the view that novel and irreducibly complex systems can come into existence, with their own structures, laws, and causal mechanisms…" (Clayton, 2004). I take into consideration several versions of strong emergence and have concentrated the main features into the following definition for our use:

> *Strong Emergence*: Describes higher-level phenomena that are unpredictable from and irreducible to lower-level phenomena irrespective of how much external information about the system is given.

Again, strong emergence has four main features: unpredictability, irreducibility, supervenience and downward causation. Unpredictability refers to the fact that no matter the starting condition of the system, the occurrence of an emergent phenomenon is an outcome that cannot be predicted from its lower-level parts just like figuring out the meaning of the poem from all the individual letters randomly laid out. Strong emergence shares this characteristic in common with weak emergence.

While discussions of unpredictability focus on the difficulty of moving from the lower to higher-level, irreducibility focuses on the reverse: moving from the higher-level to lower-level. Irreducibility refers to the higher-level emergent phenomena of the system being unable to have its origins traced back to the lower-level elements of the system. Recall from earlier the note regarding some (strongly emergent) phenomena that 'we cannot trace' (Lewes, 1891): in this case we cannot trace the higher-level phenomena down to the lower-level.

Supervenience is the notion that there can be no change in the higher-level emergent phenomena of the system without a resultant change in the lower elements of the system. Downwards causation follows from this and occurs when higher-level phenomena in the system influence lower-level states of the system. Supervenience and downwards causation have been heavily criticized but are central features to the strong-versus-weak debate in philosophy. Therefore, I will go over arguments against supervenience and downwards causation briefly below because once established it will show the lack of consistency in a workable definition for strong emergence. I add to the issues of strong emergence by showing that philosophers like Bar-Yam (2006) incorrectly identify irreducibility in strongly emergent examples. Problems with definitions of supervenience and downwards causation combined with my re-categorization of strongly emergent phenomena to weakly emergent phenomena demonstrates how there fewer strongly emergent phenomena then we initially thought. Meanwhile, the number of weakly emergent phenomena will increase from this re-categorization. This is important because it contributes to the concern there might not be any genuinely strongly emergent phenomena

To be more explicit, property (A) is supervenient on property (B) where there can be no change in (A) without a change in (B). In our case, variations amongst strongly emergent higher-level phenomena influence the arrangement of lower-level properties. Downwards causation is where emergent laws can govern their level of complexity and the relationships found at lower-levels. Downwards causation and supervenience are related in that since there can be no change in the higher-level phenomena with a change in the lower-level phenomena and the higher-level has regulatory power over the lower-levels of the system. Imagine if my poem example from earlier were strongly emergent. In this version, the higher-level emergent theme of the poem, admiration, could not change without altering the words in the poem as an example of supervenience. The higher-level theme of the poem also dictates what lower-level elements (words) can be used which is an example of downwards causation. Since strong emergence is believed to have regulatory potential like in the definition of downwards causation, the whole cannot be identified though observation of the parts because, these parts are determined by the whole.[10]

1.3.1.1) The Cacophony of Strong Emergence

Supervenience and downwards causation are so problematic for strong emergence that much of the discussion regarding strong emergence has involved attempting to find solutions to defining strong emergence either without them or in varying degrees. The following is a summarized collection of the main arguments of several very prominent scholars who discuss strong emergence. There are several fundamental differences in how these scholars define and categorize emergent phenomena which I use to show that as there are fundamental problems with strong emergence so we might be better to refocus our efforts and our energy towards weak emergence. Consider the following four scholars in emergence - Jaegwon Kim, Hong Yu Wong, Timothy O'Connor and Paul Humphreys - who argue for a strong emergence with an altered understanding of supervenience. I posit that since it is extraordinarily unclear how supervenience via emergent properties can allow for downward causation but continue a dependent relationship on lower-level constituents this serves as partial reason for why philosophers should utilize weak emergence as a source of explanation as opposed to strong emergence.

Jaegwon Kim (1993, 2006) suggests that emergence has only ontological but not explanatory merit because it risks simultaneous causation and inevitably prevents emergence from having a mechanistic explanation (via physical causal closure). Ontological emergence puts forward that when micro-level constituents reach a certain threshold of complexity that they can

[10] According to J.Kim (1985), the term supervenience was first used by D. Davidson as "Dependency without reduction", or a relationship between two properties without a law connecting those properties. A fortiori, the emergent phenomena are not reducible to lower-level interactions.

generate emergent higher-level properties. Ontological emergence is usually accompanied by a novel causal influence from higher-level phenomena to lower-level phenomena (downward causation). Kim puts forward two types of downward causation: synchronic reflexive downward causation and diachronic reflexive downward causation. Synchronic reflexive downward causation he writes off because it necessitates a simultaneous sort of causation which does not mesh with the classic definition of causation (one phenomena happens first in order to cause another). Although according to Kim, diachronic reflexive downward causation is vulnerable to his causal exclusion argument but it remains a possible, albeit problematic, explanation for strong emergence. Wong, however, attempts to provide a sound example of a diachronic reflexive downward causation case by discussing emergent properties that do not supervene on lower-level properties as a way to allow strong emergence to survive.

Hong Yu Wong (2010), who attempts to counter Kim, describes how it is unclear how supervenient emergentism allows for novel downward causation while guaranteeing co-variation of emergent properties with lower-level properties in a way that is consistent with the laws of emergence (unpredictable, irreducible, supervenient). He goes on to argue that supervenience must be grounded "solely on fundamental, non-derivative emergent laws" setting certain constraints on the explanatory ability of classical emergence based on consistency with co-variation between higher and lower-level phenomena and fundamental laws (Wong, 2010, p.9). I think Wong's position is troublesome because if strongly emergent phenomena do not have supervenience relations, what type of relationship do these phenomena have - especially compared to weak emergence which is known to have direct causal links?

Timothy O'Connor (2006) posits a non-supervening, dynamic causal concept of emergence where there could be two nominological lower-level elements contributing to the same physical concept at a particular time. He supports this causal notion because it would seem that if emergent properties are metaphysically primitive and appear at the correct time as a necessary feature of the system once a threshold of complexity is met then there can be a causal relationship between lower and higher-level phenomena. This explanation has the feel of a dualistic synchronic causality issue similar to Kim's synchronic reflexive downward causation which could be defeating and shows how these definitions of strong emergence are incompatible.

Finally, Paul Humphreys (1997) puts forward that emergent phenomena are the result of an interaction of lower-level phenomena. This interaction is known as fusion whereby it is necessary for lower-level interactions to have the casual power to generate emergent phenomena; however, if disengaged, the lower-level interactions of the system lose their novel abilities. This explanation speaks to the complexity threshold required but not definitively to the causal gap between higher and lower-level phenomena.

My reason for collecting all these scholars' views is simply to show that as there can be no consensus on even the definition, much less genuine examples of strong emergence, which should motivate us to reconsider our efforts and perhaps redirect them towards weak emergence.

1.3.1.2) Examples of Strong Emergence

The most compelling example of strong emergence seems to be the case for consciousness (see Chalmers 1996, 2002). Philosophy of mind is heavily engaged in the discussion of emergence in terms of the reductive limitations that consciousness seems to present. Currently, some researchers in philosophy and a range of sciences think that there is an unpredictable and irreducible component to consciousness that occurs when organisms become sufficiently complex. This is not to say that all organisms have consciousness per se, since even the definition of what it is to be conscious is contested, but that certain species like humans experience it and are believed to have this irreducible feature. The strong emergence explanation, in its simplest form, is that consciousness is the result of complex systems (molecular, proteomic, chemical, functional, etc.) that combine to meet a threshold of complexity that allows for consciousness to be generated. Strong emergentists argue that consciousness is unpredictable from known micro-level interactions. Consciousness as a property is irreducible to lower-level properties in the system irrespective of how much external and internal information about the system is known. Therefore, there will always be an ontological and epistemological gap between consciousness as a strongly emergent phenomenon and its lower-level parts.

The shrinking inexplicable gap that strong emergence stands on threatens to disappear as technology reveals more about substructures that were previously unobservable. However, there is an alternative. Weakly emergent phenomenon, while theorized to be unpredictable, are not required to be irreducible and can account for the ever shrinking explanatory gap between higher-level and lower-level phenomena

1.3.2) Weak Emergence

Weak emergence is an alternative explanation of the relationships between higher and lower-level phenomena. In the literature weak emergence is defined as "the view that a system's macro properties can be explained by its micro properties but only in an especially complicated way" (Bedau, 2008) or, according to Chalmers (2006), "it often happens that a high-level phenomenon is unexpected given principles of low-level domain, but is nevertheless deducible in principle from truths concerning that domain" (p.245). Distilling these two popular descriptions and common themes found in others, I will use the following definition for my investigation:

Weak emergence: weakly emergent phenomena are novel higher-level phenomena that are unpredictable from, yet reducible to lower-level interactions.

Examples of weak emergence include the semipermeability of membranes, the flocking patterns of birds, protein interactions, language semantics and likely many others as these phenomena appear to be quite ubiquitous. The swarming behaviours of insects and birds are commonly taken as weakly emergent, whereby it is impossible to predict the patterns they form, but once the patterns do occur they can be reduced to the individual actions of singular group members (Bonabeau et al., 1999). Weakly emergent properties are thought to be influential on lower-level properties as opposed to regulatory as with strong emergence (i.e, downward causation). More importantly, in terms of compatibility with empirical investigation, since weak emergence does not generate the same explanatory gap as strong emergence we can use it to make ontologically and epistemologically verifiable claims. Because the reduction is possible, weak emergence is an inherently more appealing phenomenon to consider empirically speaking. The ability for weak emergence to allow and incorporate new information into its framework of understanding should make it extraordinarily attractive to philosophers as it will remain compatible with the growing amount of empirical knowledge available. Moreover, weak emergence does not pose the same awkward regulatory supervenience and downward causation problems that strong emergence possesses. I will focus on weak emergence for the remainder of this investigation into the compatibility of science, emergence and systems biology.

