CATEGORY THEORETIC REPRESENTATION IN ARTIFICIAL LIFE

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ABSTRACT

CATEGORY THEORETIC REPRESENTATION
IN ARTIFICIAL LIFE

Ceylan, Oğuz Deniz
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This thesis suggests that category theoretic representation is suitable for modeling life. The efforts in the field of artificial life is towards building living systems from non-living ingredients or towards building models of living systems. Living systems, are thought to be different from non-living systems in certain ways. Throughout this thesis, the ideas on how living systems differ from non-living systems or whether they differ or not have been discussed. The idea of life, as a common pattern of functional relations has been presented. Accordingly a model of life, shall be capable to represent such relations in a sensible formalism. Category theoretic representation well suits in representing functional relational domains, such as life and could be beneficial in efforts to model life in artificial life.

Keywords: Artificial Life, Relational Biology, Category Theory

ÖZ

YAPAY YAŞAMDA KATEGORİ KURAMSAL TEMSİL

Ceylan, Oğuz Deniz
Yüksek Lisans, Felsefe Bölümü
Tez Yöneticisi: Doç. Dr. Aziz Fevzi Zambak
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Bu tez, yaşamı modellemek için kategori kuramsal temsilin uygun olduğunu önerir. Yapay yaşam alanındaki çabalar, canlı olmayan bileşenlerden canlı sistemler inşa etme yönünde veya canlı sistemlerin modellerini inşa etme yönündedir. Canlı sistemlerin, belli bazı yönlerden canlı olmayan sistemlerden farklı olduğu düşünülegelmiştir. Bu tez boyunca, canlı sistemlerin, cansız sistemlerden ne şekilde farklı olduğu veya farklı olup olmadığı üzerine düşünceler tartışılmıştır. Ortak bir fonksiyonel örüntü olarak yaşam fikri tanıtılmıştır. Buna uygun olarak yaşam modelleri, bu ilişkileri anlaşılır bir formalizm içerisinde temsil edebilmelidir. Kategori kuramsal temsil, canlılık gibi fonksiyonel ilişkisel alanların temsiline oldukça uygundur ve yapay yaşam alanında canlılığın modellenmesi yönündeki çabalarda faydalı olabilir.

Anahtar Kelimeler: Yapay Yaşam, İlişkisel Biyoloji, Kategori Teorisi

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CHAPTER 1

INTRODUCTION

When we look throughout the world we inhabit, we witness plenty of phenomena. We are capable of determining patterns in phenomena, and accordingly we associate phenomena comprising similar patterns with other phenomena that also exhibit similar patterns. Accordingly, our tendency is to group particular phenomena with similar patterns as the instants of a common abstraction. The abstraction, then, becomes a label of commonly shared patterns. Both Jupiter and Earth for example, are instants of the abstraction “planet” or both jeans and shirts are of the “clothing”. These are in no way fixed structures. For example the sun is not a planet, but both Jupiter, Earth and other planets and sun are “celestial bodies”. “Living things” is such an abstraction, the instants of which exhibit common patterns. Yet, we may specify further detailed patterns and make abstractions within living things, such as “kingdoms”, “phylums”, “species”, “cats”, “dogs” and etc.

In terms of daily usage of language and communication, the employment of abstractions usually are not problematic. We often achieve our aims in this context, when we refer to something as being alive. Just as Wittgenstein’s concept of the family resemblance of games, we have an intuitive understanding of what a living being is and about their similarities.

In comparison with many other phenomena, living things are peculiar and more interesting. As such, they have often roused the desire to precisely define them, and with the quest for precision, the abstraction ceases to be unproblematic. What life precisely is, is still a question that has not been satisfactorily answered.

It especially becomes problematic in terms of the instants that are close to the borders of the area that is covered by the concept, i.e. close to the area between the living and non-living. For example, whether viruses are alive or not is often debated. According to the definition of life, the viruses may or may not be considered as alive. When exactly a person should be considered dead, again depends on the definition of what it is to be alive. According to our choice for what the concept shall encompass, there may be life in another planets, or may not. For example, if we would find a metabolizing but not self-reproducing bacteria in outer space, we may well have found life in outer space, if life does not necessarily be self-reproducing. If it has to be, then, there still does not exist any concrete evidence for life in outer space.

The conceptual clarification of life, essentially is an assertion of how life differs from non-life. By determining the characteristics of life, we thereby form two sets. The members of the first set "life", are phenomena which exhibit those characteristics. The members of the second set "non-life", are phenomena which do not. There are two points to be underlined. First, no complete list of such characteristics exist at this moment. Second, even if it existed, the question of how come there exists two different sets of life and non-life is still to be answered. Historically, three different ways to answer the second question has been determined. They are called vitalistic, mechanicistic and organicistic views.

Vitalistic views assert that living beings and the non-living beings, are fundamentally different such that they are composed of fundamentally different substances. The living beings are often thought to embody a substance called a vital force, a soul or many others and it is on behalf of that substance, life differs from non-life.

Mechanicistic views, deny the existence of such substance. They broadly assert that the living beings and the non-living beings are not fundamentally different. Living beings are nothing more than the workings of their internal machinery, like a clock. In terms of the difference between the living and non-living, older mechanicistic views assert that living beings are directly created by a superior intelligence such as a god, unlike a clock which is created by humans. More modern mechanicistic views which do not employ god, deny the existence of such difference between the living and non-living beings.

The third type of view is called organicistic. Broadly, these views deny the ontological existence of a substance on behalf of which the living beings are living. Ontologically, organicistic views are closer to mechanicistic views, in terms of affirming that living beings are indeed living on behalf of nothing other than their constituent's mechanical (physico-chemical, electrical and etc.) interactions both with other constituents and with the organism's environment. Contra mechanicism, their answer to question of how come living beings being different than non-living is that, the living things realizing a common dynamic in terms of their constituent's interactions. This dynamics are often underline a different class of systems than the simple non-living systems, i.e. complex systems with nonlinear system dynamics. The living, broadly is some specific organization of matter which realize the dynamics.

The following chapter broadly surveys these three different views. In chapter 3, a concrete field which concerns itself with life, called Artificial-Life (A-life) has been presented. In A-Life, creating life from scratch or building life-like models to study life are aimed. In terms of the three views on life presented in chapter 2, A-Life holds organicistic views. An artificial organism, on which there is a wide consensus that it is alive, has not been fabricated, from inorganic matter, up to this day. On the other hand, A-Life has shown itself to be powerful in modeling living beings and their dynamics. Three examples of theoretical models, which help to assess biological theses, has been given. The examples are random graphs, Boolean Networks and a computer program RAM, which challenge biological theses in molecular and behavioral biology.

As such, this thesis does not aim to assert a definition of life or tries to explain how life could have been emerged from out of non-living components but aims to contribute to this modeling aspect of A-Life. Modeling, in this context, has been understood in terms of the "modeling relation" (Rosen, 1991) which has been presented in the 5th chapter. Modeling relation asserts that there is a positive correlation between a models success and its congruence with the natural system that it aspires to model. Congruence in this context, means the capability of the models inferential structure to mirror the natural system's dynamics and its inferential structure.

Therefore, in the 4th chapter, some important features of the biological phenomena, i.e. what is to be modeled, are presented to imply congruent model features in 5th chapter. In terms of two examples of biological concepts, the metabolism and the gene, it has been shown that there exists a difference in terms of functional information, when underlying biological processes of a metabolism are evaluated in isolation on the one hand and in terms of functional parts of the organism as a whole on the other. Many information about processes becomes revealed, only when they are evaluated in reference with the metabolism as a functioning whole. As being a biochemical reaction network, the function of a metabolism can be defined as the sustainment of the biochemical reaction network of itself. As such, many biochemical processes can be thought of as a metabolism, if they realize this function. As metabolism, life may also be thought of as a multiply realizable, functional phenomenon. A self-organizational example of a functional definition of life is presented, which is called autopoiesis (Maturana & Varela, 1980).

Functional properties are often thought to be emergent and multiply realizable. Both emergence and multiple realizability can be employed to construct arguments against reductionism in the sense that a property being nothing other than the result of its material constituents' properties. Liquidity of water has often been given as an example, as in liquidity not being existent at the level of atomic components of a water molecule; hydrogen and oxygen. As such, liquidity is emergent at the level of molecular collections, and as it is not only water but many different molecules can realize liquidity, it is multiply realizable.

Reductionism branches out, as ontological reductionism, methodological reductionism, epistemological reductionism and etc. Also, it further branches out, as in theoretical or explanatory reductionism stemming from epistemological reductionism. With such abundance, which type of reductionism being attacked may not be clear. In terms of life sciences, the recent understanding of reductionism is explanatory reductionism in the sense that a phenomena being mechanistically explicable in terms of component properties and component interactions. In the light of this definition of reductionism, a concept of emergence is presented. Emergent features in this context, are the features which are indeed caused by mechanistic interactions of its components and component properties, under specific organization of the components (Wimsatt, 2008). To make this concept of emergence clearer, two processes which are thought to be emergent are presented, the liquidity of water and benard convection cells. They are both emergent, but they differ in the amount of their possible decompositions which preserves the functional information. The first one has many more number of different decompositions in which the components preserve liquidity, whereas the most if not all decompositions of the latter loses functional information. As such, in terms of the level of its dependence on the organization of its components, the latter convection cells are highly emergent, whereas liquidity is less emergent.

Emergence presented as such and explanatory reductionism in the sense that a biological phenomenon depending on its material constituents properties, their organization and their interactions are agreeable with each other. If a biological phenomenon is highly dependent on the organization of its material constituents, it is highly emergent. As such, with the proviso of organization, the phenomenon is reducible to its underlying constituents. It is no doubt that a particular convection cell formed by a particular molecules or a particular biological phenomenon is the result of the interactions of its material constituents and the constraints imposed by their organization. It is called token-token reductionism, and both emergence and multiple realizability does not have important implications for this type of reductionism.

Though, most of the biological phenomenon are multiply realizable, as convection cells can be formed in almost all fluids. As types of processes, they are realized by different material constituents. As such, we may form an analogy with functional constructions of human engineering, such as a car or an amplifier. The functions of many different materially differing amplifiers are the same. Therefore, amplifying function may be mapped into its constituent functions. Different amplifiers then, do realize a specific functional relationships map. For systems built by humans, it is almost always the case that functions are individuated on structural components. A resistor within an amplifier is a structural component with a specific function. As such, human made systems can be disassembled to their structural components, reliably to their functional map. Unfortunately, it is almost impossible to do so, in complex natural systems. Functions of an organism is dispersed throughout its billions of material components, including hierarchically and horizontally entangled sub functions which are also distributed throughout. Life is an extremely emergent property in terms of its dependence on organization. As being such, life may be better represented as functional relationships of components, which are understood as functional components. The aim of this thesis is not to put an effort to explain how functions emerge from structure. Its aim is to assert that life as a network of extremely entangled functions realized in different mediums, can be congruently represented in a formalism in terms of functional relationship of functions.

The most famous type of decomposition in the history of science, has not been a function preserving one. It may be called the Newtonian decomposition, in which the systems under investigation are thought to be a collection of structureless particles moving from state to state under dynamical laws. As such the system is solely described in terms of the states in which those particles are in. If the system in question has functional properties dependent on the organization, the Newtonian decomposition would not preserve those functions.

In the 5th chapter, the approach of relational biology has been presented as a tool to model life. The term "Relational Biology" has been coined by the theoretical physicist Nicholas Rashevsky (1899-1972). Rashevksy, before relational biology, was interested in the physics of biology. In time, he thought that the physics of biology lied not in the physical properties of the matter but lied in the organization in which the matter interacts. As such, he believed, in terms of biological phenomena, the abstract organizational aspect of it should be inspected, rather than the particular material structure of such organization. Relational biology, then is the investigation of the abstract organizational and dynamical features of biological phenomena in terms of their functional relationships. Though Rashevsky was the forerunner, his student Robert Rosen (1934-1998) developed relational biology in its full. He offered a category theoretic formalism, in which many organizational features of biological phenomena can be represented. In terms of the modeling relation which has been presented in the 5th chapter, he offered the category theoretic formalism as a formalism which more congruently encodes a complex system such as a living being than the Newtonian formalism of structureless particles under fields of force. He claimed that many relations such as the functional ones in living beings can be fulfillingly represented in the category theoretic formalism. Basically, category theory is a high level of abstraction in mathematics, such that many different structures in mathematics can be encoded in the category theoretic formalism and that they can be described and represented in the language of a single formalism. In category theory, a category consists of objects and morphisms; the relations between objects in category theory. As such, many different mathematical structures, such as sets, topological spaces, groups can be encoded as objects of a category and accordingly the relations between them can be encoded as morphisms such as set functions, continuous functions and group homeomorphisms respectively. In terms of its objects and morphisms between objects, category theoretic representation exhibits a rich relational structure to represent the highly relational abstract structure of living things.

CHAPTER 2

THREE TYPES OF VIEWS ON HOW LIFE DIFFERS FROM NON-LIFE

"What is life" is a question which has been rousing interest to answer it, for ages. The conceptual clarification of life, successful or not, almost always meant to define how the living things are different from non-living things. There exists many definitions of life as such. Though definitions are abundant in their specifics, three main types of understandings on life can be determined according to their similarities and differences. They are called the vitalistic, mechanicistic and organicistic views on life. Not all detailed definitions of life nicely fall into one of these categories. Some definitions, while might be considered as belonging to one group in some aspects, might also be considered as belonging to other group in its other aspects. Therefore, there exists more detailed types, such as ontological mechanicism, materialistic organicism, anti-reductionist mechanicism, emergent materialism, naturalistic vitalism and etc.

2.1. Vitalism

At its simplest form, vitalism asserts that the fundamental difference between the living and the non-living is that living things embody a kind of a substance which is by its nature different than the substances out of which the non-living things are made out of. The substance is not matter as far as non-living things are made out of matter, it is thus, a vague substance. Since its vagueness, it has been defined by various concepts like, a force, a fluid, a soul, a property or etc. As it is negatively defined as non-something, say non-matter, vitalism has often been criticized by not being scientific enough, that it is not amenable to experimentation and that it does not posit any testable hypotheses', since science operates under the laws and principles of matter and energy. The counter concept to vitalism has often been mechanicism. Many biologists or philosophers of science or historians point to the division between vitalism and mechanicism as one of the main fault lines in life sciences.

Vitalism's lifespan has been long. An early vitalistic view has often been attributed to Aristotle. Vitalistic views were still around, such as Hans Driesch's and Henri Bergson's views, in the 19th and early 20th century. In such a long lifespan, vitalistic views changed so much that it might be difficult to recognize two views as both being vitalistic (Normandin & Wolfe, 2013). Though being traceable to antiquity; vitalism today is still not dead, it is much alive in the debates in artificial life (A-life). As A-life's purpose is to create living systems from non-living constituents, the difference between living and the non-living is of interest, and vitalism is basically an account for this distinction.

2.1.1. Was Aristotle a Vitalist?

Aristotle, may or may not be considered as a vitalist. The reasons why he may or may not be considered a vitalist, further clarifies what vitalism is and what it is not.

Aristotle thought that living things are the things which possess certain functional characteristics, such as reproduction, sensation, appetite and etc.[1] According to Aristotle's physics, natural bodies has natures. These natures are the efficient causes of that bodies, which are identified with the "form" or "essence" of the bodies (Code, 1987). As such, the soul is the form; it is the essence of the living beings which is responsible for the characteristics of them;

> The soul is the cause or source of the living body. The terms cause and source have many senses. But the soul is the cause of its body alike in all three senses which we explicitly recognize. It is (a) the source or origin of movement, it is (b) the end, it is (c) the essence of the whole living body. That it is the last, is

[1] Listing properties/characteristics to delineate the living is common. These kind of explanations are claimed to be suffering from the fact that the properties/characteristics they posit are either too encompassing that certain things which are never thought of as alive becomes living, or too strict that certain things which are considered as alive would not count as living things. These claims evaluate the truth value of a definition of life in reference to our intuitive understanding of life. The truth of our intuitive understanding of life has already been assumed.

> clear; for in everything the essence is identical with the ground of its being, and here, in the case of living things, their being is to live, and of their being and their living the soul in them is the cause or source (Aristoteles, 2008).

As such, according to Aristotle, living things are living because they are endowed with a soul. Therefore, Aristotle was a vitalist. Though, when the Aristotelian concept of soul is further scrutinized, whether his view is vitalistic or not becomes doubtful.

According to Aristotle, "the soul is inseparable from its body" (Aristoteles, 2008), but it is also an unnecessary question to ask whether they are one; "It is as meaningless as to ask whether the wax and the shape given to it by the stamp are one, or generally the matter of a thing and that of which it is the matter" (Aristoteles, 2008). Aristotelian soul differs from the theological understanding of a soul by not being a separate substance. Though this does not necessarily goes against vitalism.

What goes against vitalism emerges from Aristotle's analogy of the soul with the sight of an eye;

> Suppose that the eye were an animal-sight would have been its soul, for sight is the substance or essence of the eye which corresponds to the formula, the eye being merely the matter of seeing; when seeing is removed the eye is no longer an eye, except in name-it is no more a real eye than the eye of a statue or of a painted figure (Aristoteles, 2008).

As such, it seems that for Aristotle, soul is more like a functional, an organizing principle of a body (Grene & Depew, 2004), as in sight is of the eye. In this sense, Aristotle comes closer to being an organicist or holist rather than being a vitalist.

The conceptualization of the Aristotelian soul is rooted in his physics in which the distinction between the form and matter is of prime importance; the bodies are composed of matter and form, and soul is the form of the living, unlike Descartes' bodies which are simply extension which possess nothing, no form, no soul whatsoever, and accordingly their actions are accounted by principles of extension, i.e. mechanistic principles (Code, 1987). This Aristotelian distinction between the form and matter is also the hypothesis on the shoulders of which the field of A-life stands on. In A-life, it has been presupposed that an organizational form of "life" exists, which is shared by all the living.

One might, of course, assert that positing anything other than matter and motion is in fact being vitalistic, whether one calls it a function, an organization of the matter, a form or a soul. This assertion might be true for cases where what is posited, i.e. form, is taken to be ontologically existing. Yet, what has been posited could have been posited for epistemic purposes and can be denied an ontological existence. For example a question might be asked to the A-life scientists that whether they are positing the form as an ontological existence on its own or for epistemic and pragmatic purposes. Hans Driesch, a self-affirmed vitalist, claimed that the “entelechy” on behalf of which the living beings are alive, belongs to the nature in a purely logical sense. The meaning of to belong to nature in a logical sense is far from clear. It is then true that as far as one explicitly refers to an ontological existence of something that the living matter is alive because of that something, one gets in the chamber of vitalism, however the nature of that something or the way in which it interacts with matter is defined. Aristotelian soul, as being inseparable from its matter, excludes the possibility of an ontological existence on its own, yet by being as such, its power in being a causal explanation of life has been debated and often been found teleological.

In this sense, Nicholson, distinguishes three different types of vitalism, in its historical unfolding (Nicholson, 2010). They are animistic vitalism, somatic vitalism and naturalized vitalism (organicism). In animistic vitalism, what makes matter living is a vital something which enters into the body and gives its aliveness. In somatic vitalism, what is vital and the material body are not two distinct entities, but instead what is vital is somehow intrinsic to the matter. In naturalized vitalism (organicism), what is vital is the organization of the matter. Aristoteles views, then might be considered as somatic or naturalized vitalism.