1.3.2.1) Incompressible Reductive Properties

There are fewer debates with respect to weak emergence than strong emergence. There appears to be a general consensus that there are weakly emergent phenomena, with reducible higher-level phenomena based on the starting conditions of the system. The most well cited proponent of weak emergence is Mark Bedau. He has written extensively on the topic of weak emergence in terms of explanatory incompressibility and derivability via simulation (Bedau, 1997, 2002). Explanatory *incompressibility* means that the explanation is dependent on the ability to trace higher-level interactions to temporal micro-level causal interactions. The explanation is generative and assumes complete information about the micro state. Therefore, higher-level properties at any given time can be traced back to the lower-level properties at that time. What is of note here is that incompressible explanations cannot be replaced without explanatory loss by shorter explanations that risks truncating the causal network that was mapped to arrive at lower-level elements (Bedau, 2008).

What is curious about the idea of incompressible weakly emergent phenomena is that it allows for a range of degrees of emergent phenomena depending on the complexity of the lower-level phenomena. Since some lower-level phenomenon can be very complex it makes the effort to trace higher-level phenomena back to the lower-level somewhat challenging. As a result, Bedau proposes computer simulation as a means to aid in the reduction to account for the density of lower-level agents interacting with their neighbors and the environment. I propose that to investigate biological systems, we should look at synthetic and systems biology that readily use computer simulation to trace reductive relationships between higher-level and lower-level phenomena. These two tools can only be used for weakly emergent phenomena because strong emergence has, by definition, a reductive gap between emergent higher-level and lower-level phenomena that prevent it from being accurately modeled. We can tell which phenomena are weakly emergent and which are strongly emergent based on whether or not they are reducible.[11]

To summarize, the state of the debate between strong and weak emergence is as follows: discussions amongst strong emergentists have surrounded trying to explain the relationships that transcends the gap between higher-level and lower-level phenomena. It is this gap that results in irreducibility. But more troubling has been the focus on supervenience and downwards causation exemplified by Kim (2006) and Wong (2010). It has been so problematic that some philosophers (O'Connor and Humphreys) have tried to create a strong emergence without these initial defining features which shows how problematic the definition of strong emergence is. On the contrary, with the exception of Bedau, much less has been said about weak emergence except that it has the potential to perform more complex reductive relationships. However, there have not been any definitive examples of strongly emergent phenomena being re-categorized as weak yet using computation. I will provide such an example through the use of computation showing that some strongly emergent phenomena can actually be categorized as weakly emergent, thus, challenging the applicability of strong emergence and adding tangible examples to the literature to the contrary. Before going into the synthetic and systems biology examples (Chapter three) I will review the discovery and applications of synthetic and systems biology (Chapter two) to show how they can be used in the philosophy of science (Chapter three).

[11] Relying on supervenience or downward causation to distinguish between examples weak and strong emergence would be challenging since there are so many definitions of supervenience and downward causation as I showed in section 1.3.1.1 The Cacophony of Strong Emergence.

1.4) Emergence and Empirical Investigation

One very important issue that I will return to throughout the rest of my argument is that strong emergence has an irreducible component that is incompatible with empirical investigation and mechanistic explanation. Empirical investigation relies on evidence-based explanation, even though those needn't necessarily be direct. This is problematic for strong emergence because supervenience and downward causation result in a discontinuous causal relationship between higher-order macro phenomenon and lower-level micro interactions that cannot be verified because there is a gap between these two strata. This gap prevents a complete mechanistic explanation and so hinders observations of the phenomena since there must be a continuous mechanistic explanation.[12]

As a result of the lack of mechanistic explanation, the sciences have been somewhat skeptical of including strong emergence as a legitimate categorization of phenomena especially because there seems to be an increasing amount of information about this gap that is being discovered regularly, reducing the actual size of the gap between higher and lower-level phenomena. Put another way, we are learning more about both the micro-level and the density of the higher-level which reduces the amount of unknowable mechanisms. This shrinking gap risks an 'Emergence of the Gaps' where there will be a decreasing amount of areas for strong emergence to be applied.[13] Furthermore, an increase in data about the supposed gap of strong emergence risks the chance that examples might in fact be explicable via reductionism and therefore negate the strong emergence classification all together. This is important for my reason

[12] Though it might be of interest to consider since there is no material phenomena occurring within the strongly emergent gap then perhaps there is no mechanistic explanation needed. I suspect proving this might be quite problematic though.

[13] I use the term 'Emergence of the Gaps' to refer to strong emergence because as we learn more about systems I suspect that the number of phenomena considered strongly emergent will shrink. It is inspired by the 'God of the Gaps' concept and hints at the argument from ignorance fallacy. It also refers to strong emergence's necessary gap in reductive explanation between higher-level and lower-level phenomena.

in selecting weak emergence as the more viable concept because unlike strong emergence, the more information we learn about a system, the more it can benefit an understanding of the emergent phenomena compared to strong emergence which remains in peril as more information is discovered because it might end up being reducible.

1.5) Distribution & Motivation

Part of my reasoning for including a history section has been to show that a wide array of diverse scholars have written about themes related to emergence allowing it to transcend any one discipline. For example, philosophy of mind has a vested interest in understanding the nature of emergent phenomena, especially with regard to consciousness.[14] My work here will focus primarily on the rich debates in the philosophy of science by looking at the work of emergence scholars like Bedau and Kim. But, the ubiquity of deliberations about emergence across disciplines is a compelling reason for philosophers to get involved as it offers them a plateau to reach out from and engage with other theorists.

The cross-disciplinary investigation of emergence is a persuasive endeavour for philosophers who have long struggled to be applicable outside their field. Engaging with discussions of emergence in external domains therefore is not only beneficial for philosophy as a means of disseminating the craft, but also possesses the opportunity to provide insightful feedback about the ontological possibility of emergent phenomena by providing examples from multiple sources. At the core of the emergence debate rests the opportunity for philosophers to

[14] Not all theorists explain consciousness in humans as the result of emergence. Some suggest the complex nature of social groups whereas others like Michael Cabanac purport that consciousness may have evolved from sensation. (Cabanac et al., 2009) Others like Derek Denton put forward that the origins of consciousness do not emerge from external social interaction but perception of an internal one. ex: 'primordial emotions' like desire, thirst pain etc. signal to the organism that their life is at stake. (Denton, 2006)) Discussions about emergence can also be found in a multitude of discipline such as linguistics (Loreto & Steels, 2007), geomorphology (Harrison, 2001), political science (Waltz, 2010), literature (Hartstock, 2000) and others.

better comprehend one of their most fundamental questions, ‘what is the relationship between the parts and the whole?’ where the answer it seems might be built from sources external to the discipline itself in fields like synthetic and systems biology.

In chapter one I went over a brief history of use of the term ‘emergence’ starting with Lewes but with general concepts predating back to Aristotle. We then looked at proto-emergentism as a counter to reductionism, followed by emergent evolutionism with the rise of Darwinism. This brought us to our current period of neo-emergentism whereby after a quiet time there has been furious debate once more about the different kinds of emergence: weak and strong. Weak and strong emergence are both unpredictable but weakly emergent phenomena are reducible to its lower-level properties whereas strongly emergent phenomena are not. Strong emergence is also fairly controversial in that it has properties such supervenience and downward causation that it has hindered progress on the subject. Therefore, I suggest we refocus our efforts and attention towards weak emergence and characteristics of unpredictability and reduction from higher-level to lower-level elements because weak emergence is compatible with empirical investigation. Compatibility with empirical investigation is important if philosophy wants to engage with scientists. An example of the empirical methods I suggest that show this are synthetic and systems biology. The next chapter will go on to explain the development of synthetic and systems biology in preparation for my utilizing them to take examples of emergent phenomena categorized as strong and show that they are weak therefore altering our ontological, methodological and epistemological information about emergence.

CHAPTER 2
Synthetic and Systems Biology

My goal in this chapter is to describe synthetic and systems biology so that I can use them to develop reductive mechanistic explanations of weak emergence for chapter three. This chapter goes over the historical relationship between synthetic biology and systems biology. Synthetic and systems biology largely use computational power to trace the relationships between higher-level and lower-level phenomena. As a result, they can aid with assembling mechanistic explanations via reduction. I then discuss the use of nodal and chaotic systems in biology and their application to improve computer modeling for reduction. I encourage philosophers of biology to take more interest in synthetic and systems biology as they are increasingly prolific fields within science that can be used to map higher-level relationships (systems biology) to lower-level interactions (synthetic biology). The reduction from higher-level to lower-level phenomena has ontological consequences in terms of how we consider the structure of organisms. Methodological consequences occur in the inclusion of computation for reductionism. Finally, epistemic consequences result as our knowledge of what can be considered emergent is altered due to the reduction by highlighting faults in our predictions of strong emergence. In chapter three I show explicitly how some phenomena considered to be strongly emergent are actually weakly emergent by reduction via synthetic and systems biology to support my theory that the category of strongly emergent phenomena is actually smaller than we believe.

2.1) A Brief account of Synthetic Biology

Consider a watch; while you might not be able to make one on your own or understand exactly how it functions, if I were to take the initial gears needed and assemble it in front of you, winding the springs, fitting the teeth together, demonstrating how certain gear ratios work more efficiently than others, all of this would help you have a better understanding of how the watch works. The point of the watch example is to show that we can know about the watch by understanding how the parts of the watch function. Similarly, for emergent phenomena, we can know (but not predict) how these phenomena occur by being able to reduce them to their lower-level parts. Synthetic biology looks at the micro parts (or genes) of organisms, manipulates them and then analyzes the results which is why it is a useful tool to investigate emergence in living organisms.

While synthetic biology can be applied to numerous organic systems, the approach of looking at the micro (lower-level) of a system in order to understand the (higher-level) macro workings from a regulatory perspective is not uncommon. Synthetic biology is defined as " … [using] unnatural molecules to reproduce emergent behaviours from natural biology, with the goal of creating artificial life" (Benner & Sismour, 2005, p.533). Or as described in another article as " …a research field that combines the investigative nature of biology with the constructive nature of engineering" (Purnick & Weiss, 2009, p.410). Purnick & Weiss continue to explain that "Efforts in synthetic biology have largely focused on the creation and perfection of genetic devices and small modules that are constructed from these devices" (Purnick & Weiss, 2009, p.410). Reflecting on these definitions I offer the following definition for our use:

> *Synthetic biology* is the study of lower-level micro phenomena with a mandate to use molecular biology tools and techniques to engineer cellular and organismal behavior.

The desire to be able to engineer microorganisms has been a goal for centuries but now we actually have the capability to do so (Keasling, 2012). You may recall that a lower (micro) level approach has been the focus in science throughout the neo-darwinian emergence period because of a focus on genetics. Synthetic biology began due to an interest in the molecular level of genome regulation. The ability to conduct these engineering procedures did not become readily available until the turn of the millennium but since then it has become a part of almost every molecular laboratory. Barely a decade old, the expectations for and outputs of this new branch of biological research has almost produced more data than it has researchers to make sense of it (Howe et al, 2008). But, there is a plateau quickly approaching; while we might be able to point to all the parts of the system and verify their genetic signature, we remain stifled in our ability to understand their many overlapping roles and are facing systems with so many feedback mechanisms that the sheer complexity appears almost overbearing. The non-linearity of organic systems is what has allowed for their survival but has also contributed to our inability to manipulate them. To understand how this synthetic micro-level complexity arose we ought to first consider the history of its development as it is relevant to the reductive explanation of emergent phenomena I will give in chapter three.

2.1.1) History of Synthetic Biology

The development of synthetic biology can be broadly outlined as starting with a foundational period during which the experimental and cultural features of the field were established. Afterwards, the discipline moved to an intermediary period defined by an expansion in the field. The field was delayed by a lack of engineering capacity. The lag finally ended in our present state of accelerated innovation because new engineering approaches. Interest in synthetic biology began in earnest after important work by Jacob and Monod (1961) enabled advancement towards practical applications like splicing genomes.

In 1961 their study of the lac operon in E.coli led Jacob and Monod to hypothesize the existence of regulatory elements in the genome (Jacob & Monod, 1961). It would not be until the molecular details of transcriptional regulation in bacteria were discovered that biologists would begin to form a more plausible mechanism with which to actually manufacture these regulatory factors. Technologically, the advent of molecular cloning and polymerase chain reaction (PCR) in the 1970s and 1980s was insufficient to allow for artificial regulation. Automated DNA-sequencing in the 1990s with improved computational techniques meant that complete microbes could be sequenced and their cellular components catalogued. Systems biology was generated from this because scientists and computer engineers were required to collaborate in an attempt to build cellular networks around the turn of the millennia.

The formation of simple gene regulatory units began in earnest in the early 2000s and was based heavily on mathematical modeling. Model based design was exceedingly popular in order to switch certain genes 'on' and 'off' but allowed for autoregulatory negative and positive-feedback modules. Eventually, transcription-based regulation mechanisms would formalize the language and practice of the genetic circuits. Thanks to Weiss and colleagues this led to tracking more sophisticated cell-to-cell communications (Cameron et al, 2014). Towards the end of the decade (2004-2007) there began an exponential increase in scholarship with the goal of whole-genome engineering where fundamental questions related to the standardization of parts and abstraction hierarchies could be mapped onto biological systems.

Technological development from the 2000s found that DNA sequences of proteins can be known via synthetic biology and that this information could then be translated to map how proteins regulate the system. In biology, the regulation necessitates a familiarity with tertiary and quaternary protein folding for micro-analysis. Protein sequencing and folding will be a part of my exposition in the next chapter to re-categorize some strongly emergent phenomena to weakly emergent phenomena. Synthetic biology tools have produced knowledge of the microscale that has helped some to decipher how proteins can interact on a macro scale. Systems biology examines the macro-scale, which is how synthetic and systems biology are related. Next, I will go more explicitly into the development of systems biology since it focuses on the higher-level of interaction where emergent phenomena occur.

2.1) History of Systems Biology

Systems biology was the result of subsequent advancements in computer technologies applied to synthetic biology. It developed from being a branch of synthetic biology into its own discipline while continuing to contribute to synthetic biology discourse. The relationship between the two sub fields of biology while initially hierarchical has actually turned into a more cyclic relationship; systems biology describes the networking relationship between macromolecules (proteins) whereas synthetic biology monitors their occurrence, and genetic sequence. Kitano (2002) says that “To understand biology at the system level, we must examine the structure and dynamics of cell and organismal function, rather than the characteristics of isolated parts of a cell or organism” (Kitano, 2002, p. 1662). Similarly Ideker et al. (2001)

explain that “Systems biology studies biological systems by systematically perturbing them (biologically, genetically, or chemically); monitoring the gene, protein, and informational pathway responses; integrating these data; and ultimately, formulating mathematical models that describe the structure of the system and its response to individual perturbations” (Ideker et al., 2001, p.343). Based on these characteristics, the definition I will use is as follows:

> *Systems Biology* is the study of the network of self-regulated higher-level interactions in biological systems using computer modeling.

Systems biology is the result of an intense period of sequencing and cataloging in synthetic biology which resulted in the idea of organisms made out of intricate hierarchical modules. The idea was based on the strategic rearrangement of micromolecular constituents that founded the basis of systems biology with the involvement of engineers, physicists and computer scientists in the 1990s.

Systems are meant to describe a set (of proteins or cells) that interacts in an organized fashion to carry out an operation while being self-regulated by internal control mechanisms. Topics found in systems-biology can be recognized as far back as the 19th century with whole-organism embryology in the life sciences and network mathematics in the pure sciences. However, there are others (Kitano, 2002) who suggest that the idea of complex interlocking systems in ecology, developmental biology, immunology etc. have been quite established for some time, and that it is only recently that molecular biology and genomics more specifically, have formally incorporated a holistic systems biology approach. In order for systems biology to be self-regulated by internal control mechanisms the lower-level elements of the system must have some relationship with the higher-level networks. The next section will consider how synthetic and systems biology can be used in tandem to account for the entire multi-level system as it exists through time.

2.3) Levels and Time

Let me take a pause here to discuss systems biology as a holistic enterprise. Systems biology looks at the higher-level relationships of a system. In organisms, this can be at the level of the organism and how it interacts with its environment or on a different scale such as the level of protein interaction (as with the initial development of systems biology). In either the proteomic or organism case, the ability for technology to tag elements of the system and track their interactions with other elements is the purpose of systems biology. Notice, that at any higher-level designation of the system, the mapping relationship is temporally sensitive. The relationships amongst higher-level elements like proteins are not instantaneous and usually occur in a causal chain reaction over some period of time (albeit the measurement might be nanoseconds depending on the compound). Different elements enter and interact at specific times at this higher-level of the system allowing systems biology to have a more expansive categorization of the system than synthetic biology alone. Synthetic biology attempts to regulate the generation of proteins (or organisms more broadly) from the micro scale looking at the relationships as a horizontal connection between levels of the system. Systems biology is more holistic because its temporal component relies on a casual reaction that vertically transcends levels. So while synthetic biology can consider the consequences of elements at a singular stratum in some temporal capacity, it cannot consider the relationships and changes in adjacent levels over time. Systems biology has a larger temporal scope of the elements of the sub-levels and higher-levels contributing to multi-level assessment therefore allowing for a more holistic approach. Holism in systems biology is relevant to our discussion of emergent phenomena because isolated reductionism prevents a holistic understanding of the organism exhibiting the emergent phenomena; but, weak emergence can be both holistic and reductive through the use of systems biology and have a causal explanation over time.

Reductionism in both the sciences and philosophy can be defined in multiple ways. Werner (1999) states in *Science* that "Reductionism is the modeling methodology whereby the development and behavior of large (pattern)-scale features are reduced entirely to their underlying fundamental processes" (Werner, 1999, p.102). Similarly, in evolutionary biology Wagner (2000) touches on the historical transition between proto-emergentism and evolutionary emergence by saying "This [complete description of the DNA sequence of an organism] extreme molecular reductionism is the outgrowth of the 19th-century program to mechanize biology, to expunge the vestiges of mysticism from the study of life, and to bring that study within the domain of universal physical law" (Wagner, 2000 ,p. xviii). More relevant to us is Strange's (2005) definition of reductionism as "… the attempt to explain complex phenomena by defining the functional properties of the individual components that compose multicomponent systems" (Strange, 2005, p. C968). I will use the following definition of reductionism inspired by these:

> *Reductionism*: Reductionism is the attempt to trace a relationship between higher-level phenomena, and the lower-level elements that interact to make these phenomena manifest.

The establishment of systems biology suggests a paradigmatic switch in how biological systems are understood. Systems biology suggests a cyclic movement from understanding organisms as environmentally-dependent and interrelated complex systems, to reductive molecular genetic subunits when verifying the higher-level protein interactions, then back to a holistic networked system again. There has been an effort to push for a dual approach: a complexity based, genetically grounded attempt to understand organisms that is sensitive to environmental influence. This approach acknowledges changes at the macro-level that in turn affect the micro-level and cause a re-evaluation at the macro-level once more. This marks the switch away from the exclusive use of micro-level intensive technologies and pure bioinformatics to a more holistic systems approach.

Besides the vertical systems account and the horizontal synthetic account of biological phenomena, there is an additional tension between modeling organism pathways and simulation. Modeling is commonly done by high-throughput technologies (with microarrays)[15] and when used for the reductions that I discuss, is sometimes considered purely theoretical and not necessary or even relevant to understanding 'real biology'. This is because genuine simulations are believed to be based on the higher-order level of the organism. High-throughput technologies are affiliated with micro-level phenomena and limited to that particular-level. Therefore, high-throughput technologies pose great difficulty in extrapolating these results to higher-level phenomena. Alternatively, as systems biology examines a higher-level it has a more holistic approach that can occur at the level of the organism but have relationships that permeate vertically or down through the system.

[15] A high-throughput technology just allows researchers to test a multitude of different active components, enzymes, genes etc. to model biological pathways using data-processing and control software.

My idea of this multi-level description of systems biology in relation to the lower synthetic level being considered as more than just pattern recognition and as a tool for tangential phenomenological modeling is novel. While generally acknowledged that systems are the prolonged temporal result of synthetic biology and envisioned as having a larger scope, philosophers have not described it as a vertical relationship. Luckily, systems biology is quite charitably viewed today because of the richness of data available for model-building. A systems-biology based framework has spread to applications in network-based drug design and adaptive evolution amongst others. The vertical temporally-dependent relationship accessed by systems biology can be envisioned in various ways, but let us consider what generally applies for macro biology.