2.1.2. Vitalism of Hans Driesch

Hans Driesch were one of those who think that Aristotle’s theoretical biology were throughout vitalism (Driesch, 1908) and he is an important figure in the history of biology. He was an experimental biologist and he is taken to be at the forefront of what has been told to be neo-vitalism. Concerning morphogenesis, the development of an egg to an adult being, he claimed that;

> No kind of causality based upon the constellations of single physical and chemical acts can account for organic individual development; this development is not to be explained by any hypothesis about configuration of physical and chemical agents. Therefore there must be something else, which is to be regarded as the sufficient reason of individual form-production (Driesch, 1908, p. 142).

He defines this "something else" as "entelechy".

> We shall not hesitate to call by its proper name what we believe we have proved about morphogenetic phenomena. What we have proved to be true has always been called vitalism, and so it may be called in our days again. But if you think a new and less ambitious term to be better for it, let us style it the doctrine of the autonomy of life…and let that factor in life phenomena which we have shown to be a factor of true autonomy be called Entelechy… (Driesch, 1908, pp. 142–144).

What Driesch made out of entelechy was "an immaterial, regulating agent that determines which of the various potentialities resident in the developing organism become physically realized, and which are restrained" (Nicholson & Gawne, 2015) and indeed according to Driesch; "Entelechy is an agent sui generis, non-material and non-spatial, but acting "into" space, so to speak; an agent; however, that belongs to nature in the purely logical sense in which we use this word" (Driesch, 1914, p. 204).

The logic of experiments that he carried out by which he reached his conclusions, related to the experiments of another biologist, Wilhelm Roux who might be considered as a mechanicist, is as follows.

Roux (W. Roux, 1974), destroyed one of the blastomeres[2] of a frog egg. The blastomere which was left intact, instead of a becoming a full embryo, became a half-embryo. Thus, Roux concluded, the further divisions of the blastomeres, is dependent on the whole aggregate structure of two blastomeres (For if otherwise it would have been developed into a full-embryo even from a single healthy blastomere). He thought that the whole content of the two celled structure would disperse to the 4 celled structure and so on and

[2] After the first divison of a fertilized egg, each one of the two cells are called a blastomere.

so forth, and thereby it will form a compartmental, a mosaic structure which is formed out of parts, as in a machine. This is the reason why his intervention or any other intervention would result in a different outcome than the natural development. A development of an adult from an egg, from the first division of a fertilized egg to the last, according to Roux, is a mechanical step-by-step process depending on the initial conditions of the embryo.

Driesch (Driesch, 1974) was able to show that this was not the case. He was able to demonstrate that complete, though smaller, see urchin embryos would develop from two separated blastomeres. As such, from the part, developed the whole, which a machine is not capable of (Allen, 2005), and this is a contradiction if the compartmental, mosaic theory of Roux were taken to be true. Thus according to Driesch, his experiment proved that the mechanicistic theory of morphogenesis was false. He referred to the see-urchin embryo as an instant of what he called a harmonious-equipotential system. Driesch later left the field of experimental biology. His views are often referred to as a textbook example of vitalism.

Today, vitalistic views no longer seem to be seriously entertained. Mechanicistic explanations of biological phenomena became so successful that, vitalist challenges to mechanicism are thought to be easily dismissed (Ruse, 2013). Frances Crick, who discovered the structure of a DNA molecule together with James Watson went as far as stating that ones who will believe vitalism to be true in the age of modern biology, are nothing other than cranks. “To those of you who may be vitalists, I would make this prophecy: what everyone believed yesterday, and you believe today, only cranks will believe tomorrow” (Crick, 1966, p. 99).

Though not being seriously entertained, some underline that vitalism, in its attack on mechanicism, had a point in the sense that crude mechanicistic explanations are weak in fully capturing important biological phenomena. Vitalism, with its pressure as such on mechanicism, was beneficial in the extension of the mechanicistic views to cover the dynamic, complex nature of biological systems (Bechtel, 2013).

Driesch thought that given individual form production cannot be explained by physical and chemical actions i.e. mechanistically, there must be something else which is responsible from the form production. Neglecting its conclusion, the antecedent of Driesch's thought has indeed been fruitful, mechancistic views have been expanding to cover complex phenomena of life. The bottom-up approaches in A-life are an example. Bottom-up methods are means for achieving complex phenomena by letting the phenomena emerge from lower level interactions since the direct mechanicistic path to phenomena is absent.

Moreover, Driesch's conclusion is ontological in the sense that it asserts the existence of something, whereas the antecedent of the conclusion is epistemological in the sense that form production cannot be explained by physical or chemical interactions. From an epistemological antecedent, an ontological conclusion follows, which should not be necessarily the case. The epistemic irreducibility of biological phenomena, is something that could be worked on, and being advanced in the fields such as systems or theoretical biology, A-life and etc.

2.2. Mechanicism[3]

Mechanical Philosophy[4] can be thought of as a philosophical view on how the universe works. It emerged during the 17th century, as an opposing worldview to Renaissance Naturalism (Westfall, 1977). Galileo, Kepler, Descartes, Gassendi, Boyle, Newton and many others contributed to the understanding that the workings of the universe are mechanical in nature and they are mostly transparent to reason, which in turn lead to scientific revolution.

In his widely known Cartesian substance dualism, Descartes first separated god as the true substance in the sense that not being dependent on anything else for its existence

[3] The same concept has also been called "Mechanism" or "metaphysical Mechanism" or "materialism" (Gilbert & Sarkar, 2000) or "mechanistic philosophy" or "mechanical philosophy". "Mechanicism" has been chosen from the terminology of D.J. Nicholson.

[4] The coinage of the phrase "Mechanical Philosophy" has been ascribed to Robert Boyle ((S. Roux, 2017).

(Descartes, 2008). The Cartesian dualism often referred though is not the one between the god and everything else. Excluding god, Cartesian dualism asserts that there are two fundamentally different substances. Res extensa and res cogitans as in extended, unthinking thing versus unextended, thinking thing. On the synopsis of his Meditations on First Philosophy, Descartes writes; "we must conclude that all things we clearly and distinctly conceive as different substances, as mind and body are conceived, are indeed substances really distinct from each other…" (Descartes, 2008, p. 10)

Descartes assigns principal attributes to these two substances, extension such as in length, depth and etc. to res extensa and thought to res cogitans. There existed no attribute common to both. We can "have two clear and distinct notions or ideas…provided we are careful to distinguish all the attributes of thought from the attributes of extension" (Descartes, 1984-1991, p. 211). This separation of the two realms, resulted in the exclusion of everything organic, mystical or occult from the material nature, to the realm of the mind. The nature which was formerly animistic, became a materialistic one, and that nature turned out to be simply extension. As such, the material nature was matter and motion, being subject to the necessity of mechanical laws. It has been put in motion by god, but there needed be no will to keep it in motion, it endowed no active principles, sympathies or etc. (Westfall, 1977). The movement of the bodies, being part of the material nature, are no exclusion, they are no different than machines, only that the bodies have been created by god.[5] The movement of bodies would

> not seem at all strange to those who know how many kinds of automatons, or moving machines, the skill of man can construct with the use of very few parts, in comparison with the great multitude of bones, muscles, nerves, arteries, veins and all the other parts that are in the body of any animal. For they will regard this body as a machine which, having been made by the hands of God, is incomparably better ordered than any machine that can be devised by man, and contains in itself movements more wonderful than those in any such machine (Descartes, 1984-1991, p. 139).

[5] Excluding humans. Humans differed from other living beings which are machines by possessing a mind in addition to their body. Yet their bodily movements were also capable of being explained by mechanical interactions.

2.2.1. Mechanicism as a Philosophical Worldview vs. Mechanicism as a Methodology

As a philosophical worldview, mechanicism asserts that the world, including everything in it, is basically matter and motion which is subject to mechanical laws. It is possible to take an agnostic stance on this worldview, or even take it to be false, but still explain phenomena in the universe in terms of mechanical interactions. As such, whereas the philosophical worldview comprises an ontological commitment, mechanicism as a methodology does not necessarily have to carry the ontological load of the philosophical worldview. As such, it may be called methodological/ epistemological mechanicism.

Both the recent and the past literature is abundant with the above type of segmentation of mechanicism. J.H. Woodger as early as in 1929, points that;

> we have two fundamentally different kinds of mechanism. The first is dogmatic and metaphysical in the sense explained because it professes to say that the organism is a machine, whereas the second makes the more modest claim that science is only possible if it adheres to mechanistic explanations, but it abstains from making any statement about the ultimate metaphysical nature of the objects of biological study. This, then, is a methodological basis (Woodger, 1929, p. 230).

Garland E. Allen makes a distinction between the Mechanism which is the philosophical worldview and the mechanism which is operative and explanatory (Allen, 2005). The operative and explanatory mechanism in this context is the mechanism behind some biological phenomena, such as the interactions between the neurotransmitters and the receptors, resulting in an action potential (Allen, 2005). Das Chene defines two aspects of mechanical philosophy as a mechanism as natural ontology and a separate mechanism as a method of explanation (Des Chene, 2005).

The separation between two different understandings of mechanicism seems appropriate. Yet, according to the way in which one defines what an “explanation” is, the philosophical and methodological mechanicisms can either be completely independent from or somehow dependent on each other. If a definition of “explanation” comprises that it is a way to depict reality, one’s choice of method of explanation then foreshadows one’s ontological commitments. If explanation, on the other hand, is defined in such a way that it is totally independent of the reality and says nothing of its true nature in-itself in a Kantian fashion, then methodological and philosophical mechanicism can be considered as totally independent.

The criticisms are often directed against mechanicism as a philosophical worldview. The worldview has been thought of as a frame in which science is being carried out and that the methodologies and practices of science has been chosen to suit that frame. As such, considering science, we might be operating only in a small subset of a wider space of possibilities. Richard C. Lewontin, thinks that "the ur-metaphor of all of modern science, the machine model that we owe to Descartes, has ceased to be a metaphor and has become the unquestioned reality: Organisms are no longer like machines, they are machines." (Lewontin, 1996, p. 1) and this results in general that the metaphors hold "science in an iron grip and prevent us from taking directions and solving problems that lie outside their scope" (Lewontin, 1996, p. 1). From the epistemological perspective, functions of organisms can be explained in mechanical terms, organisms can be like machines in some aspects, yet from the ontological perspective, assuming that they are machines, could scientifically set us back.
Before the rise of the mechanical worldview, the foremost physiological school was the galenic physiology. It was mainly composed of animistic explanations of bodily functions, blended with some mechanical concepts such as flow and etc. The blood was thought to be comprised of natural spirits, vital spirits were thought to be flowing out of the left ventricle of the heart, vital spirits were thought to be being converted to animal spirits in the brain (Westfall, 1977).

With William Harvey and Giovanni Borelli during the 17th century, more mechanistically inclined explanations for biological phenomena have emerged. Harvey and Borelli were philosophical vitalists; but they sought mechanical explanations for biological functions. They were holding different ontological and epistemological commitments, in the light of the philosophical vs. methodological mechanicism distinction.

Giovanni Borelli, under the scope of what is to be called iatromechanics, studied the movements of various animals in terms of the behavior of simple machines; “the operations of animals are carried out using instruments and mechanical means such as scales, levers, pulleys, winding-drums, nails, spirals, etc." (Borelli, 1989, p. 2) but, the living beings, unlike machines, had a soul;

> everybody agrees that the principle and the effective cause of movement of animals is the soul. The animals live through their soul and keep moving as long as they live. When dead, i.e. when the soul stops working, the animal machine remains inert and immobile (Borelli, 1989, p. 7).

On the other hand, Harvey, while he was presenting the pump like workings of the heart and the circulatory system under mechanical conditions, was not excluding that the blood was qualitatively spiritual, and that it comprised a vital principle (Westfall, 1977).

From after 17th century, the quest for providing mechanical explanations for bodily functions took off. Until the mid-19th century, they were often in the form of analogies to simple mechanical devices. During the 19th century, the explanations which were also comprised of chemical and electrical interactions started to surface. Around the later 19th and early 20th century, mechanical investigations in embryology were directed towards the fertilization of an egg cell and the development of the embryo. The middle and late 20th century witnessed the rise of mechanistic explanations in genetics, population genetics, neurobiology, biochemistry and molecular biology. Some mechanistic biologist of the above mentioned periods were Stephen Hales (1677 – 1761), Antoine Lavoisier (1743 - 1794), Henry Dutrochet (1776 - 1847), Francois Magendie (1783 - 1855), Emil Du Bois-Reymond (1818‑96), Ernst Wilhelm von Brücke (1819 – 1892), H.Ludwig von Helmholtz (1821‑94), Carl Ludwig (1816‑95), Wilhelm His (1831 – 1904), Wilhelm Roux (1850 – 1924), Stephane Leduc (1853 - 1939) , Jacques Loeb (1859 – 1924), Ronald A. Fisher (1890‑1962) and etc. Some examples of their mechanistic methodologies and explanations of biological functions are, as follows;

- Wilhelm His, described the process of neurulation[6] in vertebrate embryonic development, by the pressure exerted by the ectoderm from the sides, in terms of how rubber sheets fold under lateral pressure.
- Jacques Loeb, explained parthenogenesis[7] in terms of physico-chemical variables such as the ionic concentrations of the fluids in which the eggs reside.
- Stephane Leduc's attempts to synthesize living beings from out of chemicals.

Nicholson sums up mechanicism as having four tenets;

> 1. The commitment to an ontological continuity between the living and the nonliving, exemplified by the quintessential mechanistic conception of organisms as machines, analogous and comparable to man-made artefacts
> 2. The view that biological wholes (i.e., organisms) are directly determined by the activities and interactions of their component parts, and that consequently all properties of organisms can be characterized from the bottom up in increasing levels of organization
> 3. The focus on the efficient and material causes of organisms, and the unequivocal repudiation of final causes in biological explanation
> 4. The commitment to explanatory and methodological reductionism in the study of living systems (Nicholson, 2010, p. 21)

Whether this list overlaps with what mechanicism in fact is, is on debate. Robert Brandon claims a line has to be drawn between mechanicism and reductionism (Brandon, 1996). He claims a mechanismic approach affirming the top-down characterization of properties as well as bottom-up exists, without reductionist commitments. A mechanicism as such, contradicts with the 2nd and 4th tenets of Nicholson's above mentioned four tenets of mechanicism.[8]

Mechanicism in the context of methodological mechanicism is a hot topic in the recent philosophy of biology which may be called "the new mechanistic philosophy" (Skipper

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[6] Neurulation is the process by which the neural plate in vertebrate embryos fold on itself and become a tube.

7 Perthenogenesis is the development of an egg without fertilization.

[8] A mechanicism divorced from its reductionistic commitments, can easily be called organicism. (See chapter on organicism)

& Millstein, 2005)[9] or “the mechanismic program” (Nicholson, 2012). Discovering mechanisms for biological phenomena, according to Wimsatt, has been the major methodology in biology; "At least in biology, most scientists see their work as explaining types of phenomena by discovering mechanisms, rather than explaining theories by deriving them from or reducing them to other theories..." (Wimsatt, 1976, p. 671). In this context, there are various definitions on what a mechanism is in recent literature. According to Machamer, Darden and Craver, "Mechanisms are entities and activities organized such that they are productive of regular changes from start or set-up to finish or termination conditions" (Machamer et al., 2000, p. 3). This definition includes activities of entities in addition to entities which is a step towards the understanding of the relational aspect of biological entities. The importance of relations and interactions of constituents is indispensable in organicist theories, yet as seen in Machamer, Darden and Craver’s definition, it is not incompatible with mechanicism. Bechtel and Abrahamsen, define mechanism as "a structure performing a function in virtue of its component parts, component operations, and their organization" (Bechtel & Abrahamsen, 2005, p. 423). In this definition, again, organization, in addition to components and their operations are declared in virtue of which a function exists. According to Glennan, a mechanism for a behavior is "a complex system that produces that behavior by the interaction of a number of parts, where the interactions between parts can be characterized by direct, invariant, change-relating generalizations" (Glennan, 2002, p. 344).

According to the types of definitions of what a mechanism is, the mechanismic program can be divided to three (Levy, 2013). According to Levy, there exists causal definitions of mechanisms, which asserts causal relations exists, in terms of mechanismic interactions. The second type is the explanatory mechanism definitions, which underlines that explaining a phenomenon is to give a mechanistic account of it. The last one is the strategic mechanism, which implies holding of a strategic position in the sense that, it takes into

[9] This is a misnomer according to Nicholson ((Nicholson, 2012), for it might imply a false connection between the new methodological mechanicism with the mechanicism as a philsophical worldview.

consideration of the cognitive capabilities in terms of the utility of a method for explanation.

Though it has often been the philosophical/ ontological mechanicism which has been criticized, the methodological mechanicism has also its critics. A major line of criticism concerns that there is a distinction between what is called to be a machine mechanism and a causal mechanism[10], which is often not recognized by the authors of the new mechanismic program (Nicholson, 2012). According to Nicholson, the machine mechanism is the “internal workings of a machine like structure” (Nicholson, 2012, p. 153) which ontologically exists whereas the causal mechanisms are concerned with "A step-by-step explanation of the mode of operation of a causal process that gives rise to a phenomenon of interest" (Nicholson, 2012, p. 153), which are ontologically non-existent heuristic tools which are abstractions.

An implication of Nicholson’s view can be that there is one single machine mechanism and many causal mechanisms concerning an organism. As such, a particular mechanistic explanation, say a metabolic cycle, is a causal mechanism which is an abstracted heuristic tool. But the machine mechanism; “internal workings of a machine like structure” can only be said to exist at the level of whole organism.

Moreover, as organisms are heavily in contact with their environment, exchanging matter and etc., an ontologically existing machine mechanism of an organism has to include the internal workings of the environment as well. This is basically the Gaia Hypothesis, claiming that the planet itself is a self-regulating organism.

Nicholson’s claim that all the mechanistic partial explanations are abstractions from the whole organism also implies that they are necessarily incomplete. Brandon, finds in this incompleteness the real power of mechanistic explanations reside. According to Brandon, as no exhaustive list of mechanisms at the level of organism exists, the mechanistic

[10] Ruse also makes a similar distinction (Ruse, 2013).

scientists are almost always on the quest of finding one and thereby increasing our knowledge in the biological domain (Brandon, 1996).

Another line of criticism comes from the fact that the definitions of what a mechanism is in the new mechanismic program, are insufficient in the sense that they lack to include cyclic, simultaneous character of these mechanisms. The definitions often underline that the processes are sequential, yet in fact biological processes are full of feedback loops and etc. (Bechtel, 2011).

2.3. Organicism[11]

The vitalistic and mechanicistic conceptualizations of life has been emerged to account for the difference between the living and non-living beings. For vitalists, being alive is on behalf of some metaphysical life force. For mechanicists, the difference between the living and the non-living is only in appearance, both systems are material systems which are of same class. The division between mechanicism and vitalism has almost been the greatest theoretical separation among the theorists and practitioners of life sciences. The third way of conceptualizing the living beings which can be called organicism, is a resolution between these two views. Broadly, the organicist accounts take living systems to be material systems just like non-living systems, which differs from them in their organization. As such, the investigation of such systems necessitate different epistemological tools.