At minimum there are four general systems in which to consider macro biology: metabolic enzymes, enzymes for energy production, proteins for synthesis and replication proteins (Deamer, 2009). All these systems work interconnectedly so discussions regarding systems and complexity are often linked. Take a metabolic enzyme used either to breakdown other molecules or build molecules necessary for life. A synthetic analysis would have the molecular subunits of this metabolic enzyme traced back to its location on the genome, then to verify the correct location of the genetic sequence that codes for this protein the scientists might alter that location slightly so as to create a change in the resultant protein. The final configuration of the protein, if altered, would help demonstrate the location of the metabolic enzyme and what elements of the genetic sequence are crucial to its formation. A systems approach would focus more on the function of the metabolic protein as opposed to the formation noting the initial interactions that the fully functioning metabolic protein might have, then observe any changes in occurrence and effectiveness thus allowing for a multi-level account of the phenomena. Note that to verify the systems approach it is necessary to have a micro-level synthetic appreciation for the protein since it is at this level that we can modify the protein and test how it functions. The ability to incorporate the lower-level synthetic account of phenomena into the higher-level description of the protein's interaction in a verifiable way is what makes systems biology so appealing empirically and more rich philosophically as it elucidates the parts-wholes distinction. Synthetic biology does not account for higher-level phenomena in the same way.

Let us now consider how the temporal aspect of the synthetic versus systems approach contributes to the limitations of our understanding of how proteins work. I suggest emphasis should be placed on a systems approach in terms of describing weakly emergent phenomena. The characterization of the lower-level protein translation from mRNA is captured as an outcrop of the organism's micro-cellular processes. The re-evaluation of metabolic protein functioning post-gene modification is again another small segment of protein behaviour. If researchers begin to look at how the selected proteins interact more elaborately with other proteins in the organism then this actually begins encroaching on what would be considered a systems approach. This would also require a continuous evaluation and monitoring of interactions so perhaps I should clarify by saying that although both synthetic and systems biology have a temporal aspect, synthetic biology has a more segmented method of observation compared to systems biology which is more continuous and thus, analogous to the difference between a photograph and video. Certainly a photograph can tell you a lot about a subject, but it cannot quite capture the dynamic interactions of the elements, while the video is actually made up of the same fragments as the photograph, just put all together over time allowing for a different understanding of how the elements in the photograph interact. The continuity of systems biology is important because it's what allows for a continuous causal mechanistic explanation in weakly emergent systems.

Thus, the difference between synthetic and systems biology is temporal and dynamic. Synthetic biology is discontinuous and limited to one general level of the system. Systems biology continuously spans several levels of the system which helps establish it as a holistic approach. Next, I will explore how exactly systems biology and synthetic biology can be used to understand higher-level emergent phenomena through the discussion of studying complexity thresholds and making more accurate models using nodal and chaotic systems. This will further refine my notion of temporal and dynamic features as the defining difference between synthetic and systems biology by looking at nodal and chaotic systems that have temporal properties transcendent of any one specific level.

2.4) Nodal Systems

Certain higher-level and even potentially lower-level phenomena contain relationships that are not evenly distributed throughout the system (see figure 1). The uneven number of connections is important to note when considering emergent phenomena because nodal and chaotic elements factor into understanding the causal link between higher and lower-level elements needed for reduction. A real world example might be a busy intersection in the centre of town compared to a slow intersection on the outskirts. The number of cars passing though the main intersection is probably far greater than the number of cars passing through the slow intersection and as a result the number of potential relationships between the intersections and their respective cars is higher

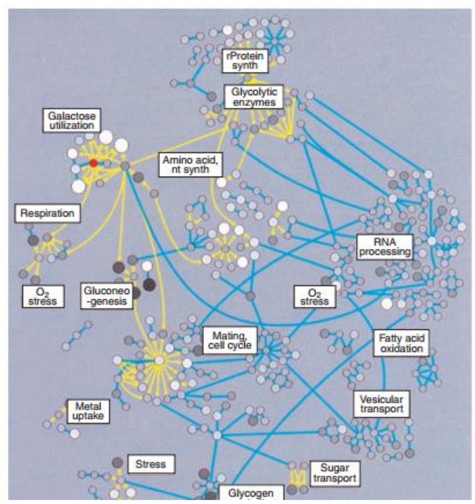

Figure 1: A network perturbation model of galactose utilization in yeast. Note the discrepancy in the number of connections certain proteins involved with sugar transport compared to rProtein synth. (Hood et al., 2004)

in one instance than another. Barabási and Oltvai (2004) describe a node as a degree of connectivity "which tells us how many links the node has to other nodes" (Barabási & Oltvai, 2004, p. 102). Similarly May (2006) explains that "If networks arise by the sequential addition of nodes, and if each new node links preferentially to highly connected nodes, then this results in a SF degree distribution" (May, 2006, p.395). [16] I will use the following definition for nodal systems that is reminiscent of these and other definitions for the remainder of this investigation into emergence.

> A *Nodal system* is one where the relationships amongst elements in the system are unevenly distributed throughout the system so that certain elements have more connections than others.

This creates areas where the network density of the system is dependent on the activity on the element and interactions within its surroundings. In biological systems, proteins commonly have interactions with each other that vary significantly in terms of frequency. For example there are several proteins that can adopt multiple roles depending on the needs of the system. This multi-functional protein process is called protein moonlighting. A real-world example are crystallin proteins found in the eye that allow for its transparency but that has also been found in heart and breast tissue. When considering proteins interacting at a cellular level, the number of relationships crystallins have to other proteins is higher than that of a protein that only interacts in one way. Therefore, crystallins are a more active node.

In systems and synthetic biology being able to recognize and account for nodal systems is important because it makes for better representations of the relationships between elements in the

[16] SF represents 'scale-free' meaning no characteristic number of links per node.

system. Therefore when considering reductive and causal explanations, it is ideal to have a program that accounts for the density discrepancy of interactions, allowing for a more thorough account of phenomena and a more complete mechanistic explanation. In addition to nodal systems being present, the connections between the nodes also need not necessarily be unidirectional or entirely predictable (hence the interest for describing emergence). Bidirectional relationships between nodes are quite common in biological systems for creating potential feedback and regulatory functioning. However, as previously mentioned, the relationship between elements of the system are not predictable, therefore when mapping the relationships or attempting to link higher and lower-level phenomena the complexity of the nodal relations is enhanced by considering the possibility of having chaotic interactions within the system.

2.5) Chaotic Systems

Chaotic systems are the focus of a mathematical field that has applications in sciences like robotics, physics, chemistry and biology as well as humanities like sociology, philosophy, economics and politics among others. We examine chaotic systems as they are crucial components to the ability for synthetic and systems biology to be able to accurately model interactions at both the lower and higher-levels of the system. Boccaletti et al. (2000) who states that the “Control of chaos refers to a process wherein tiny perturbation is applied to a chaotic system in order to realize a desirable (chaotic, periodic, or stationary) behaviour” (Boccaletti et al., 2000, p.103). With this in mind, I will use the following definition, *Chaos theory* is a method of modeling the features of phenomena by examining the dynamics of a system sensitive to the internal and sometimes random perturbations of the system.

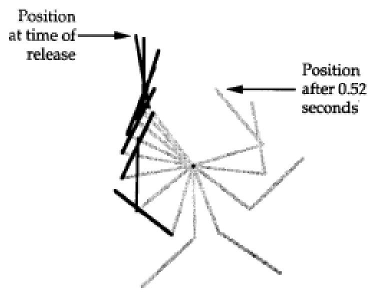

Figure 2: Reproduction of actual stroboscopic positions of pendula (from data, first initial condition, Trial 1). (Shinbrot et al., 1992)

A classic example of a chaotic system is a double pendulum (see Figure 2). A double pendulum is a pendulum with a hinge on the end and a second free-moving pendulum attached. Irrespective of whether the starting conditions of the pendulum is known: (e.g., the length of both segments of the arm, mass, the angle of arm relative to the fixed point of the arm etc.), the final position of the arm is unknowable. A slightly different starting condition would produce widely divergent outcomes making the long-term predictability of any chaotic system impossible. Note the similarity here to the requirement of emergent phenomena to be unpredictable. However, including a variable meant to represent chaos in the system helps in describing the movement of the arm.

Chaotic systems are also deterministic which means that the system's behavior is entirely decided by the initial starting conditions of the system.[17] Organic systems rarely exist where they are isolated from other elements of the environment. What this means is that the system has a purpose without prompt from outside the system. In organisms this might be to continue to self-differentiate oneself from the environment (i.e. continue living), to reproduce etc.

In biology, population models of species use deterministic systems but have now been retrofitted to include chaotic growth patterns which occur in nature. For example, occasionally

[17] Telological emergence is the notion that the emergent phenomena of the system are produced as a result of the system's ultimate end state or goal and relates to the deterministic state of the system. Emergence in this case is directed to be beneficial to the purpose of the system in the most positive case, and epiphenomenal in the least.

populations synchronize in ecological systems. Sometimes these synchronizations of species are detrimental to spatially structured populations but it appears as if phase synchronization might lead to the emergence of complex chaotic traveling wave structures that allow a species to persist over time (Blasius et al., 1999). Thus, as a result of including chaos theory into our systems level mapping programs, our models have improved in accuracy.

For weak emergence, using systems biology with additional chaotic elements programmed into the software produces a more fruitful means for analyzing higher-level phenomena. Hence, the inclusion of chaos theory is to the explanatory benefit of reductionism. Note that in so doing it does not discredit the value of reconciling the small details of the system with the larger scope and external influences on the system which can be modeled by considering chaotic movement within the lower level. Thus, this allows the system to remain unpredictable yet still applicable, with consequences not possibly determined from the initial conditions alone. The nodal elements in the system with their varying degrees of network density combined with the chaotic elements in the system contribute to overall complexity of the system. Complexity is a crucial feature of emergent properties because when a system is sufficiently complex then emergent phenomena are thought to come into fruition. The following section will discuss a bit of the history of complexity and its role in synthetic and systems biology because a threshold degree of complexity is necessity for organisms to exhibit emergent properties.

2.6) Complexity in System Biology

In the same way that nodal and chaotic theories help better inform computational reduction, so does complexity. Both nodal and chaotic accounts of interaction can actually be incorporated into the definition of a complex system though neither is required for it. It seems that contemporary complexity theory might be able to illuminate some of the remaining reductive qualms in emergence though computational power enhanced by increasingly more sophisticated mathematical constructs. Historically, these constructs would ultimately make complexity theory more useful for certain types of scientific explanation as was the case for computer science going back to WWII (Goldstein, 1999).

In terms of computation, early research into cybernetics and information theory did not focus on emergence per se, but it did outline characteristics of complex systems with emergent features; such as nonlinearity, self-organization, movement beyond equilibrium and attractors. These properties would actually go on to define complex systems (aka. Systems theory) which would become the precursor to contemporary complexity theory.[18] According to Barabási and Oltvai (2004) "The behaviour of most complex systems, from the cell to the Internet, emerges from the orchestrated activity of many components that interact with each other through pairwise interactions" (Barabási and Oltvai, 2004, p.103) and so is the case for systems in biology.

In summary, systems theory is the precursor to contemporary complexity theory and differs from the latter by having fewer degrees of interrelated networked relationships between phenomena in the micro and macro levels of the system. Complexity theory uses so much data and interconnected relations that it often requires computational analysis to account for all these interactions. In actuality it should be considered another means of examining phenomena measurably different than its predecessor because of complexity theory's nonlinearity, self-organization, movement beyond equilibrium, and attractors.

Using the definitions of nodal and chaotic systems to build a concept for complexity, I will consider three types of consequences for systems biology before showing how systems

[18] Systems theory is different than systems biology. Systems theory looks at all systems across disciplines and systems biology looks particularly at biology as a subfield using microbiology techniques as investigative tools.

biology can be used to aid in developing a reductive mechanistic explanation of emergent phenomena. The ontological consequences of accepting a systems approach to biology implies that there must be some type of grouping for elements within the system that interact. Methodologically, our assessments of these elements must now be done while considering their connection to other elements in the system when the value of their autonomy is called into question. Finally, epistemologically speaking being able to know something accurately about systems depends strongly on the types of systems we look at. In deciding which ones to study we automatically prioritize and create a hierarchy, valuing certain systems over others when in nature their weighting might be different, if at all relevant.

2.7) Philosophy and Systems Biology

In this section I will look at the ontological, methodological, and epistemological consequences of systems biology. Recall that systems biology looks vertically at the holistic scope of the systems by tracking interactions through time. Systems biology is also subject to empirical observation though use of synthetic biology because we can test our models by altering lower-level elements genetically and then observing the subsequent consequences on the entire system to see what the relationship is between the higher-level emergent phenomenon and the lower-level elements are.

Systems biology has important ontological consequences for how we consider the structure of organisms. If, as suggested, systems biology through the use of complexity-based computer modeling techniques genuinely looks at groups of elements that interact as a collective to motivate higher-level changes, then the elements should not be considered as independent from a descriptive stance. Furthermore, in many biological systems, and proteomics in particular, elements in the system are usually multi-purposed and can perform multiple regulatory functions as mentioned in my description of nodal elements (moonlighting proteins). Therefore, defining the role of the element in the system is increasingly subjective and heavily dependent on the external conditions of the system. Systems biology is designed to account for these inevitable fluxes in the state of the system and while the whole might seems to remain stable, the lower-level elements undergo perpetual change in terms of rate and role within the system. Hence, elements in the system are versatile, but the overall state of the system remains consistently defined towards the goal of the system. The goal of the system transcends the chaotic behaviour of the system and therefore ontologically limits potential states of the system. Thus, if the states of the system are limited then this creates a reasonable methodological boundary on both the potential ontological mechanisms that might allow for emergent phenomena, as well as our investigative techniques.

Methodologically, in order to examine the system as an amalgamation of elements, it would be in our best interest to move from a bottom-up combination of individual elements of the system to a bidirectional top-down and bottom-up approach. With this reorientation of analysis there is a larger emphasis placed on the elements as a web of interactive components and the overall goal of the system whether that be to reproduce, self-differentiate or maintain the system. For nodal systems, this bidirectional approach would allow for a much more generous temporal investigation of phenomena as relationships begin to occur at the higher-levels of the system. The integration of chaotic algorithms into the mapping of elements of the system is better assimilated if recognized throughout the system. Combined under the definition of complex systems the bidirectional approach encourages a complex interpretation of the connections between nodes in the system because it is able to analyze the system from the starting conditions (bottom-up) and from the end point (top-down) creating a comprehensive web for a more inclusive causal mechanism.[19]

Epistemologically, there is a direct relationship between how we anticipate a system to function and how it is related to its lower level parts. This assumption of the type of information we abstract from the research is of course contentious but I will accept that a mechanistic understanding of phenomena can tell us something useful about the causal relationships of the system. The reason why computational analysis was the catalyst that allowed for the creation of systems biology as a field is because of an epistemic limit that prevented our understanding of the plethora of factors that combine to make up biological systems. In the same way that systems biology enhanced the ability for synthetic biology to account for a larger degree of data, it can similarly liberate emergentists from seemingly irreducible systems.

Unfortunately, this added epistemic access results in epistemic biases built into the hardware of the system as well as the degree to which we can appreciate the complexity of the phenomena at higher levels. As we gain more information from synthetic biology about the elements in biological systems we will have increased data to incorporate into our models and the systems proposed will likely have to be increasingly simplified, or even reduced, in order to use them effectively in conjunction with other concepts. Hence, systems biology represents the trend in science that necessitates condensation of data for combining of concepts. Recall the incompressibility I explained earlier under Bedau's notion of weak emergence whereby the

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[19] At minimum there are two concerns with the bidirectional analysis of interaction: that it prevents less sophisticated laboratories contributing to the discussion and that the entire system might be mistakenly truncated (too narrow) or else considered as larger than the actual scope of interaction (too broad) because of an incorrect assessment on our part. A solution to the former would require a concerted effort from the international science community to acknowledge unconventional knowledge construction. The latter might be a perpetual limitation of our ability to design and test phenomena. The sensitivity of our instruments and the definition we assign to what constitutes a complete system is subjective in this respect but is more of a limitation of science as a discipline then the idea of systems per se.

explanation of the phenomena sometimes involves such a complex set of data that the only way it can be reconciled is through computation. In this same way, systems biology is able to compress and compile data to a certain point where a mechanistic reduction can then take place but there is a limit to the compressibility.

In summary, the ontological ability for systems biology to account for the nodal and chaotic elements of the system is superior to a normal reduction because it can recognize more interactions of higher-level phenomena throughout time in a more accurate reflection of their relationship compared to using synthetic biology as Bedau suggests. Methodologically, this alters the modeling approach we adopt suggesting that a bidirectional top-down and bottom-up approach might be more comprehensive. Modeling the phenomena offers us an epistemic understanding of the causal relationships (via condensed data) within the system which is useful in discerning whether weakly emergent phenomena are actually plausible and ultimately threatens to subtract phenomena once considered to be strongly emergent from the irreducible category.

To reiterate, computational analysis as found in systems biology and with help from synthetic biology can aid in explaining the causal relationship between higher-level weakly emergent phenomena and their associated lower-level elements. This is important for the discussion of emergence because computation allows us to describe more higher-level emergent phenomena via reductionism. Since only weakly emergent phenomena are permitted to be mechanistically reducible, any higher-level emergent phenomena that can be described via interactions of their lower-level elements due to computation must be weakly emergent. Therefore, in the next chapter, when I take phenomena categorized as strongly emergent and show that they can be modeled using systems biology computation it suggests that these phenomena are actually weakly emergent and thus open to empirical investigation. This is crucial to our assessment of emergent phenomena because it enables the number of weakly emergent phenomena to grow and can shrink the number of strongly emergent phenomena which shows that there are fewer strongly emergent phenomena then initially conceived.

CHAPTER 3
Strong Emergence Re-Categorized as Weak Emergence

In this chapter I will provide examples of strong emergence from the literature. Then I will show that these examples are subject to reductive mechanistic explanation via computation. These examples are meant to be examples that are generalizable on the basis of the reduction from higher-lever emergent phenomena to lower-level parts. The reduction suggests that weakly emergent phenomena are more common than generally thought and deserve more attention which should prompt us to shift are focus away from strong emergence.

I will use the definitions of emergence I established in Chapter one and its defining features like reducibility and complexity to show it is possible for strongly emergent phenomena to be categorized as weakly emergent due to computational reduction as outlined in Chapter two. I will do this reduction using two biological examples. First I will look at Bar-Yam's (2004) Key & Lock analogy. It is comprised of two parts: a key and lock metaphor which then builds to his actual protein interaction account. Bar-Yam's example will be shown to be reductive based on the fact that once the end quaternary protein interaction is known, it can be mechanistically reduced back to the micro phenomena. Bar-Yam makes fails to see the possibility of reduction as a result of assuming there to be certain limitations on current biochemical technology.

The second biology example is actually just a more sophisticated account of this same sort of protein interaction where authors Boogerd et al. (2005) use several mathematical accounts of the phenomena to show that this alleged example of strong emergence is reductionist in nature. In the latter example I will show where the authors ought to have concluded that their phenomena were weak as opposed to strongly emergent. Therefore the authors make a conceptual mistake. The analysis of these two examples are meant to show that several emergent phenomena categorized as strong actually ought to be described as weakly emergent, substantiating my initial claims that weak emergence is able to account for more phenomena than initially credited and, that as weak emergence is able to use computation as a form of mechanistic reduction subject to empirical investigation. Based on these examples I will discuss how weak emergence and computation relate to the value of knowledge and suggest that this can be generalized to other examples of strong emergence. My examples are taken from systems and synthetic biology which are large fields with several potentially quite similar examples. Also, as technology continues to give us more insight into interactions we can expect that more strongly phenomena become reducible. This will lead to the application of systems biology and weak emergence in empiricism where I will examine the ontological, methodological and epistemological consequences.