2.3.1. Pinpointing Organicism In Between Mechanicism vs. Vitalism

Organicism comprises some features of vitalism and mechanicism and rejects some other features of both. First of all, organicism is a materialistic stance, unlike vitalism. Life depends on physical conditions, instead of being caused by some non-materialistic life-force.

> …however unintelligible physically the phenomena of life may be, yet these phenomena can be shown by experiment to depend on what are admitted by the vitalists to be physical conditions in the environment. It is therefore these

[11] Also known as wholism or holism.

> physical conditions which determine the phenomena of life, though how they do so is totally obscure for the present... Vitalism is thus a quite unsatisfactory hypothesis, both ultimately and from the standpoint of scientific advance. (Haldane, 1929, p. 74).

In this manner, organicism differs from vitalism; organisms in organicism are physico-chemical systems, just like machines and other systems. This is also the feature it shares with mechanicism.

Though, organicism differs from mechanicism. Broadly, organicists assert that living systems are; though being materially equivalent with non-living systems in terms of being a result of physico-chemical interactions, are systems of peculiar organization.

> The vitalists can, however, retort, and on conclusive grounds, as we have already seen, that the mechanistic theory of life is equally unsatisfactory, since it gives no account of the co-ordination which is characteristic of all vital activity, and leads investigators to ignore the co-ordination. (Haldane, 1929, p. 75) and that a biologist deals with what can only be interpreted generally as the specifically co-ordinated and persistent phenomenon which we call life (Haldane, 1929, p. 85).

In organicist thinking, living systems are different types of systems than say simple machines, in their organizational and extremely relational character. The organicist motto; "The whole is more than the sum of its parts" underlines this feature. For living systems, it is often the case that the whole organism has such novel properties that those properties are nowhere to be found in the parts in isolation, but they emerge from the interactions and relations between the parts. In life sciences,

> analysis, which teaches us the properties of isolated elementary parts, can never give us more than a most incomplete ideal synthesis; just as knowing a solitary man would not bring us knowledge of all the institutions which result from man's association, and which can reveal themselves only through social life. In a word, when we unite physiological elements, properties appear which were imperceptible in the separate elements. We must therefore always proceed experimentally in vital synthesis, because quite characteristic phenomena may result from more and more complex union or association of organized elements. All this proves that... their union expresses more than addition of their separate properties (Bernard, 1949, p. 91).

At this point, another feature of organicistic thinking has been implied. In organicistic views, scientific analysis and reductionism are thought to be themselves not sufficient to describe biological phenomena. Organicists, as Bernard, assert that some simple systems can indeed be described by the aggregation of the descriptions of their individual parts, yet, living systems are not amongst them because of their highly relational character. For such systems, analysis must always be accompanied by synthesis, since life sciences are interested in functions and behaviors which emerge from the relational domain of constituents. Another organicistic feature results from this as well. Even though organisms are nothing but physical and chemical systems, life sciences are not reducible to physics or chemistry;

> we have seen, and we still often see chemists and physicists who… try to absorb physiology and reduce it to simple physico-chemical phenomena. They offer explanations... which harm biological science in every case, by bringing in false guidance and inaccuracy which it then takes long to dispel. In a word, biology has its own problem and its definite point of view; it borrows from other sciences only their help and their methods, not their theories (Bernard, 1949, p. 95).

Organicists also underline that for living systems, the properties of the parts are contextual, which means that the descriptions of the parts have to refer to the whole (the functional properties of the constituent parts are often understood in context within the whole; e.g. a heart being a pump-like unit only within a body), but in turn, the description of the whole is dependent on its parts. As such, to describe the whole we must refer to parts but to describe the parts we have to refer to the whole. Again in Bernard's words,

> proscribing experimental analysis of organs means arresting science and denying the experimental method; but, on the other hand, that practising physiological analysis, while losing sight of the harmonious unity of an organism, means misunderstanding the science of life and individuality, and leaving it characterless (Bernard, 1949, p. 90)

Another organicistic viewpoint is that, the living bodies consist of billions of interacting parts and that these parts are organized in hierarchical segments. Accordingly, the conceptual tools to investigate different layers are different. The concepts to investigate an individual cell can be of no help in investigation of interactions between a group of cells, say between tissues. Also, for organicists, the system is completely relational that it is not completely possible to identify the parts of a system in the way that one can identify the parts of a machine. In a machine, it is easier to map an individual function to an individual part, whereas in living beings, functions are distributed amongst parts. What has been considered as a part in biological research, say a "gene" is only an abstraction, a conceptual tool in some level of analysis in biological research.

In the light of the abovementioned characteristics of organicistic views, Bertalanffy (Bertalanffy, 1932) defines of an organism as

> a system consisting of a large number of different parts, organized in hierarchic order, in which a large number of processes are ordered in such a way that, through their continuous interactions within wide borders, with a continuous change of substances and energies, the system stays, even when disturbed from outside, in its own state, or it builds up that state, or these processes lead to the generation of similar systems (Bertalanffy, 1932; Drack, 2015)

Some prominent organicists were J.S. Haldane (1860 – 1936), E.S. Russell (1887, 1954), J.H. Woodger (1894 – 1981), L.V. Bertallanfy (1901 – 1972) and J. Needham (1900 – 1995) and etc. Organicist views, then, could be described as an ontologically mechanicistic approach. Though, they differ from simple machines in their features, such that a simple reductionist account of analysis would not do justice in investigating these features. As such, according to many, the life sciences would cultivate science further in its methodology, in an effort to account for, in addition to simple physical systems, the peculiar biological systems.

2.3.2. Some Criticisms against Organicism

Organicism is often confused with vitalism and being criticized as being a form of one.[12] This outcome can be expected because, organicists almost always refer to the "organization" of material systems on behalf of which the living systems are living. The nature of this concept of "organization" has often been left undefined or lacking clarity. Most of the organicist has openly criticized vitalistic views and wrote many paragraphs to assure their readers that they are not referring to an existence of some metaphysical entity. For example, Claude Bernard who is an organicist, claimed that what we call vital

[12] Coining the term naturalistic vitalism for organicism, as Nicholson (Nicholson, 2010) does, exacerbates this tendency.

properties are only the ones that yet cannot be reduced to physical and chemical, (Bernard, 1949). But concerning the organization, he refers to

> a special force in living beings, not met with elsewhere, presides over their organization; but the existence of this force cannot in any way change our idea of the properties of organic matter, — matter which, when once created, is endowed with fixed and determinate, physico-chemical properties. Vital force is, therefore, an organizing and nutritive force; but it does not in any way determine the manifestation of the properties of living matter (Bernard, 1949, p. 202).

These types of paragraphs are often become the reason why the organicistic views are accused of being in fact vitalism in disguise. According to Nicholson and Gawne, two generations of organicists had made use of the concept of organization in two different ways (Nicholson & Gawne, 2015). The first generation thought organization as an axiomatic root on which explanations can be build whereas second generation was insistent on the concept organization itself needed further clarification.

From its confusion with vitalism, stems other criticisms such as organicists denying scientific methodology in investigation of living beings. This is a false assertion, as almost all organicist underline the importance of scientific methodology. As an example, Von Bertalanffy (Bertalanffy, 1930) asserts that “The organic wholeness is neither a metaphysical concept nor an asylum of ignorance, but a problem which can and must be investigated with the methods of exact science” (Bertalanffy, 1930; Drack, 2009). What organicist propose in this matter is the expansion of scientific methodology to comprise living beings.

Another criticism is that in organicism, the demarcation of living systems as opposed to non-living is not fully apparent at all. Organicists assert that living systems, by having novel features and properties in reference to its parts, differ from other systems. But this might also be the case for some non-living systems. Consider features of a computer, which cannot be mapped on its individual parts. For example what John Stuart Mill indicates about the phenomena of life, not excludes and can also be told for a sufficiently complex material system which is not living;

> all organized bodies are composed of parts, similar to those composing inorganic nature, and which have even themselves existed in an inorganic state; but the phenomena of life, which result from the juxtaposition of those parts in a certain manner, bear no analogy to any of the effects which would be produced by the action of the component substances considered as mere physical agents. To whatever degree we might imagine our knowledge of the properties of the several ingredients of a living body to be extended and perfected, it is certain that no mere summing up of the separate actions of those elements will ever amount to the action of the living body itself (Mill, 1973-74, p. 371).

The cyclic relationship between the parts and the whole which organicism advocates has also been criticized (Hein, 1969). As such, the descriptive dependency of parts to the whole and whole to the parts has been labeled as a “logical dilemma imposed by their(organicists) holistic orientation” (Hein, 1969). She thought the solution of such dilemma can only be “mystical” (Hein, 1969), but in fact living systems are abundant with such cyclic mechanisms.[13]

There are also worries about the potential effects of the organicist importance put on the organismic whole, while choosing a methodology of research (Brandon, 1996). Brandon thinks that the assumption can lead to a methodology which refuses taking the organism apart because of the distinctive information being then lost. This research then, according to Brandon, has no potential to refute the holistic assumption. Given that the commitment of organicists to scientific methods, the worry seems to be redundant.

In asking what life is, we thereby try to draw its conceptual borders, as opposed to non-life. As presented, the answers may told to be falling into one of the three categories. The modern scientific assumption is that life emerged from non-life. Then, when thinking of what may help to find an answer to the question, one of the first thing that comes to mind is to look for how non-life transitions to life. As such, there is a field which aims to synthesize life from non-life. It is called Artificial Life (A-life).

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[13] Robert Rosen, thinks that these cyclic mechanisms are, not only abundant, but the distinctive feature of living systems (Rosen, 1991).

CHAPTER 3

ARTIFICIAL LIFE

Life has been always a great subject of interest. From Aristotle's concept of soul to Descartes' mechanisms, or more modern versions such as autopoiesis (Maturana & Varela, 1980) there have been a great number of accounts and explanations which try to shed light on what life is.

A-life also concerns itself with the subject of life. It is an interdisciplinary study, which includes; and have many implications for; the fields such as molecular and theoretical biology, computer science, physics, philosophy and etc.

A-life studies life and processes which are characteristic of living systems. The difference between A-life and biology which also studies living systems is that whereas biology concerns itself with naturally occurring living systems, A-life focuses on human-made systems and processes. Some of these processes which naturally occur and are being modeled by A-life are self-organization, self-reproduction, evolution, metabolization, emergence and etc.

A-life can be categorized according to the medium in which the models are trying to be built. They are called hard, wet and soft A-life, in which the building blocks are hardware such as steel and plastics, organic materials and the virtual environment of computers respectively (Bedau, 2007). To exemplify, the research on artificial cells might be categorized under wet, Lipson and Pollock's (Hod Lipson & Jordan P. Pollack, 2010) robotic life forms in the manufacture of which biological processes has been used might be categorized under hard and Tom Ray's Tierra, in which self-replicating computer programs which simulate organisms as they populate the environment of a computer memory and consuming CPU time as a resource under soft A-life. Another categorization of A-Life can be made in terms of the biological level of the phenomenon which is being modeled. The models may be at molecular, cellular, organismal or population levels (Taylor & Jefferson, 1993).

The formation of the field of A-life stands on a hypothesis (Bedau, 1992). It is that according to A-life scientists, there are fundamental principles of life, which are essential in nature and shared by all the living beings. For A-life scientists, “life”; as a generic noun, "is in itself a legitimate object of scientific scrutiny" (Rosen, 1999, p. 6), just as a living system is. With such a hypothesis, the method of A-life research becomes apparent; to find what is essential, one must abstract away from different physical systems which are already known to be living, build models according to those abstractions, and examine the models. A-life is thus both theoretical and experimental; theoretical in the sense that “life” may itself be an object of scientific inquiry just as the individual living specimens, and experimental in the sense of building models (Boden, 1996).

Christopher Langton, who organized the first conference which recognized the field of A-life as a distinct field of study, opens up his 1989 article, “Artificial Life” with a contrast between life and life on earth based on carbon-chain chemistry (Langton, 1996). He assumes that life on earth is a single example of a broader, generic category which we may call “life” (Langton, 1996). He claims that theoretical biology suffers from deriving general principles since there is only one single example of the generic theme “life” at its reach and he suggests that A-life would remedy the situation, as it would become another example for theoretical biology to work on (Langton, 1996)

Such understanding of life as something fundamental; something essential which is possibly distinct from the individual specimens, is a suitable ground from which the philosophical concept of vitalism in its mystical character might stem from. A-life denies this mystical character (Emmeche, 1994). It does not invoke a different kind of substance. Instead, A-life situates itself in the broader category of complex systems science (Bedau, 1998) in which the features of the systems are understood as a result of the complex interactions between the components of the system and between the components and the environment rather than due to some metaphysical life-force. Thus, in A-life, the key to understand what life essentially is, is in the organization, relations, interactions and processes between the components of a living system and between the components of a living system and its environment.

This way of understanding justifies the way in which A-life is taken to be both reductionist and anti-reductionist (Boden, 1996). It is reductionist, for the features of living systems depend solely on the component parts and their interactions and nothing else. There is no place for vitalism in this scheme. It is also anti-reductionist for that it takes the features of the living systems as real, which may only be described by theoretical concepts which are ill-suited for describing the features of the components. It also justifies two other important features of A-life, namely its preference of synthesis over analysis and its preference of a bottom-up approach instead of a top-down approach. Because the living systems are complex, the features of the system depend on the non-linear interactions between the components, individual analysis of the components in isolation; the analytical method; is of no help. This understanding has consequences since analysis/reducing systems to component parts is the method which covers almost all the work done in most of the sciences.

A-life's understanding of life as an organizational pattern, as a dynamical process, or as "form" which is shared by all the living physical structures, raises further questions, such as whether it is possible to create genuinely living systems out of any material substance, whether they are organic or not. Since life is form, any combination which realizes this form might well be considered alive. This is called the strong thesis of A-life.

Strong thesis of A-life is often debated. It becomes especially complicated in the field of soft A-life, where the material foundation which realizes the dynamical process is not material at all, but bits and bytes on a virtual environment. On the other hand, the weak thesis of A-life does not make such strong claims as its name suggests, it argues that the models of the living systems, independent of the types of their building blocks, are a beneficial tool for biology.

The validity of these theses depend on the concept of "form" as been understood by A-life. Thus, A-life's roots of how come it became to embrace the thesis that life is essentially form follows.

3.1. The Roots of Artificial Life

A-life essentially is the assumption that life or biological phenomena are dynamical processes. Thus, modeling these processes and working on these models, without being concerned with the medium in which the processes are realized is justified. We can work on non-natural systems to gain knowledge on the natural systems. According to most of the A-life scientists, life is a pattern in space and time which can be instantiated in various mediums (Farmer & Belin, 1992). Langton asserts that

> Life is a property of form, not matter, a result of the organization of matter rather than something that inheres in the matter itself. Neither nucleotides, nor amino acids, nor any other carbon-chain molecule is alive- yet put them together in the right way, and the dynamic behavior that emerges out of their interactions is what we call life (Langton, 1996, p. 53).

The assumption is historically founded on that;

> the formal application of logic to the mechanical process of arithmetic led to the abstract formulation of a 'procedure'. The works of Church, Kleene, Gödel, Turing and Post formalized the notion of logical sequence of steps, leading to the realization that the essence of a mechanical process, -the thing that is responsible for its dynamic behavior- is not a thing at all but an abstract control structure, or 'program' –a sequence of simple actions selected from a finite repertoire. Furthermore, it was recognized that the essential features of this control structure could be captured within an abstract set of rules, -a formal specification- without regard to the material out of which the machine was constructed (Langton, 1996, p. 44).

This separation of "logical form" of a machine from its material basis of construction, and arriving that machineness is the property of the former, not the latter and thinking of machines in terms of their abstract, formal specifications hence equating machine with an algorithm, led to the idea that things which might be considered as machines can also be described as abstract, formal specifications (Langton, 1996).

John Von Neumann has often been quoted as replying to a critic who stressed the incapability of machines to think, as he can always make a machine which would do the thing that the critic claims that the machine cannot do, if the critic could tell him precisely what that thing is. As far as telling something precisely can be understood as being algorithmic in the sense that following a set of rules in a mechanical step by step manner, it is safe to assert that Von Neumann was thinking in the frame of same machine-algorithm equivalency. If can be told precisely, i.e. algorithmic, then a machine can do that, since machines are essentially algorithms.

It is then no surprise that it was Von Neumann, by attempting to abstract the formal structure, the "logic" of a biological process, which was not generally associated with machines but organisms laid the foundations of A-Life as far as the field of A-life is devoted to the investigation of the question of "whether it is possible to abstract the logical form of an organism from its biochemical wetware" (Langton, 1996, p. 55).

The process he tried to abstract was self-reproduction and if he could show that it can be formalized, it could then indeed be realized by a machine in principle.[14]

Von Neumann envisaged an automaton, which is a general constructor, in the sense that this automaton A, would construct any other automaton X from a freely floating pool of elements or parts (Waters, 2012). Hence it could also construct itself. To construct, the automaton A has to be fed with a description of a target automaton X.[15] The description

[14] According to McMullin, Von Neumann's motive was not to formalize self-organization per se, but to find a solution to the deeper problem of the contradiction between the increasing open-ended complexity in the organic nature and the incapability of machines to give rise to structures of more or equal complexity McMullin (2000)

[15]This general constructor was similar to an universal Turing Machine, in the sense that they both being universal and by being in need of a description to operate (Waters, 2012). A Turing Machine is simply made out of 3 parts, a tape on which there are binary symbols, a head which reads, changes or erases these symbols, and a list of internal states which commands the way in which the head behaves. A universal Turing Machine can in principle simulate the behavior of any Turing Machine, because the internal state table of any Turing Machine in principle can be coded in binary on a tape, and a suitably designed Turing Machine can thus produce the same output with that Turing Machine when fed with that tape.

would be *Φ(X)* for any Automaton X. Then, for A to construct itself it needs the description *Φ (A).* But we would be needing two *Φ (A)'s* because the daughter automaton A' would also need a description, to keep reproducing itself. Thus Von Neumann envisaged a second automaton B, which copies any description *Φ(X)*. Thus the self-reproducing automaton became A+B. He envisaged another automaton C, the controller, which would bring a description *Φ(X)* to B for copying, then take one of the copies to A to construct the target automaton A'. Lastly, it would tie the remaining copy of the description to the target automaton.

Now that the resulting automaton would be (A+B+C) plus the description of itself *Φ (A+B+C)*. First C would take *Φ (A+B+C)* to B and B makes a copy of *Φ (A+B+C); Φ (A+B+C)'.* Then C takes *Φ (A+B+C)* to A, and A builds (A+B+C)' from the elements in the environment. For the last part C brings the remaining copy of the description *Φ (A+B+C)'* and connects it to (A+B+C)'. Thus the automaton (A+B+C) + *Φ (A+B+C)* would have reproduced itself as (A+B+C)' + *Φ (A+B+C)'.* This automaton A+B+C is also open to mutations, in the sense that for example when it'd be fed with a description *Φ (A+B+C+D),* it would construct an automaton (A+B+C+D)'.

The automaton has never been actually realized, but Von Neumann showed in principle that a biological process can be formalized.

3.2. The Strong Thesis of A-life

With Von Neumann, it has been shown that a biological process, in principle, can be formalized. The form could then, at least in principle be implemented in another medium. The totality of the biological processes which constitute a living thing could, then, in principle, also be implemented in another medium. Thus, the form is essential to life, rather than the material in which it actualizes. We may then call a structure in any medium, which actualizes the form, the dynamical process of life, alive. This is called the strong thesis of A-life.

It is easier to embrace the strong thesis in wet and hard A-life. As far as metaphysical/vitalist theses are exiled, the living things are indeed nothing other than a dynamical process of interactions of matter and energy. The medium in which the models of the living are being built in wet and hard A-life are also matter and energy. As such, as far as they actualize every dynamic process of a living being, a wet or hard A-life model could be considered as alive. It is in the field of soft A-life the strong thesis becomes more interesting and complicated, where the medium is the virtual environment of a computer.

Can a purely informational process, without any material basis be thought of as on the same ontological status with naturally living beings? Plenty of A-life scientists think it can. They claim that as life is the dynamic behavior that emerges out of the interactions of the constituent parts, it does not matter whether the constituents have different ontological statuses. The constituents of evolving physical living systems and the constituents of evolving computer programs might have different ontological statuses, but their behavior which emerge from their interactions have the same ontological status. In a simulation of the flocking behavior of birds, where the boids which follow local rules end up in flocking behavior globally, boids have different ontological statuses than the birds they simulate. But the flocking behavior of each are at the same ontological level, both are genuine flocking. "The "artificial" in A-life refers to the component parts, not the emergent processes. "If the component parts are implemented correctly, the processes they support are genuine- every bit as genuine as the natural processes they imitate" (Langton, 1996). In general;

> that a properly organized set of artificial primitives carrying out the same functional roles as the biomolecules in natural living systems will support a process that will be 'alive' in the same way that natural organisms are alive. A-life will therefore be genuine life- it will simply be made of different stuff than the life that has evolved here on Earth (Langton, 1996, p. 69)

Thomas Ray's thoughts on A-life models are another example (Ray, 1996). He suggests that, in a logical environment of a computer, an A-life model does not represent but instantiate a biological process. The biological process and its computational counterpart are ontologically equivalent, both being instants of same process. They are both genuine. Though he leaves the issue of whether an A-life model which instantiates a biological process could literally be considered alive as a semantic problem, theoretically, an A-life model which instantiates all the biological processes, those processes being genuine instantiations, must be considered alive.

Rasmussen's argument outlines a 6 foot argument for strong A-life.

1) A universal computer at the Turing Machine level can simulate any physical process (Physical Church-Turing thesis).
2) Life is a physical process. *Corollary 1: It is possible to simulate life on a universal computer.*
3) There exist criteria by which we are able to distinguish living from non-living objects. *Corollary 2: It is possible to determine whether a computer process is alive or not.*
4) An artificial organism must perceive a reality $R_{2,}$ which, for it, is just as real as our "real" reality, $R_{1,}$ is for us. (R_1 and R_2 may be the same).
5) R_1 and R_2 have the same ontological status. *Corollary 3: With corollary 1, Ontological status of a living process is independent of the hardware that carries it.*
6) It is possible to learn something about the fundamental properties of realities in general, and R_1 in particular, by studying the details of different R_2's. An example of such a property is the physics of a reality. (Rasmussen, 1992).

It has been argued against postulate 5 by taking off from Gödel's incompleteness theorems (Sullins III, 1997). Sullins claims that since R_2 would be a formalized reality of a computer which is artificially created in any case, by being completely formalized, it would at least not be same with our own reality R_1 for broadly speaking our own reality R1 contains mathematics which is something that is not completely formalizable according to Gödel's theorems. Thus R_1 and R_2 could not be on the same ontological status.

It has also been argued against postulate 1, though not being directly. It has been asserted that physical Church-Turing thesis is false (Kampis, 1991), (Rosen, 1991). According to Kampis, not every physical process or system is simulable, life being amongst one. Robert Rosen also argues against postulate 1. He claims that there are two types of physical systems, simple and complex ones. According to Rosen, simple systems have a largest model, by the aid of which the system can be fully described. The largest model could be a combination of different models which represent the system. These models and also the largest model, are Turing-Computable, in other words simulable. The complex systems such as the living systems are complex, they do not have a largest model and they have non-simulable models.

There are other strong arguments against the strong thesis of A-life. Sober (Sober, 2010) argues that by understanding life and biological processes as something which is multiply realizable in the sense that they can be actualized in different mediums, A-life is a functionalist enterprise. Functionalism, according to Sober, already exists in biology, yet A-life scientists are taking functionalism and abstracting away from physical systems too far, at a level where they confuse the mathematical structure of a process with its empirical content. The shoe/fly fallacy he asserts broadly suggests that two processes, such as shoes on a production line and reproduction of flies could theoretically be describable by same laws, but they are not necessarily supposed to be qualitatively equivalent. Flies are alive, yet shoes are not. According to this view, A-life scientists are committing the shoe/fly fallacy.

As being independent from the material medium, the properties are often described as being informational, computational and etc. Margaret Boden argues that there are processes which are peculiar to life, such as metabolization, which is not informational or computational at all. Metabolization, if understood as involving "the autonomous use of matter and energy in building, growing, developing and maintaining the bodily fabric of a living thing" (Boden, 2010), then nothing without a body could be considered as alive.

The way in which the form and matter are being partitioned by the A-life scientist and the weight which has been put on the form leads to many debates. The form, as something distinct from the matter, needs an explanation. In A-life, the explanation has been given as it is something computational/informational. The answer leads to further debates. In biology, abstract form is indeed being used. In fact, biology already assumes "that real life is both form and matter, and that the proper object of life science is to study both aspects and their dynamic interdependence" (Emmeche, 1992, p. 469). To conclude, we may get help from an useful distinction, namely following a rule and acting in accordance with a rule which has been made by Kant (Sober, 2010). The dynamical process, the logical form which has been abstracted away from physical systems by A-life scientist, has been understood in A-life more like a rule, a representation, an algorithm which the system consults to and behaves accordingly, an ontological entity on its own. On the other hand, in biology, the dynamical process is being understood as something which the physical system acts in accordance with, the behavior of the system implying the form, not the other way around. The dynamical process is not an ontological entity of its own.

Setting the prospects for the strong A-life aside, the study of the form in A-life is indeed a beneficial tool in biology. The weak thesis supports this view.

3.3. The Weak Thesis of A-life

There are not as many debates about whether the weak thesis of A-life is true or not as about the strong thesis. The assumption that the study of processes peculiar to the living beings in various mediums would be beneficial to biology seems to be unobjectionable.

An example of how models of biological functions can give insights in the science of the living beings may be found is the works of Stuart Kauffman (Kauffman, 2010). By working on computational/mathematical models of complex systems, he assesses the plausibility of biological theses. The RNA-world hypothesis is a hypothesis on how life emerged from non-life in the first place. It hypothesizes a RNA molecule called ribozyme which came first from a prebiotic soup[16]. This molecule is supposed to be catalyzing its own reproduction. It has been hypothesized as such, because catalyzing its own reproduction is what a modern cell does, by its DNA/RNA and protein machinery. This machinery is already a very complex structure in which a DNA molecule is being transcribed to mRNA by catalysis of the transcription by other molecules, and the mRNA being translated to proteins in the ribosomes. No macromolecule reproduces itself but they reproduce collectively. Ribozyme, is hypothesized as a simpler precursor from which such complexity arose. The complex orderliness of the DNA/RNA/Protein machinery has been assumed as that it must have been originated from a simpler, but still from an orderly

[16] Prebiotic soup is the hypothesized totality of conditions when life first emerged from non-life.

entity. Kauffmann shows, theoretically, that order does not necessarily require order to emerge from (Kauffman, 2010).

In a random graph, there are nodes and edges. The edges connect the nodes. When the ratio between the number of edges and the number of nodes crosses a certain threshold, subsystems emerge. As such, we could consider a chemical reaction graph, in which the molecules are nodes and the reactions between them are the edges. In such a system, for every additional molecule, the number of possible additional reactions is greater than one, hence the ratio of reactions to molecules increases when the number of molecules increases. With sufficient number of molecules, a subsystem such as the DNA/RNA and protein machinery could, at least theoretically, emerge. As such, order does not have to necessarily require order to emerge from, but it may spontaneously emerge.

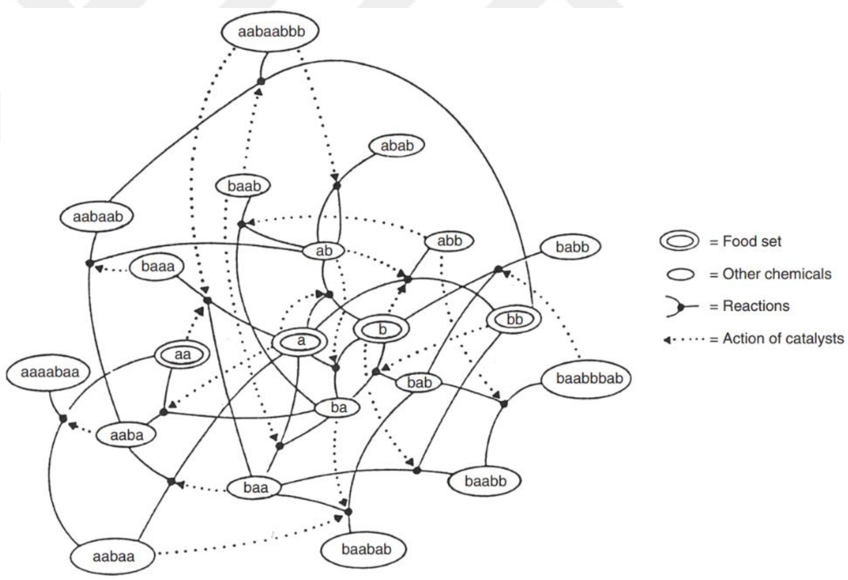

Figure 3.1: A chemical reaction graph, which consists of molecules a and b (Kauffman, 2010).

With complete theoretical models, in addition to demonstrating that order does not necessarily require order, we may challenge its sufficiency as well by the aid of Boolean networks (Kauffman, 2010). Boolean networks consists of Boolean variables. The variables could be in two different states at time t. Their state on time t+1 depends on the input they receive from other variables (states of the other variables) and its own Boolean function. Boolean networks are similar to a genome in the sense that a genome is a network of complex molecular interactions by which the genes are regulating the activities of each other. Since living things are complex systems which are a giant network of activities, they should be enormously chaotic. But instead, they are orderly. We know that for natural selection to work on, order must be preserved, the fluctuations must be offset and etc. and this is exactly how the living systems behave. This behavior may be explained by an analogy with Boolean networks. In Boolean networks, a state cycle forms when a starting state S, ends again in S after consecutive states, thereby forming a loop. Similarly, living systems can be thought off as being strongly convergent to attractors in their state space. Huge Boolean networks having variables as much as 100000, also can have state cycles, but for the amount of time for the formation of a cycle to be reasonable, certain conditions have to be met, such as letting a single variable having inputs only from two other variables and etc. Under different conditions, the formation of the state cycles could take forever. As such, as far as a genome could be likened to a high variable Boolean network, (say 100000 genes corresponding to 100000 variables) it may be asserted that an orderly molecule such as a DNA, is not sufficient by itself, without the addition of other systemic regulatory conditions such as a gene being affected by only two other genes or etc., to account for the orderly dynamic behavior of the living systems.

A-life models are not only being useful in assessment of theses which may be considered as an interest for molecular biology, but they are useful nearly in all areas of biology, such as in behavioral or population biology. In terms of behavioral biology, experimenting in an artificial program called RAM, about the mating preferences of lek-breeding species[17] (Gibson et al., 1990) can be given. The way in which the leks are formed, their distances from each other, their sizes, their distance from the female nests and etc. are often thought to be affected by female preferences over mating. As such, it has been hypothesized that, by observing the characteristics of leks, we may assess whether a type of a preference

[17] Lek breeding species are species in which males often form clusters which is visited by females to breed. Clusters of males are called leks.

really exists for females. For example, it has been hypothesized that distance between the leks shall indicate whether females prefer for leks with larger population of males (Bradbury, 1981). If females preferred for larger leks, then the male tendency had to be towards a single large lek. As such, no two leks should be closer to each other than an average female range diameter (Gibson et al., 1990). By using artificial models, it has been argued that no conclusion of whether there exists a female preference for a larger lek can be driven from the average distance between the leks (Gibson et al., 1990). The researches used the computer program of RAM, which through its subprograms models the individuals in a lek-breeding population. The subprograms control the individual behaviors of 100 males and 100 females, randomly dispersed on a 10x10 squared grid, by simultaneous execution of all the subprograms until the population in leks become stable before 10 iterations. For males, the subprograms controlled the desirability of grids in terms of the quality of the males in a grid and the number of matings in a grid. The subprograms for females were designed to control the female behavior in terms of the lek's distance from their nest, how large the lek is or the quality of the best male in the lek, and the level of competition between females for a male in a lek. In executions with different weightings of these three criteria, females assessed the desirability of each grid, and moved to the most desirable grid at the end of the execution of their subprograms. As a result, the researchers demonstrated that a closer distance between the leks than the female range diameter, does not necessarily mean that there does not exist a female preference for larger leks. The preference for larger leks, together with other preferences, such as the preference for a shorter distance of a lek to females nest or lower level of competition, could result in multiple leks closer to each other than the female range diameter.

As exemplified, artificial models can be used to assess many other biological theses. The success of the assessment, depends on how loyal the model is to the natural system that it aspires to model. As such, some important features of the natural system to be modeled, are presented in the next chapter.

CHAPTER 4

CHARACTERISTICS OF WHAT IS BEING MODELED

In A-life, the importance is put on the form, rather that the material structure which realizes the specific form. As such, one needs to find the form which is specific to life. The form of life, necessarily is, or the result of, the type of interactions which take place within an organism. We already know that the interactions are physico-chemical, electro-chemical and etc. What makes living beings different than non-living beings which are also results of physico-chemical reactions is the specific pattern of those interactions in living beings.

Metabolism of a cell is, for example, a biochemical reaction network. A biochemical reaction is often in the form of an input (substrate) which is transformed into an output (product) by an enzyme. An example is the transformation of aspartate to lysine, by an enzyme called aspartokinase (Cornish-Bowden, 2006). Lysine, also, by binding to aspartokinase, inhibits its activity of transforming aspartate to lysine. One may ask, "Why lysine inhibits an enzyme which produces itself?", and as far as the information been given up until here, one cannot answer such a question. Only with the additional information that lysine is not only an output, but an input for other reactions by which proteins are produced, the question makes sense, and we may answer it such that, lysine inhibits its own production, so that the specific rate of protein production can be achieved, without excess lysine (Cornish-Bowden, 2006). Though, adding the proteins to the aspartate → lysine scheme, would in turn introduce extra questions in terms of the proteins and etc. Also, what causes the transformation, i.e. the enzymes such as the aspartokinase, are often produced within metabolism, the production of which in turn, require other enzymes. This is what is meant, by referring to metabolism as a biochemical reaction network. Almost no output is an end in itself, but they are inputs and catalysts for other reactions, and collectively, they form metabolism, the function of which, as a reaction network, is to sustain itself as a reaction network. Therefore, we may assert, one may make precise sense of the reactions in a metabolism, only if one refers to the metabolic activity itself. The functions of the components are dependent on the function of the whole.

A specific gene found in living beings is called p53 (Kaneko, 2010). P53, causes many things, such as inhibition of the growth of cancer cells, regeneration of blood vessels, DNA repair and etc. The specific function it realizes depends on its interactions with other components in its environment. Therefore, we may say p53 causes nothing whatsoever by itself, but itself and the context in which it is embedded in, jointly cause such functions.

In 1928, Winterstein (Winterstein, 1928) wrote;

> When we attempt to conceive the vital occurrences of an organism we are at once confronted with the fact that we shall not succeed if attention is confined to the single processes going on in it at a given moment. We can only reach a satisfactory understanding if we consider them as partial processes in relation to the whole…"purposive" is nothing else than a short expression for all phenomena upon which the maintenance of an observed state or process depends (Bertalanffy, 1933; Winterstein, 1928).

Therefore, we may assert that what makes cell metabolism different than another reaction network is its function, its formal structure, which is the sustainment of itself. It is the pattern in which the biochemical reactions take place. We may accordingly, call another biochemical reaction network of different substrates and enzymes, which sustains itself, a metabolism. Analogously, there are answers given to the question of “What life is?” in terms of its formal structure as in one functionally answers what a metabolism is. Some answers are that their formal structure being autopoietic (Maturana & Varela, 1980), that they are metabolism-repair (M-R) systems (Rosen, 1991), or that they are teleodynamic processes (Deacon, 2012).

4.1. Self-Organization

Self-organization implies an organized whole, and that the source of the organization is the internal interdependent workings of the components of the whole[18]. Self-organized wholes are often contrasted with other organized wholes the organization of which are imposed from outside, instead of from within. As opposed to a car or a computer, the orderliness of some systems such as living beings are not imposed from outside but they are the source of their internal dynamics.

Slime mold is an organism which lives as an individual cell (Ismael, 2011). When food is scarce, or to reproduce, slime molds aggregate together, and differentiate, thereby forming an assembly of individual cells. The assembly is an orderly organismal unity. How does this order generated and preserved? For its generation, no information of an assembly towards which all individual cells assembly into exists. For its preservation, there is no information about the scarcity of the food which is represented to the assembly in whole, so that the assembly itself could become the agent which either keeps itself together or dissolve. There is no central governance at the level of the assembly. The organization is generated and preserved as a result of the interactions at the level of the individual slime mold cells. When food is scarce, the individual molds emit a substance called cAMP, which causes other molds that it contacts to emit cAMP. A gradient field of cAMP is thereby being produced. The molds are individually programmed to assemble at where the cAMP concentration is the greatest. As such, the source for the orderliness of the assembly is the internal workings of its individual cells.

The source for an orderliness is interesting because, orderliness is the exception, not the norm. Broadly, the second law of thermodynamics states that, overall, orderliness decreases over time (entropy increases over time). Yet, systems hypothetically abstracted from their environment such as living things seem to be extremely orderly and they seem

[18] This does not mean that there does not exist any external perturbation whatsoever. Self organizing phenomena are often formed in existence of some perturbation from outside. It is self organizing in the sense that the resulting organization is not imposed from the outside readily as that organization, say as opposed to the organization imposed to a car during its production.

to be almost everywhere. This in fact implies no contradiction, for there exists chemical processes, which by increasing the local orderliness, decreases the overall order. These chemical process are under thermodynamic control, and assuming that the living systems are an aggregate of chemical processes, they do not refute the second law of thermodynamics but affirm.

The meaning of the concept of self-organization transformed over time (Keller, 2007). It was first used to underline the source of organization, thereby used to delineate the living from other organized structures such as machines. Later it has been related with the engineering approaches which tried to produce self-organizing machines, with feedback loops and circular interactions (Keller, 2007). A third transformation in understanding surfaced with nonlinear dynamical systems theory in physics and mathematics (Keller, 2007). Self-organization were then related with nonlinearly dynamical far from equilibrium systems resulting in organized phenomena such as stable attractors, dissipative structures and etc.

Accordingly, the phenomena which have thought to be self-organizing, varied. It was first, organisms which was self-organizing. Population of organisms are also thought to be self-organizing, such as an ant colony. It has been shown that machines such as cellular automata could also be thought of in principle as self-organizing. Vortices, whirlpools, special convection cells such as Benard convection cells, has also been thought as self-organizing phenomena. The planet earth has been thought as a self-organizing system. Accordingly, the universe has also been conceptualized as a self-organizing phenomenon (Smolin, 2003).