3.1) Example one: Unlocking Enzymes

The first example I will look at is Bar-Yam's Key & Lock analogy to begin re-categorizing examples of strong emergence. I will provide background on why Bar-Yam is using the Key & Lock analogy as well as expand some of the details in the actual proteomics part of the example. Since the argument is presented in two parts, after the background I will analyze each part of the argument separately showing how his irreducible assumption in the Key & Lock analogy translates to actual protein interaction and ultimately fails him by being reducible. This failure is important because it will show that strongly emergent phenomena can be reduced to lower-level parts though computational analysis. This demonstrates that the phenomenon is weakly emergent. Computational reduction from higher-level emergent phenomena to lower-level elements combines the algorithmic calculation capacity of modern mathematical software with the multi-level vertical reductive relationships between components in each level.

3.1.1) Key & Lock analogy

The Key & Lock analogy is representative of the sort of examples found in emergence literature. In philosopher Bar-Yam's paper 'A Mathematical Theory of Strong Emergence Using Multiscale Variety' he outlines a mathematical theory of strong emergence and meaningful novel physical states that function only as a collective (Bar-Yam, 2004). Bar-Yam uses the example of protein-protein interaction as a case of a strongly emergent property proposing it to be analogous to the relationship between a key and a door (see figure 3). He uses this to suggest the level of protein interaction as a scientifically meaningful example of strong emergence. His explanation of a lock and door are as follows:

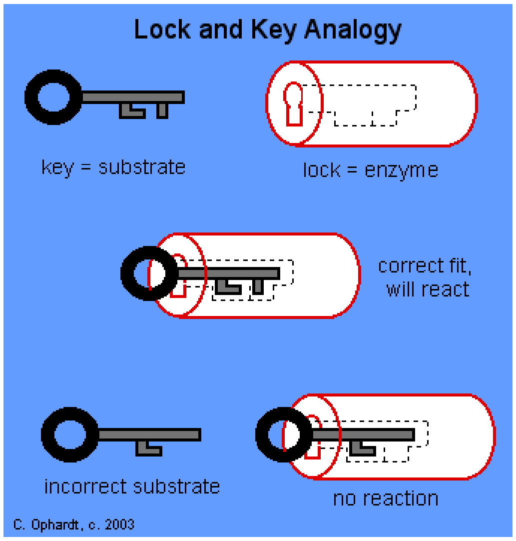

Figure 3: Representation of the Key & Lock analogy to the protein analogy implicitly made by Bar-Yam. (Ophardt, 2003)

> The properties of a key in opening a door are not contained in a description of the parts of the key. Instead they are contained in the relationship between the components of the key and the components of the lock. This relationship is not present in the description of the parts of the key by themselves. We can note that when viewing a system that includes both the key and lock, their relationship is that of a constraint that is not contained in the description of the parts themselves but rather in the description of the relationships between them. Still, in this case the ability of the key to open the door for a particular

> instance can be inferred from the structure of the parts themselves without reference to the ensemble of possible keys and doors. (Bar-Yam, 2004, p. 19)

Bar-Yam intends to represent the relationship between the system and aspects of the environment where the higher-level phenomena of the unlocking and opening of the door is understood entirely based on interaction of the correct key fitting into and turning the lock (a threshold of complexity) to open the door. According to Bar-Yam, the relationship between the key and lock is not present in either the description of the key, the description of the lock, or the combination of the key and the open door or the lock and the open door. Rather, the lower-level elements of the system are the key and the lock. The relationship or interaction between the key and the lock to form a combined unit represents a higher-level degree of complexity than just the key and lock elements, whereby if the correct key and lock are combined then the threshold of complexity is met and as a result an emergent phenomena is instantiated (the opening/locking of the door). However, I will show that contrary to what Bar-Yam assumes about the ability of the key to open the door only being able to be described by the key-lock subunit, it is actually expressed in the most basic elements of the system (the key and lock individually).

3.1.2) From Key& Lock to Proteins

Based on his description of the key and lock being the determining characteristic for emergent phenomena (the open or closed door) Bar-Yam builds an analogous protein example with the substrate being similar to the key and the enzyme acting as the lock. In this instance the interaction between the substrate and enzyme as a functioning unit is the complexity threshold required for the emergent phenomena to occur: whatever the function of this active enzyme is (unspecified in the example). Bar-Yam's protein substrate-enzyme binding example for enzymatic activity is as follows:

> When we consider that even at the molecular level, the behavior of proteins is often considered quite similar to that of a lock and key, with proteins fitting into one another, and enzymatic processes controlled by geometric fitting and chemical binding, the idea of type 3 [strong] emergence as a relationship between the system and aspects of the environment is clearly central to the function of complex systems in the world around us. Such cases are not contained in the descriptions of the parts in isolation, even if their properties can be defined, the relevance of these properties depends on the existence of complementary molecules and substrates in the environment. Thus, even fully described, such relationships are not captured unless information about the environment is included. This is not contained in the conventional discussion of properties of a system as determined by the system itself. (Bar-Yam, 2004, p. 19)[20]

There are few things to note about this example before continuing in the analysis, primarily that although Bar-Yam is right to acknowledge that the relationship between the system and aspects of the environment are crucial to determining the state of the system, this in no way helps distinguish it as a strongly emergent occurrence. Recall that for strong emergence all the information (internal and external) could be known about the system and higher-level phenomena should still be irreducible to lower-level phenomena. Bar-Yam reiterates this "Thus, even fully described, such relationships are not captured unless information about the environment is included" (Bar-Yam, 2004, p.19). This would do fine if it were not the case that in this protein interaction, when all the information about the system is known, that the reduction

[20] His emergence is one of degrees that can be subdivided into either Type A or Type B. My analysis will apply to Type A phenomena which includes two types of strongly emergent phenomena Type 2 and Type 3.

between higher-level macro interactions and micro interactions is not only possible, but is readily done by biochemists using synthetic and systems biology as tools.

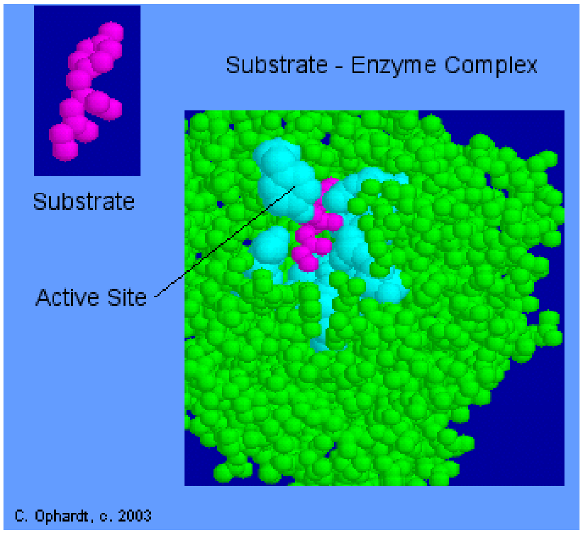

Figure 4: Representation of protein substrate (pink) and interaction with the active binding site (light blue) of the enzyme (green) (Ophardt, 2003).

The substrate enzyme complex, like any protein, is based on a series of aminoacids strung together in a polypeptide chain (see figure 4). There are a finite number of amino acids each with their unique molecular structure. These amino acids can be easily recognized once the protein complex is isolated from the system and assayed – a common high throughput procedure in microbiology as mentioned in chapter two. To verify and make sure the correct number and order of amino acids has been proposed biochemists can use synthetic biology to alter site specific RNA sequences (used to code for these amino acids in translation) and monitor any effect the change has on the system. Of course certain changes might not prove detrimental (e.g., conservative mutation) or occur at a spot on the protein that is not crucial for binding with the substrate. In these cases, there might be little effect on the enzyme-substrate complex; however, if an alteration is made corresponding to the active site or a crucial folding section of the enzyme it can render the protein inactive. The activity of the protein is monitored using systems biology as it maps the relationship of the enzyme to other proteins and can discern if the protein is working correctly (properly folded, functioning active site etc.). Therefore, once the end state (the enzyme-substrate) compound is known then a reduction to lower-level elements of the system is readily possible and able to be investigated empirically.

3.1.3) Consequences of Reductive Explanation

Bar-Yam's Key & Lock analogy and description of substrate-enzyme binding both fail as cases of strongly emergent phenomena because although it may seem as if the higher-level components produce novel irreducible phenomena in the case of the Key & Lock, if the relationship between the open/closed state of the door and the lock is known then determining the type of key to open this lock would be equally as explainable (top-down explanation). Thus the higher-level phenomenon (open or closed door) is reducible to the lower-level elements. Similarly, once the final conformation of the substrate-enzyme is confirmed then a computational systems analysis would show which other elements of the system this higher-order phenomenon is engaged with. Additionally, with a synthetic analysis, the chemical composition of the substrate-enzyme complex can be quantified into each part's respective amino acid sequence and approximate conformation therefore explaining how the complex arrived from the initial RNA sequence.

Hence in terms of emergence, the idea that either the Key & Lock analogy or the substrate-enzyme complex could be considered strongly emergent is highly suspect. Prior to computational reduction, showing how protein composites and interactions are explicable at the atomic level might have been near impossible to explain; but, high-throughput microbio assays are now able to address this relationship and provide an explicit reductive account. This means that there is one less example of strong emergence. This supports my position of strong emergence being susceptible to reduction through computation. Furthermore, it subtracts from the number of strongly emergent phenomena. Next I will show that even with a more sophisticated version of this protein example by Boogerd et al., the protein complex phenomena can still be considered weakly emergent even though it is classified as strongly emergent. In Bar-Yam's case he erred because of his unfamiliarity with the technical limitations of our investigations, not the phenomenon itself. With Boogerd et al., they make a conceptual error that could also be found in other strong emergence examples.