4.1.1. Autopoiesis

Autopoiesis, is a self-organizational functional theory on life. The word auto refers to the self and poiesis means producing or making. The characterizing principle of living systems is that they are systems which continually produce themselves (Maturana & Varela, 1992). More specifically;

> an autopoietic system is organized (defined as unity) as a network of processes of production (synthesis and destruction) of components such that these components: i) continuously regenerate and realize the network that produces them, and ii) constitute the system as a distinguishable unity in the domain in which they exist (Varela, 2013, p. 26).

In contrast, sytems which produce something other then themselves are called allopoietic and systems which are designed for some specific purpose are called heteropoietic.

A cell for example is an autopoietic unity. The chemical reactions inside a cell, continually produces materials, some of which in turn participate in these reactions, some of them are secreted as waste and etc. The reaction network of a cell is kept intact as a result of the reactions. The boundary of a cell for example is produced as a result of the chemical reactions within the cell, in turn, the boundary has a role in the reaction network which produced itself. A role such that, without the boundary, those reaction networks would dissolve. Yet, according to Maturana and Varela, it is meaningless to ask whether boundary or any component precedes reaction network or the reactions precedes components (Maturana & Varela, 1992). These are not sequential processes, but the reaction network and the components emerge simultaneously by pulling themselves up from their own bootstraps. (Maturana & Varela, 1992).

The defining feature of the autopoietic theory on minimal conditions of life is that it is organizational. In Maturana and Varela's terminology, it is organizational as opposed to being structural. Organizational aspect is the dynamical relations which may be abstracted from various concrete systems which realize those dynamics. Structural aspect in contrast is the actual concrete relations that hold between the components of a system. So, many different structural topologies, can be self-producing, and thus realize the same organizational aspect of autopoiesis. Hence, self-organization is also multiply realizable. Accordingly what makes a chemical reaction a subject for biology is how it is related to the formal aspect of life. A reaction of transformation of aspartate to lysine by aspartokinase, individually, is not a subject for biology, but chemistry. Only in terms of its place in the reaction network of a metabolism within a cell boundary it becomes biological; "under no circumstances is a biological phenomenon defined by the properties of its component elements, but it is always defined and constituted by a concatenation of processes in relations subordinated to the autopoiesis.." (Maturana & Varela, 1980, p. 113). As such theoretical biology in the frame of formal/ organizational theory of autopoiesis is possible;

> As the mechanical phenomenology of physical autopoietic machines, the biological phenomenology is perfectly defined, and, hence, amenable to theoretical treatment through the theory of autopoiesis. It follows that such a theory as a formal theory will be a theory of the concatenation of processes of production that constitute autopoietic systems, and not a theory of properties of components of living systems. It also follows that a theoretical biology would be possible as a theory of the biological phenomenology, and not as the application of physical or chemical notions, which pertain to a different phenomenological domain, to the analysis of the biological phenomena (Maturana & Varela, 1980, p. 113).

Autopoiesis, implies that there exists an undeniable formal/ functional aspect of biology.

4.2. Emergence and Reductionism

Living systems are also thought to possess emergent features. The properties which are multiply realizable, or the self-organization itself, are also often thought to be emergent. These features of living systems, have implications for the way in which they are to be investigated, such as the use of reductionist methodology and etc.

4.2.1. Emergence

There are some observable phenomena, which seem to appear from out of nowhere. Consider the geometrical structure of a line segment. A line segment is a segment of a line which is a collection of points. It has the property of length, but its components, points, does not have such property. Where did the length come from? Water is basically a molecular combination of hydrogen and oxygen atoms. The properties of water though, are nowhere to be found in either oxygen or hydrogen atoms in isolation. The protein myoglobin has iron and oxygen binding properties. These properties does not exist in amino acids which constitute myoglobin (Luisi, 2006). The individual neurons seem like they do not possess any consciousness whatsoever, yet a collection of them interacting seem to have such a property. A cellular automata is composed out of cells, which individually follow simple rules. Even though these rules do not dictate any behavior for the automata at macro level, macro patterns manifest themselves. In economics, macroeconomic features, such as inflation and etc. are non-existent in terms of individual's daily economic activities. These type of phenomena came to be called emergent.

The examples given above illustrate a general understanding on emergence. On the other hand, it is more difficult to find an agreed upon precise definition. "Seemingly appearing from out of nowhere" may translate into many things with varying connotations such as emergent phenomena may be irreducible to, unexplainable by, or unpredictable (non-deducible) from the knowledge of the components and etc. Moreover, the precise definitions of emergence vary on what is in fact being emergent. What is taken to be emergent might be different things such as substances, properties, theories and etc.

A historical philosophical movement around the middle 19th century, which came to be called British emergentism has often been pointed as from where the discussions of emergence started (McLaughlin, 2008). The main works and the authors of the movement were J.S. Mill and System of Logic, Lloyd Morgan and Emergent Evolution, C.D. Broad and The Mind and Its Place in Nature, G.H. Lewes and Problems of Life and Mind and etc.

A special type of phenomena, first came to be called emergent in Lewes' Problems of Life and Mind (Blitz, 1992). Lewes defined two different types of phenomena, resultant and emergent phenomena, in which the resultants are composed of components (parts) whereas emergents are composed of constituents (elements) and that;

> all quantitative relations are componental; all qualitative relations elemental. The combinations of the first issue in Resultants, which may be analytically displayed; the combinations of the other issue in Emergents, which cannot be seen in the elements, nor deduced from them. A number is seen to be the sum of its units; a direction of movement is seen to be the line which would be occupied by the body if each of the incident forces had successively acted on it during an infinitesimal time; but a chemical or vital product is a combination of elements which cannot be seen in the elements. It emerges from them as a new phenomenon (Lewes, 1874-75, p. 98).

Vitalism also was an answer to the “seemingly appearing out of nowhere” character of the phenomenon of life. British emergentism were also developed in this context. C.D. Broad in his The Mind and Its Place In Nature, asserted “emergent vitalism” as an answer to discussions between “substantial vitalism” and “biological mechanism” (Broad, 1980). Emergent vitalism,

> denies that there need be any peculiar component which is present in all things that behave in a certain way and is absent from all things which do not behave in this way… it tries to explain the difference of behavior wholly in terms of difference of structure (Broad, 1980, pp. 58–59).

Broad asserts that this theory might take two different forms, according to whether the behavior of the whole is deducible from the knowledge on the components or not; and he calls the “Theory of Emergence” to the form in which the behavior of the whole is not deducible from the knowledge of the components even in principle (Broad, 1980).

The two forms that Broad underlined, also amounts to the distinction between the strong emergence and the weak emergence. Strong emergence implies that the emergent properties of the wholes are not deducible from the properties of the components. The non-deducibility in this case is fundamental in the sense that if a property is deducible from the properties of the components, then it is not emergent. On the other hand, in weak emergence, non-deducibility of the emergent properties is not a fundamental impossibility. Phenomena can be both emergent and deducible.

4.2.2. Reductionism

Reductionism broadly comprises the view that, certain phenomena P1 can be reduced to other phenomena P2 and in this context, reduced means that P1 is in fact nothing other than P2. A mental state such as anger, say P1, can potentially be reduced to some specific state of neurons and other physico-chemical and electro-chemical elements P2. This translates as anger is nothing other than some special state of neurons and physico-chemical and electro-chemical elements.

Reductionism, branches out, such as ontological reductionism, epistemological reductionism and others according to the type of the relata in the reduction relation. Some main categorizations of reductionism are; ontological, methodological and theory (Hull, 1981), ontological, methodological and epistemological (Hoyningen-Huene, 1989) (Ayala & Dobzhansky, 2013), constitutive, explanatory, theory (Mayr, 2003), (Sarkar, 1992) and etc.[19]

Concerning these categorizations, constitutive and ontological reductionisms are equivalent in content. Explanatory reductionisms and theoretical reductionisms can be grouped under the wider term, epistemological reductionisms.[20] Thus, we will be following the widely accepted categorization of the ontological, epistemological and methodological reductionisms.

Ontological reductionism amounts to the idea that a thing T1 can be reduced to another thing T2 and in accordance with the general reductionism definition, T1 is in fact T2 and nothing other than T2. A molecule being nothing other than its atoms, an object such as a table, being nothing other than its molecules can be given as examples. Concerning life sciences, the belief that an organism being nothing other than its constituent material parts is an example of ontological reductionism. Vitalistic views contradict ontological reductionism in the sense that, an organism is affirmed as something other than its physico-chemical structure on behalf of the metaphysical life-force that it possess. Organicistic and mechanicistic views, on the other hand, affirm ontological reductionism. Ontological reductionism is the most widely accepted form of reductionism in line with materialism prevailing as a philosophical worldview. As far as the universe is composed

[19] John Searle, identifies five different types of reductionism (Searle, 2008). In addition to the familiar categories of ontological and theory reductionisms, he adds Property ontological reductionism, logical and definitional reductionism and causal reductionism. Property ontological reductionism is a branch of ontological reductionism, and the relata of the reduction relation are properties. In logical and definitional reductionism, it is words and sentences which are being reduced to one another. For example, category theory can speak of other mathematical structures in terms of its own concepts. Then, a sentence about the mathematical structure ring in algebraic ring theory for example, can be reduced to a sentence about a category in category theory. In causal reductionism the relata in this branch are two things which have causal powers. If the causal power of a thing can be explained in terms of causal power of another, than the former thing would be causally reduced to the latter.

[20] Explanatory reductionism were defined as a type of methodological reductionism according to Paul Hoyningen-Huene instead of a type of epistemological reductionism (Hoyningen-Huene, 1989)

of a single type of substance, i.e. matter, whatever exist, necessarily ontologically reduces to matter, in the sense that it is nothing other than matter.

Methodological reductionism, comprises the views concerning the value of reductionism as a method for scientific investigation and gaining knowledge. Without doubt, scientific experience tells us that reductionist strategies have been one of the best methodologies to investigate phenomena, if not the most.

4.2.2.1. Epistemological Reductionism and Biological Explanation

Epistemological reductionism is the branch where the most controversy exists. Broadly, epistemological reductionism states that, given everything is composed out of matter which obeys physical and chemical laws; the complete knowledge of fundamental units of matter and the fundamental laws would suffice to know everything about the material system in question. Epistemological reductionism in life sciences, then, broadly asserts that given an organism is a material system, the complete knowledge of its fundamental units and fundamental laws would be sufficient to gain the complete knowledge of the organism. As we have seen in the second chapter, this assumption has its roots in the 17th century mechanicism. As an organism being a subject of life sciences, and fundamental units being subject of physics, epistemological reductionism also brings into question the reduction of life sciences to physics, and the independence of the life sciences from physical sciences.

Epistemological reductionism, as a branch of reductionism, itself branches out, according to the relata in reduction relation. The branch of epistemological reductionism the analysis of which first emerged was theoretical reductionism in a logical empiricist frame. With the discussions on the importance and place of theory in actual practice of specific sciences such as life sciences, a different form of epistemological reductionism started to be on the forefront, which may be called explanatory reductionism.

Broadly, theoretical reductionism asserts that the relata in reduction relation are two theories and reduction means that the laws or axioms of the reduced theory being deducible from the reducing theory. This perspective on theory reduction was proposed by Ernest Nagel (Nagel, 1961). In this context a theory is composed of sentences of laws in a formal language. According to Nagel, when a reducing theory T1, comprises all the concepts and terms of the reduced theory T2, and if all the laws and axioms of T2 are derivable from the laws and axioms of T1, then T2 can be directly reduced to T1. This is called homogenous reduction. If the reduced theory T2 contains concepts which does not exist in the reducing theory T1, then T1 must contain conditions which define the nature of the connections between different concepts (often called bridge laws) in two theories and the reduction is called heterogeneous reduction.

The Nagelian theoretical reductionism is often told to be in line with the logical empiricist tradition. This is because, theoretical reductionism of Nagel is based on deductive-nomological (DN) explanation model developed by Hempel & Oppenheim in logical empiricist framework. According to Hempel & Oppenheim, an explanation is composed of two types of sentences, an explanandum and an explanans (Hempel & Oppenheim, 1948). An explanans, explains explanandum, in the sense that the explanandum is being logically derivable from the explanans. And according to Nagel, reduction is "the explanation of a theory or a set of experimental laws established in one area of inquiry, by a theory usually though not invariably formulated for some other domain" (Nagel, 1961, p. 338). Reduction then, is an explanation. Moreover, reduction has two necessary and sufficient conditions according to Nagel, which are "conditions of connectability" and "conditions of derivability" (Nagel, 1961). The latter, suggests that for a theory T2 to be reduced to another T1, every law of T2 must be logically derivable from laws of T1. Reductionism than, as a type of an explanation is in line with the definition of explanation of Hemplel & Oppenheim's.

The main criticism against theoretical reduction in the logical empiricist DN explanation sense, has been that it does not correspond to the practical work carried out in science, especially, in life sciences.[21] The argument asserts that no theory exists, with its complete list of laws and axioms in life sciences. Therefore, no such deduction or logical derivation from a theory to theory exists either. For example, a theory of Mendelian Genetics, with

[21] See, (Hoyningen-Huene, 1989) for objections.

its specific list of laws and axioms, does not exist, let alone one can reduce it to molecular genetics, which also does not exist as a formal axiomatic theory at all.

To assert that the DN model of explanation is inadequate to characterize explanations in scientific practice, appeal to scientific practice to find and point different types of explanations, in which an explanandum is not being necessarily deduced from the explanans has been a common practice of philosophers. To be sure, almost all philosophers including the advocates of DN model of explanation, agree on that there is a pluralism concerning types of scientific explanation. In this light, Hempel modified the DN model with an IS model, in which IS is short for inductive statistical. W. Salmon introduced the statistical relevance, SR model, as a model for scientific explanation as opposed to IS model, but he also later abandoned this model for its lack of harboring the concept of causality which, "rather than statistical relevance, is what has explanatory import" (Salmon, 1998). The conceptualizations of scientific explanation as a formal argumentative relation between an explanandum and explanans lacked the concept of causality, yet "putting the "cause" back into "because" is no simple matter" (Salmon, 1998). Kauffman also asserted that "typical explanations in biology exhibit the manner in which parts and processes articulate together to cause the system to do some particular thing" (Kauffman, 1976)

The more the causal mechanistic[22] type of explanations gained support as being the foremost type of explanation in life sciences, the discussions in reductionism turned to be more and more about the reduction of a biological phenomena to the underlying mechanismic phenomena rather than reduction of formal theories.

Wimsatt for example, agrees with Salmon's SR model[23], under two conditions (Wimsatt, 1976). One of the conditions is that the search for statistically relevant factors in the SR model, must be done with the aim of determining mechanisms which cause the

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[22] For definitions of mechanism, see chapter 2.

[23] The SR model Wimsatt refers to is the one which Salmon later abandoned for its lack of harboring the concept of causality.

phenomenon. When the mechanisms which cause a phenomenon are at a lower level than the phenomenon, Wimsatt calls this a reductive explanation. Sarkar defines a reductive explanation as an explanation of a phenomenon which; passes the requirements of being a scientific explanation, which can and only include parts and interactions of the parts of the phenomenon in which the interactions are not fictive and in concordance with physics (Sarkar, 1992).

4.2.3. Emergence, Reductionism and Organization

Reductionism means many things. As shown, reductionism may refer to ontological reductionism, epistemological reductionism and etc. Further, in a more specific manner, it may refer to theoretical reductionism or explanatory reductionism. In the beginning of this chapter, two examples from the living beings has been given, in which how additional information about a partial process within a living system emerges when it is evaluated in terms of the whole within it operates. As such, decomposing a system loses information. This has often been thought of as having implications for reductionism. Also, properties being multiply realizable, in the sense that same property can be seen to result from interactions of different structural components, goes against reductionism. If interactions of different structural components may result in same phenomena, then the phenomena should not be as dependent as on the structural components themselves but rather on their relations.

As an example, let us think of the multiple realizability of the fitness property. The argument goes as since the finesses of two different organisms are the results of different physico-chemical interactions of different material substrates, fitness property cannot be reduced to specific types of material substrates and their interactions. Against these, in favor of reductionism, it has been argued that, there exists two different kinds of reductionism, a type-type reductionism and a token-token reductionism. A token-token reductionism is the idea that a particular property of a particular organism, depends on the particular material substrates and the physico-chemical interactions between the material substrates of that particular organism. Multiple realizability does not argue against this type of reductionism. Type-type reductionism is on the other hand, concerns theory reduction.

In terms of explanatory reductionism, then it is safe to assert that a particular emergent phenomenon, may be the result of its particular components and their interactions. This, though, is nothing more than an affirmation of ontological reductionism. To bridge the gap between the emergent phenomenon and the lack of it in its constituents, the concept of organization has often been introduced (Wimsatt, 2008). According to Wimsatt, emergence is not a binary quality. It is not the case of either emergent or not, but that, there exists a scale of emergence (Wimsatt, 2008). The properties on the one end of the scale are mildly emergent whereas ones in the other end are extremely emergent. Where a property belongs in this scale depends on how tightly the property depends on the organization of its constituents. If a property preserves itself under many various different decompositions, then the property is mildly emergent. Mass for example, preserves itself under all different decompositions of a whole. On the other hand if a property easily dissolves under various decompositions, in other words if its highly specific for a certain organization of its parts, then it is extremely emergent. An example can be the immune system.

To understand emergence in terms of a scale of emergence in which the level of emergence of a phenomenon depends on how tightly it depends on organization better; two processes of liquid water and Benard convection cells are presented.

Liquidity of water has often been thought to be an emergent property. The individual molecules cannot be in a state of liquidity whatsoever, but the collection of molecules can. The phase of matter, therefore is a conceptual apparatus for the collection of molecules. It does not mean anything at the level of an individual molecule. It emerges out of molecular properties and molecular interactions, being subject to second law of thermodynamics.[24] Liquidity is also multiply realizable. Not only water, but collections of many different molecular compounds may be liquids. It is true that the properties of individual molecules

24 Second law of thermodynamics broadly states that closed systems tend to maximize entropy(disorder) with time.

effect properties of liquids, such as liquid's viscosity values and etc. But liquidity itself, seems to be more generic, realized by many different combinations in which the molecular constituents are different. As such, liquidity is often explained statistically in terms of an aggregate of interactions (bondings) between them. And indeed, quantum theory by taking into account the statistical dynamics, explains how liquidity is being produced from the properties of the molecules and how these properties effect their interactions (Deacon, 2006). So, liquidity can be considered as being reducible to its molecular components and their interactions.

How come liquidity is generated statistically by an aggregate of interactions? According to the second law of thermodynamics, systems tend to reach an equilibrium state in which disorder is going to be maximized with time. The liquid is close to equilibrium (entropy is maximized) in its macro state, because, many molecular perturbations cancel each other out in a statistical manner. Concerning the liquidity, "the diversity of momenta, directions of relative movement, and orientation geometries of molecular interactions cancel one another out in aggregate, the ratio of hydrogen bond strength to energy of collision and its effect on molecular distances expresses itself as large-scale aggregate properties because these features produce an average net effect" (Deacon, 2003, p. 288).

The second process to be presented is the textbook example of the self-organizing phenomenon of Benard Convection cells[25]. When a liquid in a dish with a shallow depth is heated from below, the heat enters the system from below and dissipates from above. A hexagonal structure, called convection cells, thereby form on the surface of the liquid.