3.2) Example Two: Modeling Proteomic Reduction

In their highly detailed and well researched exploration of emergent phenomena scientists Boogerd et al.(2005) offer cell physiology as an example of strong emergence. They even go as so far as to explain the role of system properties and how biochemical networks that use only mechanistic explanations are still strongly emergent. Boogerd et al. put forward that microorganisms are 'essentially large biochemical networks' with properties such as homeostasis and plasticity that transcend the physical properties of the micro elements in the system but then admit that all cellular phenomena are mechanistically explainable and that emergent phenomena have mechanical effects (Boogerd et al., 2005, p.133). It should be obvious from here that this description is not strongly emergent in the least because it can be described as a reductive mechanism.

To articulate Boogerd et al.'s argument properly I will have to clarify a few of their terms. The authors believe in three basic tenents of weak emergence, the last one being the most important. First is physical monism where the phenomenon is composed entirely of physical entities. Second are organizational (also known as collective properties) properties that the system has but none of the parts have (the emergent phenomena). Third is synchronic determinism where the micro-level of the system determines the higher-level state of the system (a covariance relationship stronger than mereological supervenience alone).

My work here has focused on an explanation of all three of these characteristics discussing how weak emergence is an entirely physical account of self-organizing phenomena that result from a threshold of complexity being met that is unpredictable from the starting conditions but entirely dependent on the lower-level. Instead of looking for similarities in their arguments to that of weak emergence, Boogerd et al. immediately declare weak emergence to be too unattractive a description to account for anything, "Weak emergentism is too weak. All organizational properties turn out to be emergent. And there are many. This shows that the notion of weak emergence is too weak to be useful. We are interested in strong emergence." (Boogerd et al., 2005, p.135). The disregard for the ability of weak emergence to capture and describe phenomena is too rash.

Let us go though some of Boogerd et al.'s assumptions more thoroughly. At the point where the authors speak about the organizational properties of weak emergence they stress that almost all phenomena could be considered weakly emergent. With regards to organizational properties determining weakly emergent phenomena, they claim that weak emergence broadens the category of emergent phenomena to the point where it is no longer a unique type of phenomena. This is an overestimation: only phenomena that are *unpredictable and organizational* could be considered weakly emergent which is considerably less then just all organized higher-level phenomena! Leaving this problem aside, what will ultimately prove devastating for their argument is their synchronic determinism and a horizontal irreducible relationship.

In the upcoming section I will go through the example provided by Boogerd et al. regarding the rate at which enzymes convert substrates to indicate the capacities of the parts and the system as a whole. Boogerd et al. conclude that because the properties of the function can only be categorized in isolation that this leads to capacities of the organism that are indeterminate. I point out that this not problematic for weak emergence but this does not make this phenomena strongly emergent by any accord. It seems to be the case that either Boogerd et al. are using a misinformed definition of strong emergence (one that is mechanistically reducible) or they are in fact just unaware of the viability of weak emergence.

3.2.1) Mechanistic Enzymatic activity

As suggested earlier, the example provided by Boogerd et al. is a more detailed account of the Key & Lock / enzymatic activity example that Bar-Yam puts forward. The two examples differ in that Bar-Yam has a practical error with regards to what we are capable of reducing, whereas Boogerd et al. have a conceptual problem and misuse the term strong emergence. Unlike Bar-Yam who mistakenly assumes the higher-level interactive potential of the enzyme and substrate are irreducible, Boogerd et al. use the seemingly horizontal irreducibility of the rate of the enzymatic reaction to a substrate concentration to state that this phenomena is strongly emergent when it is entirely reducible. In fact, the authors give all the necessary equations (see pages Boogerd et al. (2005) 146-148, 152-153 and 157-159) and effectively model the phenomena but draw the incorrect conclusion.

> The [enzymatic activity] case we described emphasizes the importance of the properties of the parts within the system (component properties), as well as the significance of a rigorous and precise mathematical quantification of mechanical explanations. We combine the roles played by the parts in a mathematical model to yield a description and explanation of the systemic behavior; that is, we describe a mechanical explanation of the systemic phenomenon in mathematical terms. This is a mathematical equivalent of

> what Stuart Glennan introduced as a mechanical model (Glennan, 2002). Having a precise mathematical description allows for a more exact examination of the properties exhibited by the system. (Boogerd et al., 2005, p.154)

A complete mathematical modeling account of phenomena is a reductive one. Calling this phenomenon strongly emergent is just factually incorrect. Hence, this adds another example of strong emergence that is actually weakly emergent.

Again, if phenomenological properties are genuinely irreducible then no prospective increase in scientific knowledge about the system will close the gap between physical qualities and phenomenological states (Boogerd et al., p.137). The complete argument that Boogerd et al. put forward for the strong emergence in cellular biological systems is as follows:

> We will illustrate emergence in cell biological systems, which are both functionalizable and mechanistically explainable. Their properties are describable in terms of the properties and behaviors of their realizers. There is no failure of analyzability in these biological systems. There is emergence nonetheless: knowing the properties the parts exhibit "in isolation" or "in other systems" is sometimes insufficient to predict the properties and behavior they exhibit in this very system. (Boogerd et al., 2005, p. 140)

Notice here that they admit that cell biological systems are functionalizable as used by Kim (e.g., reducible with the exception of qualitative components) and mechanistically explainable, a defining feature of weak emergence. The authors purport that the unpredictable component of the phenomena is what allows it to be thought of as strongly emergent, but unpredictability is a feature of both strong and weakly emergent phenomena. The self-evident problem of unpredictability and accounting for phenomena as a feature unique to strong emergence is a miscategorization of weak emergence. See an excerpt of Boogerd et al.'s argument below where they effectively describe a weakly emergent phenomena but conclude it to be strong.

> We will show that physiological properties can be fully accounted for in terms of system properties of biochemical networks and that this can be experimentally tested through precise modeling of biochemistry. These biochemical networks exhibit organizational properties, ones not manifested at the level of the parts, but which result from the interactions among the parts. Consequently, they should be explained in terms of component properties, which depend both on the properties of the parts and on the state of the entire system. (Boogerd et al., 2005, p.142)

Note the 'physiological properties that can be fully accounted for' phrase. Are the additional properties of the system that are unaccounted for? If so does this not risk a vitalist approach which calls to question using an empirical example in the first place. So the authors begin by effectively admitting that their example is reducible (vertically) which is a core feature of weak emergence but then claim that there are also non-reducible horizontal relationships.

> Although the organizational properties we encounter in biochemistry will always be vertically reducible, there are some cases of non-deducibility if we restrict the deduction base appropriately. Thus, we are able to present cases of emergence from a horizontal perspective. (Boogerd et al., 2005, p.142)

In order to have a strongly emergent phenomenon according to Boogerd et al., the reduction needs either to fail vertically or horizontally. A vertical failure would entail an incomplete mechanistic explanation where the properties and behaviours of the system could not be deduced from the lower-level parts of the system. A horizontal failure would mean the conditions or parts within the whole cannot be predicted from their properties and behaviours in ordered systems. Therefore, if either fails then the phenomena are strongly emergent (and irreducible).

The potentially irreducible horizontal relationship is not problematic for weak emergence because horizontal relationships do not need to be reductive as they do not have a causal relationship to the emergent phenomena and are more akin to epiphenomena. An example of a horizontal irreducible relationship might be from higher-level proteins that interact on this higher-level contributing to the larger complexity of the system but remain reductive to their lower-level elements. Also a horizontal domain restriction to make a phenomena seem irreducible negates the clause of strong emergence being irreducible even if all the information about the system is known since this could include information from different levels of the system.

3.2.2) Closing the Enzymatic Case

The authors go on to consider modular systems and an intermediate level of complexity (p. 155), and conclude that the system depends on the component properties of the modules and while this could have been considered an example of strong emergence exhibiting supervenience, if as they suggest that "the dynamics of the entire system can be explained in terms of the properties of the modules; however, this requires an appeal to the component properties of the modules" (Boogerd et al, p.155) then this is a weakly emergent phenomena. Thus, though something might seem complex and have multiple interconnected level-specific components that have a dynamic feedback relationship, if computational analysis can contribute to the modeling and causal explanation of the system then it is not strongly emergent since the definition of strong emergence demands that the phenomena be irreducible irrespective of how much information is gained from the system. Therefore, even if there is a qualitative change in the system, this does not detract from the still possible reductive quantifiable explanation of the system making any qualitative feature epiphenomenal at best. Which is why when the authors conclude that synchronic unpredictability means that the higher-level systemic property of the system are not predictable, it is not at all inhibitory for weak emergence.

The authors I have used as a sample of the sorts of errors made by philosophers and scientists show two different mistakes: a practical one based on an incorrect evaluation of our computational capacity and a conceptual one based on the standard definition of strong emergence. Bar-Yam mistakenly assumes that the higher-level interaction of the substrate-enzyme complex cannot be reduced to the lower-levels of the system, but this is false. Boogerd et al. believe that protein binding is strongly emergent after giving the reader the explicit mechanistic modeling equations for the phenomena. This is also incorrect. Hence, computational reduction to understand protein folding and rate of reaction in Bar-Yam and Boogerd's examples, respectively, tell us how higher-level emergent phenomena can be traced back down to the lower-level and therefore should be considered weakly emergent. These examples offer a template of how to look for similar miscategorized examples of strong emergence. In the next section I will discuss how our ability to reduce organizational elements in biochemistry of the sort in Boogerd et al.'s example relates to knowledge and understanding.

3.3) Systems and Knowledge

As previously suggested, systems biology is becoming ubiquitous in the natural sciences and is highly relevant to our knowledge and understanding of complex systems. As a discipline, philosophy must consider what role systems analysis plays in revealing the relationships between parts and wholes as seen its application to emergent phenomena. My work here aims to formally continue to establish systems biology and synthetic biology as avenues to continue emergence research.

Systems biology models are built based on our understanding or ability to recognize and note interactions between micro-elements and their combined effects on the overall macrosystem. I put forward that weakly emergent phenomena that use computation as part of the reduction process encourage a greater understanding of the system by producing additional knowledge of the system. Here knowledge and understanding are not mutually exclusive with the later growing exponentially as additional relevant micro-level information of the system becomes available through synthetic biology research. Without systems biology though, there is a risk that we will increase only knowledge of phenomena without understanding because we would acquire only factual propositional knowledge (micro-level synthetic biology) in absence of objective knowledge from the macro-level (systems) that frames the capability of the micro interactions as a whole.

In the next section I discuss how weakly emergent phenomena are valuable ontologically, methodologically and epistemologically. In particular the knowledge gained from computational analysis of the sort used in synthetic biology and systems biology more specifically is more scientifically productive because the reduction of macro-level phenomena to micro-level phenomena is quantifiable and verifiable. Furthermore, the causal relationship between lower-level phenomena to produce higher-level phenomena also contributes useful knowledge about the ontological construction of the world and our philosophical assumptions about empiricism.

3.4) Philosophical Consequences for Emergence

Let us consider how weak emergence and systems biology apply together to be subject to empirical investigation. As previously mentioned weakly emergent phenomena use reductionism to describe the causal relationship between higher and lower-level phenomena. The continuity of this relationship allows for empiricism to test the intermediary stages of the relationship in a way that reinforces the likelihood of its plausibility (as seen in the horizontal and vertical systems assessment). Alternatively, because strong emergence does not have this reductive relationship between higher and lower emergent phenomena, it is not empirically viable. I will now go over the ontological, methodological and epistemic features of using computational reduction for weak emergence to illustrate why it is relevant for philosophers and not just scientists.

3.4.1) Ontological Features

Ontologically, the combination of systems biology and computational reduction allows for both a theoretical and practical approach to investigate weakly emergent phenomena. Emergent properties have new causal powers that are reflected in the laws that connect to lower-level properties. The novelty of these weakly emergent phenomena is not merely temporal but a fundamental type of property seen specifically at certain levels. The laws at the emergent level are fundamental and as a result are not reducible to the laws at the lower-level of the system even given the ideal boundary conditions. In terms of strongly emergent systems the emergent phenomena have both same-level and lower-level effects through downward causation that might help accommodate for the irreducibility of laws. But, weakly emergent phenomena again need not worry about this concern and can have reductive laws, or lower-level laws that build to higher-level phenomena. The integrative levels of organization that weak emergence has between levels of the system are fortified through the use of computational reduction because it aids in quantifying the material as seen through the rate reactions that Boogerd et al. use as part of their methodological mechanistic explanation (even though they draw the wrong conclusion about emergence).

3.4.2) Methodological Features

Using computational reduction to evaluate weakly emergent phenomena alters the methodological procedures of the system to focus on finite empirical observations. The methodology of discovery represents the process of generating new ideas under the goal of solving (providing a full mechanistic explanation) for the system.

There are criticisms of course, for example suggesting that because the computer cannot devise new concepts it is limited to the concepts of the computer language and any phenomena that cannot be addressed using this will be excluded from evaluation. While this is true, it is a criticism that occurs in any attempt to account for phenomena whether philosophically, linguistically or empirically, etc. Therefore, we must take this as a given as with any epistemic evaluation and be aware that there might be other ways to investigate the phenomena and propose solutions to the problem and focus on the reductive ability of weak emergence.

3.4.5) Epistemological Features

Generally, when considering the difference between the epistemic merit of conceiving and validating a theory, computational reduction can be exceptionally useful. Compared to other pursuits, the systems approach and take on computational reduction allows us to purposefully use systems models from other systems as part of the model and subsequent reduction. While the macro-level of the phenomena are likely at the organismal level of the system the reduction can remain within a biological framework down to the micro-level (proteomic) or arguably extend even further (chemical, physiochemical and lastly atomic and sub-atomic). If this is the case, then the computational reduction actually needs to include modules from other disciplines to account for system's behaviours. Therefore, computational reduction in systems is able to transcend a particular discipline and contribute to connecting our various epistemic approaches.

The combination of systems biology with weak emergence offers substantial epistemological consequences as found though the exposition of the value of knowledge and understanding. Weak emergence with only synthetic biology (as Bedau suggests) offers a view of emergence focused too exclusively on reductionism and risks the relationships amongst micro-level phenomena being prioritized over that of the macro-level. This risks assigning value only to lower-level elements which would be incomplete since the higher-level emergent phenomena can contribute substantially to the overall functioning of the system. This is where Bedau suggests that weak emergence is best able to utilize advancements in computation to produce more factive propositional knowledge. His view of incompressibility is involved here as computation is able to help distill highly complex interactions into the requisite reductive relationships between higher and lower-level phenomena. Without computational assistance it might be too difficult or even impossible to gather this information. I propose that systems biology founded as a sub-discipline of synthetic biology is on par with, if not better than, synthetic biology in terms of its ability to map relationships and as a result has a greater epistemological consequence.

In summary, there are ontological, methodological and epistemological consequences to using a computational systems approach to understanding weakly emergent phenomena.

Ontologically we can recognize emergent phenomena and trace causal connections between levels. Methodologically, computational systems and systems analysis can help in the justification of these ontological elements and levels. Epistemologically, a systems approach requires an interdisciplinary approach and can contribute to knowledge of how the higher and lower-level phenomena work. Thus examples of emergence in biology systems, and weak emergence more broadly, are worth further philosophical investigation especially because the consequences I suggest as an outcome of a systems analysis is one method of reduction but it need not be the only one.

3.5) Is Systems Biology the only answer?

While I have professed the merit of a systems approach to learning more about emergent phenomena via use of reduction in weak emergence, I should be clear that it is not the systems network that gives this argument its strength, but the reduction. Hence, the systems approach with computation is currently the most efficient means but not necessarily the sole one. So long as the mechanistic reduction is possible, it allows for weakly emergent phenomena to persist and remain compatible with empiricism.

Computation aids in reduction when there are so many elements at the macro-level that a reduction to the micro-scale would be too time-consuming or difficult that it could not be done without the aid of a modeling program. Note that it may be the case that once the computational reduction has outlined how the micro-level relates to the macro-level in causal terms it might be possible to do the reduction without the aid of a computer. Were that the case, one might argue that the computation isn't necessary but the reduction still is. So for this reason the reductive relationship between higher order and lower-level elements of the system is still paramount.

Hence, while a systems approach is a better means than synthetic biology as proposed by Bedau because it helps in the reduction, it is the reduction itself that gives the argument its strength and I have simply suggested a better way to perform this reduction.

In conclusion, embedding systems dynamics as a mechanism to further the reductive potential of weak emergence offers additional knowledge about how emergent phenomena relate to lower-level elements. The combination allows weak emergence to have ontological and epistemological merit and in so doing changes the methodology of investigation. In addition, the causal relationship between higher-level and lower-level elements allows for weak emergence to be compatible with empiricism. However, systems dynamics are not the only means to investigate weak emergence. It is the heightened reductive potential that systems offers weak emergence that makes the argument compelling; yet, any way to further the reduction would be beneficial so it need not be computational systems.

3.6) Summary

My discussion into the possible methods for elucidating the reductive relationship between higher-level phenomenon and lower-lever interactions in weak emergence builds on Bedau's latest endeavour discussing the feasibility of weak emergence. Bedau suggests that synthetic biology through the use of computation is the best means for performing the reduction in biological systems since at some point there is an incompressible amount of information that can be accounted for through computation. He advocates for the use of computation when the number of events involved in the macro level are too complex for an unassisted human to account for with the phenomena. I propose that synthetic biology is a useful tool, but that systems biology is a better approach. Systems biology has a holistic view of higher-level interactions that synthetic biology cannot encompass. Systems biology is more able to account for external influences on the system while modeling the respondent flux in the system and vice versa. Furthermore, systems biology has the important computational aspects of approaches like synthetic biology built into its models. Therefore, it is a more detailed and versatile account of the phenomena.

Systems biology is subject to empirical investigation. A systems approach needn't apply exclusively to biology but it can be used for any system that has a multitude of lower-level elements that combine to form higher-level phenomena, irrespective of discipline. Note that a systems approach need not necessarily be an unpredictable approach but for the sake of the discussion about emergence, it is.

Ontologically combining the reduction found in weak emergence with systems biology is a means to try and comprehend how components interact in nature. This is a more readily reflective account of these phenomena as they naturally occur since they are rarely found in isolation and more often as a cooperative whole. Epistemologically seeing the higher-level components of the system as an interwoven structure where relationships emerge as a result of lower-level interactions might be conceptually difficult to grasp. Part of this is due to the sheer number of elements involved in conjunction with the number of tertiary connections they have not only to other elements in their level but other elements in parallel levels. Therefore having a mechanism with which to evaluate and account for this multitude of connections makes reduction a plausible contribution to the epistemic usefulness of weak emergence. Methodologically, having a systems approach requires access to technology that the systems approach thrives on for the computational aspect. In this respect, systems biology is exclusionary in terms of who is able to access the reduction of some weakly emergent phenomena.

Furthermore, since systems biology uses a multi-modal network approach it might cause theorists to focus on systems that have this quantifiable degree of complexity which might overlook systems that are complex in a different way or insufficiently complex altogether. If this is a legitimate concern, then perhaps these other systems are better suited to fit under a different non-emergent framework.

In conclusion, systems biology is a method for mapping reductive relationships in weakly emergent systems. I have shown that some situations deemed strongly emergent are actually weakly emergent when the 'irreducible' aspect of the phenomena is investigated using computation. Therefore, since some strongly emergent phenomena can be re-categorized as weakly emergent phenomena, the number of strongly emergent phenomena is actually smaller than previously thought. Systems biology uses a verifiable methodology that is compatible with empirical investigation and can include a holistic account of the situation where other methods like synthetic biology alone are limited. I have put forward practical definitions of weak emergence, strong emergence, reductionism, synthetic and systems biology as well as nodal and chaotic systems based on historical accounts to explore the possibilities that computational reduction has in describing emergent phenomena. In so doing, I have offered actual examples of the re-categorization of strongly emergent phenomena using computational biology and a systems biology approach. Therefore, I propose that a systems account of emergent phenomena should be made wherever possible to have the most comprehensive account of unpredictable relationships and ultimately aid in giving weak emergence the epistemic, ontological and methodology claims it has long sought. Ultimately, the systems computational approach will show that weak emergence can apply to more phenomena than originally proposed but more importantly, that the number of phenomena considered strongly emergence is shrinking if not inevitably obsolete.

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