[25] A convection cell is a phenomenon which happens when there are density differences in a liquid.

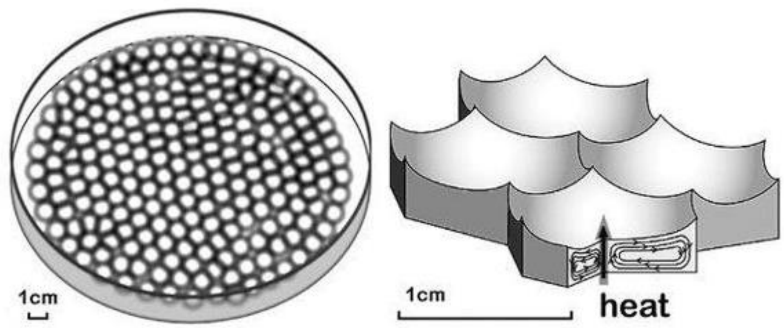


Figure 4.1: Benard Convection Cells (Deacon, 2012)

The mechanism of the phenomenon (Deacon, 2012) is as follows;

- When the temperature gradient is low, the faster molecules below bump into slower molecules above and transfer their momentum to slower molecules. The same happens, layer by layer through the surface and in the end the momentum caused by heat gets transferred to air molecules and thereby gets dissipated.
- When the temperature gradient is higher, the heat introduced becomes greater than the liquid can dissipate with the above method. As such, hotter local regions of molecules form. Since these molecules move faster, the distance between them are greater, hence they are less dense.
- The less dense molecular groups rise to the surface, while denser and cooler ones sink.
- The rising molecular groups and sinking molecular groups tend to correlate. This tendency exists, because in uncorrelated regions, the opposing streams of rising and sinking molecules produce a friction which results in a lesser dissipation of heat and accordingly, heat builds up in those regions. Molecular tendency is again to escape from those regions, rising groups tend to correlate with the rising and the sinking with sinking. The hexagonal areas are vertically aligned molecular movement areas.

- They are hexagons, because, hexagons most efficiently fill the planar surface and thereby the heat dissipation is evenly distributed to whole surface.

The process is self-organizing because, the hexagonal structure, has not been imposed as a hexagonal structure, but formed as a result of internal dynamics[26] of the liquid in a dish under an external perturbation, in a completely naturalistic manner. It is natural, in the sense that the thermodynamic tendency in the process of liquid water, is still there. The system, tends to dissipate the flux of energy that it is being exposed to, towards an equilibrium. The hexagonal structure is the most effective way with which the system can deal with the heat perturbation towards that goal. After the formation of the hexagonal pattern, the entropy of the system tends to stay stable. Discontinuing the perturbation, would result in the dissolution of the hexagonal structure towards the equilibrium of the simple thermodynamic process of liquid water.

There are differences between the processes of the liquid water in near equilibrium and the heated liquid water resulting in Benard convection cells. The difference can be explained by a concept of constrain (Deacon, 2012). The states that a system can be in is defined as the phase space of the system. For example, the size of the phase space of a dice is six. The dice is in one of these states at a given instant. Concerning the process of liquid water, there are billions of different combinations, in which the molecular components of water can be in, and in every instant, one of the possibilities are being realized. In terms of possibility, there are not any superiority of any state over one another. And since there is no strong correlation between the molecules, the result of microstructural interactions cancel each other out, instead of amplifying and resulting in macrostructural patterns. In other words, the system is minimally constrained. It is high in degrees of freedom in terms of being able to be in each possible state in its phase space without an effort. Therefore, the increase in entropy can be equated with decrease in constrain. An ordered system on the other hand is a highly constrained system which

[26] Not only internal dynamics but also external conditions such as the depth and shape of the dish are also effective.

cannot be in some states in its phase space. A near equilibrium system contains very small number of constrains.

On the other hand, the system of convection cells, is highly constrained (decreased in entropy). The orderliness produced by the system by the reaction of its molecular dynamics to the external perturbation, is a constrained state which the system can reach, by naturally (thermodynamically) not being able to be in its other states. The system, as long as the external perturbation is kept uniform, traces only a subset of the billions of the states that it could be in if it were not under perturbation. These states are called attractors in the mathematical language. What causes the dynamical system to trace only a subset of its possible states are the constrains imposed on it by organizational features, such as the depth of the dish, its circular shape, and etc.

The process of liquid water is minimally constrained (higher in entropy), whereas the convection cells are more constrained (lower in entropy). Now let us assume the possible decomposition of these two systems. The components of the first one, would preserve the liquidity under many different decompositions. The second one, on the other hand, is highly organized. Therefore, almost none, if there are any, components of different decompositions would preserve the self-organized hexagonal structure. To be sure, both processes are emergent. The emergence of the first process would have been noticeable if it had been decomposed as individual molecules, which would not preserve the liquidity.

The emergent properties are often being defined in terms of a concept called supervenience. A definition of emergence in terms of supervenience is that "If P is a property of w, then P is emergent iff P supervenes with nomological necessity, but not with logical necessity, on the properties of the parts of w" (van Cleve, 1990, p. 222). To supervene in this context means that a change in the higher level property P necessarily implies a change in the lower level. From the abovementioned organizational perspective, the non necessity of logical supervenience means that the higher level property is not necessarily deducable from the lower level properties, because, the lower level properties does not necessarily imply the higher level property in every possible organization of the constituents.

In terms of token-token reductionism, then, the emergent phenomenon of convection cells formed by perturbing the liquid water, can be explained in terms of the water molecules and their dynamical interactions under thermodynamic conditions under suitable organizational features. Though, convection cells, as a type of a phenomenon, can be observed in any fluid, not only in liquid water. It is even realizable in earth's atmosphere. Therefore, there is nothing being specific in terms of molecules being water molecules, many different collections of molecular compounds can realize the phenomenon. As such, as a type of a phenomenon, general explanation of a convection cell does not necessarily depend on specifics of its structural components, but depends on the dynamics between the more abstract structures of "molecules", just as in one does not need to know the internal workings of a transistor, to make sense of the amplifying function of an amplifier which also is highly organization dependent (Wimsatt, 2008). The description function of a transistor in terms of its input-output relations shall be enough. As such, it is a better strategy to try to map highly organization specific functional properties on underlying functions, rather than trying to map them on fundamental structural components.

One thing worth to mention is that in systems of human engineering, functions often overlap with structural components such as a transistor in an amplifier having a specific function. In such systems, there is always a better option of structurally decomposing the system in a function preserving way between many possible decompositions. In organisms, this is definitely not the case. Organism is a functional network, in which functions are dispersed throughout the structural components entangled with each other, the components in turn being functional wholes themselves. Therefore, it has been asserted, life, as a type of a phenomenon which is multiply realizable, is a functional property. As such, it is emergent in the sense that it is highly organization specific. Decompose life in any structural manner, and life as such would vanish. As such, decomposing it in the abstract, in terms of functions, and investigate the relations and the organization of functions has been asserted as a method for biological research. This is called relational biology (Rosen, 1991) or biotopology (Rashevsky, 1954). As such, relational biology, in terms of modeling with category theory, can be a tool in A-life, which is interested in the "form" of life, as opposed to its material construction.

CHAPTER 5

RELATIONAL BIOLOGY

One may ask, what science is and an effort to give a comprehensive answer can turn out to take volumes of work. But very broadly, it may be defined as the systematic investigation of the phenomena which humans come across. Since the investigation depends on our cognitive abilities, science has a subjective aspect. With the agency of our minds, we investigate what is out there in the world, including ourselves. Therefore, science is intertwined with the abilities of the mind, such as being able to make abstractions. Even a simple measurement can be called an abstraction, in the sense that it is an act of encoding a phenomena to an abstract concept such as a number (Rosen, 1991). Robert Rosen, gives a general framework for the act of abstraction, with his "modeling relation" (Rosen, 1991). Modeling relation is the general framework for scientific activity, which broadly is the act of encoding a natural system to a formal inferential system. The main formalism which the phenomena have been encoded in stemmed from the celestial mechanics of Newton, which we may call the Newtonian formalism. Newtonian formalism is prevalent in almost all sciences, including biology, since Newton. Rosen's main argument is that, for complex systems which comprise of emergent, self-organizing and self-maintaining and other functional features, including the living, Newtonian formalism is so specific such that a richer relational formalism is required (Rosen, 1991). In line of this argument, the general understanding that biology, as being a part of the physical universe, is a specialized subset of physics has been flipped. On the contrary, physics in the frame of Newtonian formalism, is so specific that it only accounts for a subset of systems in the physical universe. It does not congruently encode many different class of physical systems, such as the living beings. As such, biology requires a broader framework than Newtonian physical formalism. A relational formalism, with the help of theory of categories, has been asserted as a formalism in investigation of living things. It is called relational biology (Rosen, 1991).

The term relational biology has been coined and stemmed from the works of theoretical physicist Nicholas Rashevsky (1899-1972), but developed in its full by his student, theoretical biologist Robert Rosen (1934-1998) and being pursued by his student, A.H. Louie to this day. Rashevsky, being a physicist, at a certain moment in his career became interested in physical aspects of cell division and other biological functions. He worked for a long time in physics of biology. In time, he grew cold to reductionist approaches under the Newtonian formalism of giving mechanistic descriptions of specific organic functions. The reason was that he began to think that the totality of such particular descriptions in no way answers the question of what life is. The answer to the question of what life is, he started to believe, lied in a principle in which all the physical processes are connected in the organic unity of an organism. He stated that;

> a direct application of the physical principles, used in the mathematical models of biological phenomena, for the purpose of building a theory of life as an aggregate of individual cells is not likely to be fruitful. We must look for a principle which connects the different physical phenomena involved and expresses the biological unity of the organism and of the organic world as a whole (Rashevsky, 1954, p. 321).

Relational biology, became the name for the search for such principle (Rosen, 1991).

To be sure, what Rashevsky was after was the life as is common to living beings. As such he understood life as form, as being understood in A-life. Accordingly, what is relational in relational biology, are biological functions. A map, or maybe a block diagram of interrelations of such functions, which may be mathematically transformable in a structure preserving way in between living organisms, can be what life in abstract, is.

> Although, for example, the processes of locomotion, ingestion, and digestion in a human are much more complex than in a protozoan, the general relations between these processes are the same in all organisms... If the relations between various biological functions of an organism are represented geometrically in an appropriate topological space or by an appropriate topological complex, then the spaces or complexes representing different organisms must be obtainable by a

> proper transformation from one or very few primordial spaces or complexes. (Rashevsky, 1954, p. 317)

Rashevsky thought that a graph of functional relations from a fundamental living being, or from a few beings, can be obtained, and this graphs can be transformed to relations of functions in other organisms (Rashevsky, 1954). Therefore, a tool to suitably represent functional relationships, i.e. category theory, has been introduced by Robert Rosen (Rosen, 1991).

5.1. The Modeling Relation

The modeling relation is the epistemic concept introduced by Rosen (Rosen, 1991). To illustrate the modeling relation, Rosen introduces the concept of a formal system. A formal system (a formalism) is a mathematical/ logical concept. It is composed of axioms, rules of inference and theorems which result by the application of the rules of inference to the axioms. The theorems are told to be entailed by or inferred from the axioms according to the rules of inference of the formalism. The axioms are taken to be true without entailment by something else within the formalism. The proper application of the rules of inference to the axioms, assures the truth value of the theorems entailed by the axioms. As such, the rules of inference are further applicable to the theorems themselves. The catalogue of the rules of inference which has been used in each step of a specific path from an axiom to a theorem can be called an algorithm. The truth of a theorem T, can be proven by demonstrating that it can be obtained by validly applying the rules of inference to the axioms; in other words by specifying an algorithm.

There exists many different formalisms, with different axioms and different rules of inference. If prepositions of a formalism F1 can be somehow encoded in a second formalism F2, and prepositions of F2 can be decoded in F1, these formalisms can be comparable [27] (Rosen, 1991).

[27] By being able to compare formalisms, arithmetics has been proven to be not completly and consistently formalizable simultaneously by Godel. Assuming arithmetics is itself an inferential structure, he encoded it in a formal axiomatic system and has proven that all the propositions of arithmetics can not be both consistently and completly inferred within the formalism.

If we may consider a natural system as not a formal but a causal inferential structure[28], the modeling relation between a natural system and a formalism becomes;

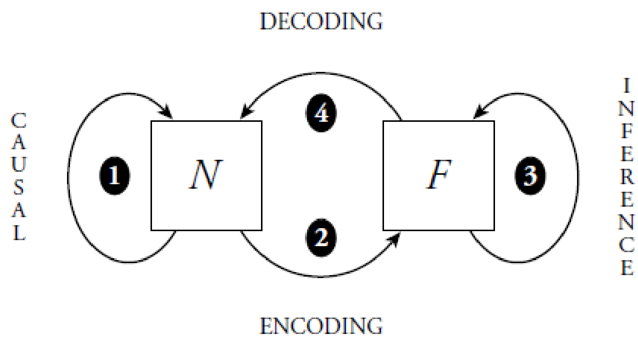


Figure 5.1: The Modeling Relation

Let us suppose a phenomena P in N, such that it causally entails (arrow 1) a phenomena P' in N. Now if it's possible to encode (arrow 2) the phenomena P to F and employ the inferential machinery of F (arrow 3), we may obtain F'. We may than decode F' (arrow 4). If the result of the decoding F' is equal to P', than we may call F a model of N or N a realization of F, in the sense that the two systems inferential structures are in congruence (Rosen, 1991). To some extent, we may use F to predict the behavior of N.

According to Rosen, the modeling relation, amounts to what science broadly is (Rosen, 1991). There are two scientific assumptions. The first one is that the phenomena in environment are not completely arbitrary, that there exists an inferential orderliness between phenomena. The second assumption is that, the scientist, is cognitively capable of grasping such orderliness, in terms of formal inferential structures, such as language or mathematics. The first assumption is analogous to the N and the second is to F of the modeling relation. Encodings might be considered as analogous to measurements and decodings are analogous to predictions.

[28] Rosen argues that science is entailed by this assumption ((Rosen, 1991). He argues that if the phenomena were arbitrary, there wouldn't be any science, to investigate the phenomena. Since there exists science, then this assumption is true.

5.2. The Newtonian Modeling

As far systems are recognized within an environment, the general practice to investigate them is through encoding them into formal models. The fundamental epistemological underpinnings of the way in which this has been done, has almost always been Newtonian, since Newton. In the Newtonian frame, systems have been considered as population of structureless particles under fields of force. The particles positions and their velocities at a time *t*, is called the state or phase of this system of particles at time *t*. By applying dynamical laws to the state at time *t*, the state of the system at time *t+1* can be deduced.[29] The particles are structureless, in the sense that what pertains them are just their mass and their position in three dimensional space. With the help of differential calculus, the rate of change of the position (temporal derivative) of a structureless particle has been defined as its velocity. Newton's first law states that a particle's velocity changes if and only if a force has been exerted on the particle. In Newton's second law of motion, this force is identified as the product of particles mass with the temporal derivative of its velocity, its acceleration. As the ambiance has been divided into two as a system and its environment and what abovementioned Newtonian picture mentions about the environment is only in terms of its effect on the system. The system on the other hand, is described by its states in time, the state being the position and velocities of their component structureless particles. Then, considering in terms of the modeling relation, the events of the natural system N, are encoded as states (phases) in a formalism. States and dynamical laws, entail new states in this Newtonian formalism.

Two things must be stressed out about the above mentioned formalism. The first one is that it is a particular encoding of a material system. There may be different encodings. The utility of the Newtonian encoding has been so high, such that it has become almost the exclusive encoding in all scientific practice. As such, that it is a formalism amongst formalisms has almost been forgotten, and the epistemological underpinning that the modeling relation asserts has almost always been overlooked. The second point to stress

[29] This is analogous to applying rules of inference to axioms and theorems in a formalism ((Rosen, 1991).

is that the Newtonian formalism is a congruent formalism for systems which are composed of structureless particles. As far as the natural system in question can be described as a composition of structureless particles, the Newtonian formalism is almost always congruent in describing the system behavior. Following from the two, reductionism in the sense of determining fundamental structureless units and the forces under which they operate has been the de facto methodology in investigation of material systems. As such, we may decompose the system anyway we like, without losing information, since any component of any decomposition is again fundamentally a population of structureless particles. Even in molecular biology, this reductionist methodology prevails.

Yet, in terms of the inferential entailments it allows, the Newtonian formalism may not be the most profound formalism for modeling some class of natural systems, such as the complex dynamical mechanisms which pertain to life (Casti, 2012; Rosen, 1991). The inferential entailment in the Newtonian formalism is the deduction of the next phase from the former phase, under dynamical laws. The phase being the position and velocities (the phase variables) of the particles, the system moves from phase to phase in its phase space.[30] As far as it encodes a natural system, formalisms inferential structures implies things about the causal structure of the natural system that they encode (Rosen, 1991). Accordingly, the causal entailment of a natural system has to be in congruence with such a formal entailment structure, and whatever we cannot find in the formal version has congruently been omitted from the causal structure of the natural system.

The living, as natural systems are thought to be complex. They are thought of as open, self-organizing systems with emergent functional features. As such, they have more complicated entailment structures, such as functions entailing functions, than simple systems. The Newtonian formalism, well describes simple system behavior. Because of its success, it has been the foremost candidate for the description of complex system behavior as well. As a simple system formalism, it approximates to the complex system behavior, but since the complex system is an open system, with no fixed phase space, a

[30] Phase space being the set of possible phases in which the system can be in, as in the size of a dice's phase space being six.

simple inferential formalism is not capable of describing specific complex system behavior such as emergence of functional properties and etc. (Rosen, 1985). As such, a complex system in the sense of its entailment structure and its qualitative features is not equal to an aggregate of its simple subsystems. Therefore, there does not exist a totality of simple subsystem formalisms, which itself is a simple formalism in which the complex system can be encoded into.[31] Complex systems, cannot be reduced to simple systems. Accordingly they require a richer formalism.

Relational biology aspires to describe the systems in terms of functional relationships. In the abovementioned Newtonian formalism, the system description is solely the particles phase trajectory under the dynamical laws. By integration of the dynamical laws to particles position and velocities, the next phase of particles and hence the phase of the system is being deduced. Functional relationships does not exists in this formalism. As such, it may be called the internal description of a system (Rosen, 1977). Another type of system description is external or black-box (Rosen, 1977), in which the system is perturbed in ways to observe its behavior. Whereas the internal description is structural, the external descriptions are functional (Rosen, 1977). In complex systems, contra simple systems, mapping the structural descriptions to the functional ones becomes a more difficult objective since same structures can have many functions, or partial functions or they may have changing functions.

5.3. A Relational Biology in a Category Theoretical Sense

To stress out again, relational biology as a formalism, leans on the assumption that complex systems are qualitatively different than simple systems, in the sense that they are not the aggregation of their simple subsystems. For example, no amount of combination of simple system formalisms in which there is no functional entailment, can result in a formalism with a functional entailment. As such, there does not exist a simple formalism, which is the aggregation of the simple formalisms of these simple subsystems which

[31] See for example the three body problem, in which the behaviour of a system composed of 3 components could not be deduced from two separate simple systems of a two body system and a single body system.

congruently encodes the material system in question. Since there does not exist such simple formalism, there is a requirement for a different, richer formalism.

A richer formalism, as briefly mentioned, must be able to functionally describe the system as well, in terms of an external/ black box descriptions. To find such descriptions, we may call an initial state of a system including its inputs and outputs as *S1*, and interfere with some part of it. We may, thus, intentionally shift the system to a new state *S2*, including its inputs and outputs. We may then, map the difference between the outputs of *S2* and *S1*, to the function of the part of the system that we had interfered with. We may call that part, a component of the system (Rosen, 1991). Since functions are dispersed through many structures in living beings, the component is rather functional than structural. For example, there are thousands of enzymes operating in a cell thus interfering with a random one has no detectable effect (Cornish-Bowden, 2006). A component with an observable effect, thus may be composed of many different substrates and enzymes, i.e. structurally dispersed as in a molecular pathway.

As such, a formalism with a functional aspect shall, represent the relations between the components and the relations of the components with the whole and with the environment as well. Since the description of a component requires a reference to the whole within which it functions, in terms of a formalism, it is a finalistic entailment. Finalistic entailment is not possible in a Newtonian formalism, a phase of a system is only entailed by the former phase it was in, the dynamical laws and the value of the former phase variables. But as natural systems, living systems are full of self-referential causal mechanisms and finalistic entailments, composed of functional units and etc. As such, they can be more congruently encoded in a formalism with the above mentioned functional capabilities.

The difference between a simple system formalism and a supposedly richer version can be explained in terms of the biological concept of the gene. Assuming that the human body at time *t* is as at a state *S* in terms of its cellular composition, what entails this state is the former state *S1* under physico chemical laws. Going backwards in time, it was entailed by the zygote[32] and physico-chemical laws. Zygote was entailed by the egg and sperm cells. What entails those? At some stage, the answer were thought to be the gene. Genes, were thought to be, under physico-chemical laws, entailing the gametes and all of their phenotype. In terms of inferential structure, this is analogous to Newtonian formalism in which an event is entailed by former events under dynamical laws. But in terms of the causal structure of the natural system in question, it turned out not to be congruent with it. The function of gene turned out to be extremely context dependent, in terms of the effects of transcription factors, chaperons, alternative splicing and etc. In reality, no gene in isolation exists which causes something without a context, a functional unity in which the gene operates. 80% of the genes of yeast are silent, their deletion does not result in any discernible phenotypic difference (Cornish-Bowden, 2006). In functional terms, an analysis of a gene in isolation is futile. As such, a formalism shall encode a functional component in which a gene is part, in terms of the functioning of the whole organism, i.e. in functional relationships.

There exists differences between considering a gene as analogous to a particle in a simple system formalism or as analogous to a component in a relational formalism. First of all, in a simple system formalism, the properties of a particle, are the properties of the particle, whether the particle is in isolation, or it is operating in a system of particles. A component of a relational formalism on the other hand, acquires functions according to its interactions with other functions. Moreover, whereas a particle does not acquire new functions according to its context, a component is capable of doing that, therefore, a component is conceptually capable of encoding concepts such as emergent features (Rosen, 1991).

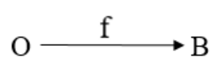
The component is context dependent, in the sense that it is in an input output relationship with the context it has been embedded in. If the context changes, the input output relationships change, therefore the function of the component might change. Though being context dependent, a component shall also have at least some form of identity on its own, on behalf of which it may be recognized as a component (Rosen, 1991). So a formalism to encode such a component must represent both its context dependence and

[32] Zygote is the cell formed by the fertilization of an egg cell with a sperm cell.

its identity. A category theoretic formalism can encode a component preserving these qualities, as in encoding it in terms of a mapping $f: A \rightarrow B$ (Rosen, 1991). Preliminaries on such an encoding is that, it is a simple category theoretic mapping between the domain *A* and codomain *B*. So the component *f* represented by $f: A \rightarrow B$, which takes inputs from *A* and transforms them to *B*. The specific function it acquires depends on what it operates on within *A* (members of *A*), its inputs. In terms of component's identity, as *f*, it has an identity of its own, it is the mapping which takes inputs from *A* and transforms them to *B*.

In category theory, a category consists of;

1. A class of objects as in $O \in C$; the object *O* in *C*
2. For each pair of object *(O, B)* in a category, there exists a set of morphisms between the objects as in *hom (O, B)*. Elements of this set are also called maps or arrows. These morphisms are formalized as $f: O \rightarrow B$ or f_{OB} as in f is a morphism between the objects O and *B*. O is called the domain and B is called the codomain of the morphism. A more intuitive representation is;



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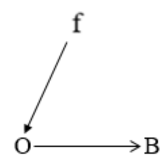
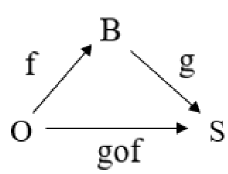


3. The morphisms can be composed when the intersection of one morphisms codomain and another one's domain is not empty. If $f: O \rightarrow B$ and $g: B \rightarrow S$ then there exists, $gof: O \rightarrow S$



4. There exists an identity morphism for every object in a category. $1_O: O \rightarrow O$ and with composition, $1_O \circ f_{BO} = f_{BO}$ and $f_{OB} \circ 1_O = f_{OB}$.

The above mentioned are basics of category theory. Considering 3, category theoretical formalism allows us to compose components. As we have seen a component can be encoded like $f: O \to B$ and $g: B \to S$. With composition, we may write $gof: O \to S$, in which gof is a larger component than both f and g. Composition is one of the basic tenets of category theory which makes it a rich relational tool in which many types of relations can be encoded into. It may be interpreted as *f* had the function of transforming *O* to *B*. But within the enlarged context including the component *g*, it became a part of a bigger functional component of gof which functions as producing *S* from *O*. Some examples are as follows.

For $f: O \to B$, let us assume that *f* maps the element *"o"* in *O*. We may represent the element in its codomain *B* that it maps *"o"* onto as *f (o)*. So, we may write, *f* entails the entailment of *f (o)* by *"o"* for any *"o"* in *O*, or *f ⇒(o ⇒f (o))*. Then, to get to the *f (o)*, both the *"o"* and *f* had to be. We thus said, the entailment *f*, entails *"o"* to *f (o)*. We were able to speak of "the entailment" itself, because it is individually represented in this category theoretic scheme. As we will see, not only objects but the entailments themselves can be entailed, which is called the functional entailment.

As told, morphisms and objects are separately represented in the category theoretic formalism. Morphisms, entail objects in their domain to objects in their codomain. Yet, the highly abstract structure of the category lets morphisms to entail not just objects but other morphisms as well. In fact, the composition principle of morphisms in 3, can be represented as an axiom entailing that whenever there are two morphisms *f* and *g* in which the intersection of *f*'s codomain and *g*'s domain is not empty, *f* and *g* entails gof for that intersection.

Moreover, all morphisms between say two objects, which are sets, *A* and *B*, is itself a set, as in 2; *hom (A, B)*. As such, we may think of a morphism say $m: K \to hom(A, B)$. Since the codomain of the morphism is a set of morphisms between *A* and *B*, the morphism *"m"* maps a *"k"* from *K* to another morphism in *hom (A, B)*, which we may call *m(k)*. *m(k)* is an entailment from *A* to *B*. Thus an entailment m entailed *m(k)* which itself is an entailment. This is again possible, since in category theoretic formalism, morphisms and objects they morph are, though being separately represented, are also defined in terms of each other, which is something very powerful in terms of relational representation of functions.

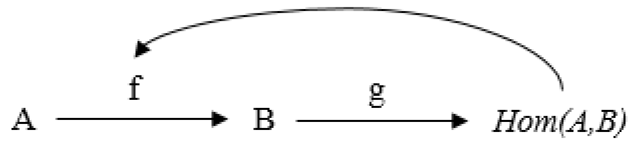
In terms of this representation, finalistic, i.e. circular entailments in biology can easily be modeled. The central dogma of the contemporary biology is that DNA is transcribed to mRNA, and the mRNA is translated to proteins through ribosomes. This is called the DNA/RNA and protein machinery. To transcribe DNA into mRNA, an enzyme called RNA polymerase is needed to catalyze the transcription. RNA polymerase itself must be transcribed from the DNA and the transcription cannot occur without the catalyst RNA polymerase. No macromolecule in the system reproduces itself, but the system as a whole reproduces itself in a modern cell. Therefore it is a functional component, with the function of reproducing itself. Now in terms of the category theoretical formalism; let us try to formalize the central dogma. In terms of the formalism we may represent the machinery;

Figure 5.2: DNA/ RNA/ Protein Scheme

as,

$$A \xrightarrow{f} B \xrightarrow{g} Hom(A,B) \qquad (5.1)$$

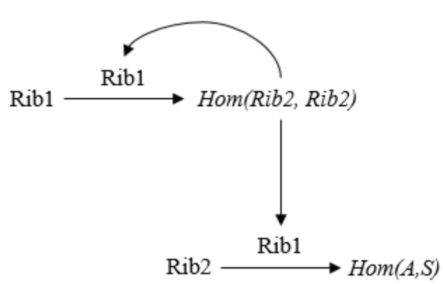
Since *hom (A, B)* is the set of entailments from *A* to *B*, *f* in the diagram is a member of *hom (A, B)*. Therefore the diagram can be represented as;



(5.2)

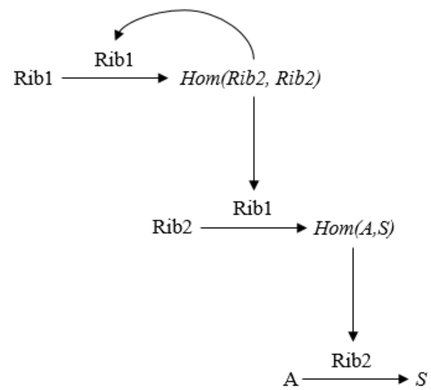
So, what this diagram effectively tells in terms of the DNA/RNA/Protein Machinery is this. By RNA Polymerase (*f*), DNA (a member of *A*) is transformed into mRNA (a member of *B*). mRNA (a member of *B*) in turn, transcribed into a set of proteins in which RNA Polymerase (*f*) is a member by ribosomes (*g*). From the diagram, we may assert that the function of component RNA Polymerase (*f*) is to produce mRNA (a member of *B*) from DNA (a member of *A*). The function of component ribosome (*g*) is to produce *f* (a member of *hom(A, B)*. The function of the functional component which is the composition of the two components, *gof* is to produce, RNA Polymerase (*f*), from A. As such, the function of the component *f*, has been changed when its context has been changed, with the addition of *g* and thereby forming the composite component *gof*.

Another example is the RNA world hypothesis which is presented on the 3rd chapter. It asserts the existence of a minimal cell containing two ribozymes as an hypothesis of a transitional cell from inorganic matter to the DNA/RNA/Protein Machinery (Luisi et al., 2006). The first ribozyme *Rib1* both self-replicates and also replicates the second ribozyme *Rib2*. *Rib2*, from a precursor *A*, produces *S*. *S* forms the cell boundary. In terms of relational formalism; *Rib1* has a special feature. Since it reproduces itself, it is the case that *Rib1* is both a mapping and an object, such that it maps itself onto itself. We may represent the *Rib1* self-replicating itself, and that it replicates *Rib2* as follows;



(5.3)

We were able to write *hom(Rib2,Rib2)* instead of *Rib1*, since *Rib1* is defined as making copies of *Rib2* from *Rib2* and therefore it's a member of the set of mappings between *Rib2* and *Rib2*. If we add that *Rib2* making *S* from *A*, the diagram becomes;



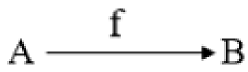
(5.4)

Again, we were able to write *hom (A, S)* instead of *Rib2*, since *Rib2* is a member of the set of morphisms from *A* to *S*. We may also have written the component *Rib1* as;

1. $Rib1: Rib1 \rightarrow Rib1$ (*Rib1* is the component which catalyzes its self-replication.)
2. $Rib1: (hom\ (Rib2 \rightarrow Rib2)) \rightarrow (hom(Rib2 \rightarrow Rib2))$
3. $Rib1: (hom(hom(A,S) \rightarrow hom(A,S)) \rightarrow hom(hom\ (A,S) \rightarrow hom\ (A,S)))$

In terms of entailments then, *Rib1* is both functionally and materially and efficiently entailed by itself. In other words, the function of *Rib1* is to replicate itself, from itself, by itself and it also has the function of replicating *Rib2*. The function of *Rib2* is to produce the cell wall *S* from *A*, it is materially entailed by itself and efficiently entailed by *Rib1*. The whole component functions as producing *S* from *Rib1*, in which *S* wraps the functional network and thereby the network keeps working.

In the abovementioned sense, Robert Rosen defines life in terms of functional relationship diagram of a simple metabolism-repair (M-R) system (Rosen, 1991). It is that cells function is basically a metabolic function (*f*), in which inputs *A* are transformed to outputs *B*.



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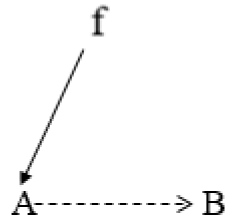
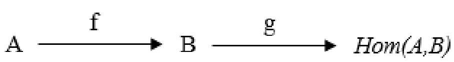


(5.5)

By a repair function (*g*), the metabolic function is being kept intact.



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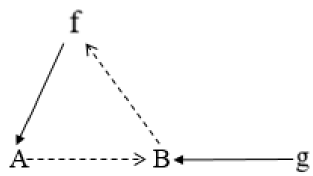

(5.6)

As seen, this diagram is the same with DNA/RNA/Protein machinery (5.2). The crucial point in an M-R system is that, everything expect the repair function *g* is entailed in it. *A* is the already existent inputs for metabolism, *B* is the outputs which are entailed by metabolic function *f*. The metabolic function *f*, in turn is entailed materially by *hom(A, B)*, and functionally by the repair function *g*. We may add an additional functional component to entail *g*, but in turn, that function would have to be entailed and etc. The crucial point in an M-R system is that Rosen (Rosen, 1991), mathematically proves that it is not impossible that the repair function *g* can already be entailed from the above diagram under some circumstances, as in *B* functioning as producing the repair function *g* from the metabolic function *f*.

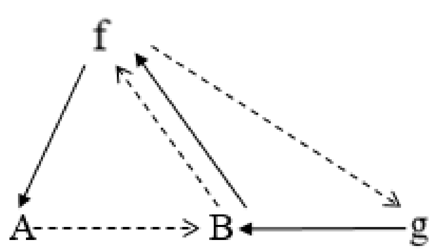

Figure 5.3: A metabolism-repair (M-R) System (Rosen, 1991).

Figure 5.3 represents an M-R system, a basic functional representation of life (Rosen, 1991). Every functional component of the diagram is entailed within the diagram, which is in turn the functional description of life, as a network of interactions sustaining itself.

The school of relational biology in the Rashevsky-Rosen tradition is still active. A.H. Louie, a mathematical biologist who has been a student of Robert Rosen, has more recently dated category theoretical works such as “More Than Life Itself: A Synthetic Continuation in Relational Biology” (Louie, 2009), “The Reflection of Life: Functional Entailment and Imminence in Relational Biology” (Louie, 2013) and “Intangible Life: Functorial Connections in Relational Biology” (Louie, 2017). For example, A.H. Louie, investigates pathophysiologies[33] in terms of functional relations, such that a metabolism-repair system (*H*)[34] being infected by a virus (*S*), in which a virus is defined as a repair function without a metabolic function which interferes with an M-R systems metabolic function (Louie, 2013). Different deductions can be made according to which part of the M-R system the virus interfered with and etc. (Louie, 2013).

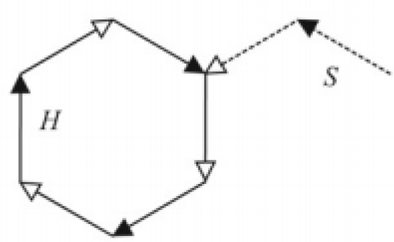

Figure 5.4: M-R sytem being infected by a virus S (Louie, 2013).

As exemplified, many different phenomena in natural systems and their abstract functional relations, can be encoded in terms of category theoretical relational formalism. We may, in principle, build relational diagrams of extreme complexity, from objects and morphisms between the objects. By such encodings and diagrams, we may formally study the abstract structure of organization of functions, in an objective way. We may thus assert that, since A-Life is basically the study of the life in terms of its formal aspects, a relational formalism

[33] Pathophysiology is a disordered physiological process.

[34] H is an equivalent representation of a M-R system.

such as the above mentioned category theoretical one can be a tool which congruently encodes the living beings in abstract relational structures.

CHAPTER 6

CONCLUSION

A system is broadly defined as a group of entities or devices which interact with each other. A gas in a container for example, may be considered as system of interacting molecules. A car or a computer or an amplifier, are also systems of interacting components. The latter examples are often realized by humans, with some specific purpose to fulfill. As such, they permit functional descriptions as the function of a car being changing ones location using power produced from an engine, in shorter amounts of time say then by walking. A gas in a container, on the other hand, does not permit functional descriptions.

Living beings can be likened to both. They are similar to a gas in a container as they can be considered as molecular components which interact with each other and that their formation being without agency, as far as we know it. Though, just like the products of human engineering, living beings also admit functional descriptions, as in a function of immune system being the protection of organism from external threats, or as in the function of the respiratory system being the procurement of oxygen and excretion of carbon dioxide and etc.

It has been presented that, an analysis of a biological process in isolation, lacks functional information about that process when it is isolated from the context which it is embedded in. Even, at the level of the above mentioned higher level functions in terms of systems, there exists a lack of information when they are not considered in context of the whole organism; all these functions, jointly function to keep the organism alive which does not exist when isolated. As such, an organism can be considered as a hierarchically and horizontally entangled relational network of functions. It is because of this feature of living systems that Maturana and Varela asserts that a process is biological only when it is considered in the context of its autopoietic unity (Maturana & Varela, 1980).

Functional properties are almost always emergent, in the sense that they exist only under some specific organization imposed through their components. As such, an emergent functional property would dissolve in many structural decompositions of a system. For example, an amplifier realizes its amplifying function, only under some specific organization of its components (Wimsatt, 2008). Therefore, a random decomposition would not be helpful, if one wants to investigate the amplifying function. A decomposition as such should, preserve the specific organization from which the amplifying function emerges. In terms of an amplifier, functional descriptions of the components and their interactions would explain the amplifying function. There is no need of a description in terms of fundamental particles of matter when it is the amplifying function which is the subject of interest.

As the amplifying function, when life is the subject of interest, it may be investigated in terms of functional relations of its components. Though, unlike an amplifier, biological functions often do not fall nicely onto structural components. They are dispersed throughout the organism. As such, when we are talking about a component of an organism, it shall be understood as a functional component in abstract but not necessarily a structural one. The aim of this thesis is not to show how function emerges from structure, but to assert that a formalism capable of representing interrelated functional relations can be used beneficially in terms of information gathering, while modeling life. Category theoretic tools are capable of such a representation which may be beneficial in the modeling efforts of A-life.

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APPENDICES

A. TURKISH SUMMARY/ TÜRKÇE ÖZET

Canlı varlıklar, çevremizde tanık olduğumuz fenomenler arasında en ilginç olanlardandır. Bu bağlamda canlılığın ve yaşamın ne olduğu sorusu, çağlar boyunca insanlığın ilgisini çekmiştir ve çeşitli şekillerde cevaplanmıştır. Bu soruya verilen cevaplar, niteliklerine göre üç ana başlıkta toplanabilir. Bunlar, dirimselci görüş, mekanikçi görüş ve organikçi görüş olarak tanımlanabilir. Cevapların niteliklerine göre, ontolojik mekanikçilik, maddeci organikçilik, anti-indirgemeci mekanikçilik gibi daha ayrıntılı sınıflandırmalar da yapılabilir.

Canlılığın ne olduğu sorusunun yanıtı, temelde, canlı varlıkların cansız varlıklardan ne şekilde farklı olduğunun bir yanıtıdır. Bu bağlamda, genel olarak dirimselci görüşler, canlı varlıkların cansız varlıklarda bulunmayan bir töz barındırdığını öne sürerler. Bu tözün niteliği belirsizdir. Bu belirsizlik sebebiyle bu töz, bir ruh, bir yaşamsal güç, bir özellik gibi pek çok farklı şekilde tanımlanmaya çalışılmıştır. Aristo'dan 19. Yüzyıl ve 20. Yüzyıl başlarında yaşamış Hans Driesch ve Henri Bergson'a kadar geniş bir zaman aralığında dirimselci görüşlere rastlanmaktadır.

Dirimselci görüşleri daha iyi kavrayabilmek için Aristo'nun yaşam ile ilgili görüşlerinin dirimselci olup olmadığı tartışılmıştır. Bu bağlamda, Aristo'da yaşamın kaynağı veya sebebi olarak ruh kavramı, dirimselci bir görüş olarak nitelenmektedir. Fakat Aristo'nun ruh kavramlaştırmasının teolojik veya pratikteki anlamıyla ruh kavramından farklı olması dolayısıyla, dirimselci bir görüş olup olmadığı tartışmalıdır. Aristo'nun kavramlaştırması bağlamında, örneğin göz organı yaşayan bir canlıya benzetildiğinde, bu canlının ruhu görüş yeteneği olacaktır (Aristoteles, 2008). Ruhun fonksiyonel bir özellik, bir düzenleyici prensip şeklinde bu kavramlaştırılması, dirimselci görüşten ziyade organikçi görüşe yakındır (Grene & Depew, 2004).

Dirimselci görüşler arasında sınıflandırma, canlıcı dirimselcilik, somatik dirimselcilik ve doğal dirimselcilik şeklindedir (Nicholson, 2010). Canlıcı dirimselci görüşlerde canlı varlığı canlı kılan töz, canlı varlığa dışarıdan dahil olmakta ve canlılığının kaynağı olmaktadır. Somatik dirimselci görüşlerde canlı varlığın maddesel vücudu ve yaşamsal tözü birbirinden iki farklı varlık değildir: Yaşamsal töz, maddeye bir şekilde içkindir. Doğal dirimselci görüşler ise organikçi görüşler olarak nitelenebilir. Bu görüşlere göre canlı varlıklar maddeseldir fakat canlılığın kaynağı maddenin özel bir düzenlenişidir.

Mekanikçi görüşler, yaşam bilimleri kapsamında dirimselci görüşlere karşıt olarak gelişmiştir. 17. Yüzyılda Rönesans doğalcılığına karşı gelişen mekanik felsefe bir dünya görüşü olarak tanık olunan bütün fenomenlerin mekanik etkileşimlerden ibaret olduğu görüşündedir. Buna göre canlı varlıklar da bir saatin mekanik işleyişi gibi organik bileşenlerinin mekanik işleyişlerinin bir sonucudur ve dirimselci görüşlere karşıt olarak canlı varlıklar herhangi bir yaşam tözü taşımazlar.

Tüm fenomenlerin mekanik etkileşimlerden ibaret olduğu varsayımını doğru veya yanlış olarak kabul etmeksizin, bazı fenomenleri mekanik etkileşimler vasıtasıyla açıklamak mümkündür. Bu durumu, felsefi bir dünya görüşü olarak mekanikçilikten bağımsız olarak, yöntemsel mekanikçilik olarak tanımlamak mümkündür. 17. Yüzyıldan itibaren yaşamsal fonksiyonlara mekanik açıklamalar getirme yöntemi gittikçe artan şekilde yaşam bilimleri için başat açıklama biçimi haline gelmiştir.

Mekanikçi ve dirimselci görüşler arasındaki çatışma yaşam bilimleri tarihindeki ana fikir ayrılığı hatlarından biridir. Yine yaşam bilimleri bağlamında organikçi görüşler ise hem dirimselci hem de mekanikçi görüşlerden ayrılmaktadır. Organikçi görüşler, dirimselci görüşlerden farklı olarak, canlı varlıklarda canlı olmayan varlıklarda bulunmayan bir tözün varlığını reddederler. Bu bakımdan organikçi görüşler yaşamın diğer bütün fenomenlerde olduğu gibi fiziksel ve kimyasal süreçlerin bir sonucu olduğu varsayımında mekanikçi görüşlerle ortaktır. Fakat mekanikçi görüşlerden farklı olarak organikçi görüşler canlı varlıkların basit mekanik sistemler olmadığını öne sürer. Buna göre canlı sistemler özel bir düzenliliğe sahip ve parçaları arasında yoğun ilişkiselliğin bulunduğu karmaşık sistemlerdir. Bu yoğun ilişkisellik neticesinde parçaların oluşturduğu bütünde, parçaların kendilerinde olmayan özelliklerin ortaya çıkması söz konusudur. Bu bağlamda, parçaları birbirinden ayırarak yalnız başlarına incelemeye dayanan analitik indirgemeci yöntemlerin canlı varlıkların incelenmesinde yetersiz olacağı öne sürülür.

Canlılığın ne olduğu sorusunun canlı varlıkların cansız varlıklardan ne şekilde farklı olduğunun tespiti ile cevaplanabilecek olması bağlamında yapay yaşam çalışmaları aydınlatıcı olma potansiyeli taşımaktadır. Bu alanda faaliyet gösteren bilim insanlarının ana amacı cansız parçalardan canlı varlıklar meydana getirmek veya yaşamın kendisi ve yaşam ile ilgili diğer fenomenleri modellemektir.

Yapay yaşam çalışmaları gerçekleştirilmeye çalışılan yaşamsal fenomenin seviyesine bağlı olarak moleküler, hücresel, popülasyon vb. şeklinde sınıflandırılabilir (Taylor & Jefferson, 1993). Bir başka sınıflandırma da, yaşam meydana getirmek için kullanılan cansız malzemenin niteliğine göre yapılabilir. Bu bağlamda, organik parçalardan yapay yaşam üretme çalışmalarına ıslak yapay yaşam, plastik, çelik gibi malzemelerden yapay yaşam üretme çalışmalarına sert yapay yaşam, bilgisayar ortamının soyut komponentleri ile yaşam üretme çalışmalarına yumuşak yapay yaşam denilebilir (Bedau, 2007).

Yapay yaşamın gerçekleştirilmesinin mümkün olduğu inancının temelinde, yaşamın maddesel altyapısının niteliğinden çok, maddesel altyapısının özel bir düzenlenişinden kaynaklandığı organikçi görüşü yer almaktadır. Bu bağlamda, aynı ilişkisel düzenlilik yapısını gösteren fakat farklı malzemelerden yapılmış sistemler canlı olarak nitelenebilecektir. Buna yapay yaşamın güçlü tezi denebilir.

Yapay yaşamın güçlü tezi canlı sistemlerin meydana getirileceği cansız parçaların somut olduğu ıslak yapay yaşam ve sert yapay yaşam alanlarında bilgisayarların sanal ortamlarında üretilen yumuşak yapay yaşam alanında olabileceğinden daha akla yatkındır. Yumuşak yapay yaşam alanında meydana getirilen bir sanal sistemin canlı sayılıp sayılamayacağına dair çeşitli görüşler tartışılmıştır.

Bu bağlamda yapay yaşamda, yaşamın materyal altyapısından bağımsız olarak uzay zamanda bulunan bir dinamik örüntü, bir düzenlilik biçimi olarak kavramlaştırıyor olmasının tarihsel kökleri incelenmiştir. Bu kavramlaştırmanın tarihsel kökleri mekanik olmak kavramının algoritmik olmak soyutlaması ile özdeş olduğunun öne sürülmesinde bulunabilir. Bu bağlamda mekanik olmanın özü, materyal altyapısından bağımsız olarak, belirli dinamik kurallar çerçevesinde sistemin içerisinde bulunduğu bir durumun bir önceki durumundan çıkarsanabilmesidir. Bu bağlamda, örneğin aksiyomlardan çıkarım kuralları dahilinde türetilebilen teoremlerin bulunduğu formel sistemler de soyut olmalarına rağmen mekanik sistemlerdir. Yaşam veya yaşam ile ilgili diğer fenomenler de, mekanik oldukları ölçüde, özünde algoritmik ve soyutlanabilirdir. Bu bağlamda, yaşama has ve mekanik sitemlerin yetenekleri dahilinde olduğuna tanık olunmamış bir fenomen olan kendi kendini üretebilme özelliğinin, mekanik bir özellik olabileceği John Von Neumann (Neumann & Burks, 1966) tarafından teorik olarak gösterilmeye çalışılmıştır.

Bu tartışmalardan bağımsız olarak, yapay yaşamın zayıf tezi daha makul bir önermede bulunur. Yapay yaşamın zayıf tezine göre yapay yaşam alanında gerçekleştirilen modeller, özgün olarak yaşıyor olmaları veya yalnızca birer model olmaları tartışmaları bir tarafa, yaşam bilimlerinde gerçekleştirilen araştırmalar için faydalıdır. Bu önerme, yaşamın maddesel altyapısından ziyade tamamen bu altyapının dinamik ilişkisel düzenliliğinden kaynaklandığı güçlü varsayımı yerine, yaşamın ilişkisel dinamik düzenliliğine bağlı olan bir tarafı olduğunu kabul etmekle yetinir. Bu bağlamda, bu dinamik düzenlilik başka tipte materyal altyapılarda da incelenebilirdir ve yaşam hakkında bilgi verir. Bu bağlamda, bazı biyolojik tezleri değerlendirmede kullanılan üç farkı model tanıtılmıştır. Bunlar rasgele çizge (random graph) ve Boolean ağları (Boolean Networks) (Kauffman, 2010) ve RAM isimli bir bilgisayar yazılımıdır (Gibson et al., 1990). Modern hücre biyolojisinin temelinde DNA/RNA/Protein mekanizması bulunmaktadır. Bu yapı oldukça karmaşık ve düzenli bir yapıdır. Bu düzenli yapının kendisinden daha az karmaşık fakat yine düzenli bir yapıdan evrimleşmiş olduğu RNA dünyası hipotezi olarak adlandırılan biyolojik bir tezdir. Stuart Kauffman, rastgele çizgeler vasıtası ile bu tezin doğru olmayabileceğini ve düzenli bir durumun düzensiz bir durumdan da ortaya çıkabileceğini teorik olarak gösterir

(Kauffman, 2010). Yine Boole ağları vasıtasıyla, yalnızca basit bir düzenli durumun varlığının kendinden daha karmaşık bir düzenli durumun ortaya çıkması için yeterli olmadığını ve başka koşulların da sağlanması gerektiğini, yine teorik olarak gösterir (Kauffman, 2010). Moleküler biyoloji dışında biyolojik bir tez örneği olarak, davranış biyolojisinde RAM isimli bir yazılım uygulamasının kullanımı gösterilmiştir (Gibson et al., 1990). Türün erkeklerinin kümelenerek dişilerin bu kümeleri ziyaret etmesi şeklinde çiftleşme davranışı gösteren türlerin simulasyonunun bilgisayar ortamında çalıştırılması sonucunda, bu alandaki çalışmalarda önerilen kümeler arası mesafeler gibi belli parametrelerden dişilerin seçim karakteristikleri gibi belli çıkarımların yapılabileceği tezinin doğru olmayabileceği gösterilmiştir (Gibson et al., 1990).

Bu tezin amacı yaşamın ne olduğu ve bu bağlamda yaşamın cansız varlıklardan nasıl ortaya çıkmış olabileceği sorusuna cevap vermek değildir. Bu tezin amacı yapay yaşamın zayıf tezi bağlamında, yaşamın dinamik ilişkisel düzenliliğinin nasıl modellenebileceği yönünde bazı prensipler ortaya koymaktır. Bir modelin modellemekte olduğu fenomenin ne kadar iyi bir modeli olduğu, o fenomeni ortaya çıkaran nedensellik dahil ilişkisel dinamik düzenliliğini ne kadar iyi temsil edebildiği ile doğru orantılıdır. Bu sebeple, canlı sistemlerin bazı kendilerine has ilişkisel özellikleri ortaya konmaya çalışılmıştır.

Örneğin, hücre metabolizması bir biyokimyasal reaksiyon ağıdır. Reaksiyon, bir enzim vasıtası ile girdinin, çıktıya dönüştürülmesi olarak tanımlanabilir. Örneğin hücre metabolizmasında aspartat molekülü aspartokinaz enzimi vasıtası ile lizin molekülüne dönüştürülmektedir. Lizin, aynı zamanda aspartokinaza bağlanarak aspartokinazin aktivitesini baskılayan bir aspartokinaz inhibitörüdür. Bu şema dahilinde sorulabilecek soru, lizinin kendi üretiminin katalizörü olan aspartokinaz enzimini neden baskıladığı sorusudur ve bu sorunun bu şema içerisinde bir cevabı yoktur. (Cornish-Bowden, 2006). Ancak, reaksiyonun bu tasvirinin lizinde sonlandırılıyor olması bir soyutlamadır. Çerçeve biraz genişletildiğinde lizinin metabolizma dahilinde protein üretimi için başka reaksiyonların girdisi olarak kullanıldığı görülebilir. Şemanın proteinler eklenerek genişletilmiş bu halinde, lizinin kendi üretiminin katalizörü olan aspartokinaz enzimini neden baskıladığı sorusuna bir cevap verilebilir. Lizin, kendi üretimini belirli bir protein üretim hızını ortamda fazla lizin oluşmadan tutturabilmek için baskılamaktadır (Cornish-Bowden, 2006). Fakat şemanın bu genişletilmiş hali de esasen bir soyutlamadır ancak bu sefer de “neden proteinler?” gibi sorular yanıtsız kalmaktadır. Yine bu büyüklükte bir çerçevede, aspartokinaz enziminin de kaynağı belirsizdir. Esasen hücre metabolizması içerisinde bulunan çoğu reaksiyon girdileri, çıktıları ve reaksiyonları mümkün kılan enzimler yine bu metabolizmanın içerisindeki başka reaksiyonların girdileri ve çıktılarıdır. Metabolizmanın bir biyokimyasal reaksiyon *ağı* olması ile kastedilen budur. Bu bağlamda, metabolizmayı oluşturan reaksiyonlar, yani hücreyi oluşturan parçalar ile ilgili maksimum bilgi, hücre metabolizması bir bütün olarak kavramlaştırıldığında ortaya çıkar. Metabolizmayı oluşturan reaksiyon parçaları metabolizmadan ayrı olarak tek tek incelendiğinde bütünün parçası olarak içerdikleri bilgiye kıyasla daha az bilgi içerirler. Yine bu parçaların ayrı ayrı içerdiği bilgilerin toplamı da metabolizmanın bütün fonksiyonelliğini tanımlayamaz. Öyleyse, metabolizma bütününü oluşturan reaksiyon parçalarının önemli fonksiyonları, bütüne bağlı olarak tanımlanabilir. Bu fonksiyonlar, bütünden ayrı olarak tek başlarına reaksiyonların kendilerinde bulunmazlar. Dolayısıyla fonksiyonun, bir reaksiyon parçasından ziyade, bütünü oluşturan parçaların tümü üzerine dağılımlı olduğu söylenebilir.

Bu bağlamda metabolizmanın fonksiyonu bir reaksiyon ağı olarak kendi devamını sağlamaktır. Dolayısıyla, kendi devamını sağlayan bir başka reaksiyon ağı da metabolizma olarak nitelenebilir. Metabolizmanın bu fonksiyonel tanımına benzer şekilde yaşamın kendisi de fonksiyonel olarak tanımlanabilir. Örnek olarak, Humberto R. Maturana ve Francisco J. Varela tarafından öne sürülen yaşamın temelde otopoietik fonksiyon gösteren bir sistem olması gösterilebilir (Maturana & Varela, 1980). Bu tanıma göre otopoietik sistemler, sistemi oluşturan parçaların sürekli olarak sistemin faaliyetleri sonucunda üretilip yokedildiği ve bu parçaların sürekli olarak bu sistem faaliyetlerini gerçekleştirdiği ve sistemi bulunduğu bağlam içerisinde bir birim olarak ayrıştırabildiği sistemlerdir (Varela, 2013). Görüldüğü üzere, bu tanım sistemin materyal parçalarının niteliğinden bağımsızdır ve pek çok farklı materyal sistem tarafından gerçekleştirilebilecek fonksiyonel bir tanımdır. Maturana ve Varela’ya göre, biyolojik bir fenomen kendisini oluşturan parçaların özellikleri ile değil, otopoietik bütün içerisindeki ilişkiselliği ile tanımlanır (Maturana & Varela, 1980).

Canlı varlıkların sahip olduğu özelliklerden çoğu, bu varlıkları oluşturan parçaların kendilerinde bulunmaz. Bu özelliklerin "ortaya çıktığı" (emergent) söylenebilir. Canlılık dışında bir örnek olarak, sıvı olma özelliğinin ortaya çıkan bir özellik olduğu, sıvı olma özelliğinin tek tek moleküllerin kendilerinde bulunmaması fakat moleküllerden oluşan bütünde bulunması bağlamında söylenebilir. Fenomenlerin ortaya çıkan özelliklerinin fenomenleri oluşturan parçalarda tek tek bulunmaması bağlamında bir fenomeni parçalarına ayırıp, o parçaları tek tek inceleyerek fenomenin bütün hakkında bilgi edinme yöntemi olarak tanımlanabilecek indirgemecilik yöntemi bir yöntem olarak sorgulanabilir hale gelmektedir.

İndiregemecilik, indirgenen ve indirgenilen şeylerin nitelikleri bakımından farklı anlamlara gelebilir. İndirgenen ve indirgenilen şeyler, doğruluk değerleri olan bazı teoremler olabileceği gibi yaşam bilimleri özelinde biyolojik bir fenomenin, o fenomene yol açan mekanizmaya indirgenmesi de olabilir. Bu mekanizma, fenomeni oluşturan parçalar ve o parçalar arasındaki ilişkilerin tanımlanması ile tanımlanabilir. Bu bağlamda, fenomenlerin bazı özelliklerinin parçalar ve parçalar arasındaki ilişkiler sonucu ortaya çıkması, o özelliklerin tek başına parçaların hiçbirinde bulunmuyor olmasını açıklar. Çünkü parçalar arasındaki ilişkiler de fenomenlerin ortaya çıkışında etkendir. Fenomenlerin bazı özellikleri parçalar arasındaki ilişkilere, yani parçaların düzenlilik durumuna bağlıdır.

Ortaya çıkma ve indirgemecilik arasındaki bu çatışmanın, parçaların düzenliliği bakımından çözümü, William Wimsatt tarafından önerilmiştir (Wimsatt, 2008). Bu bağlamda, bir özellik, kendisini oluşturan parçaların düzenliliğine ne kadar bağlı ise o kadar ortaya çıkmıştır. Yani ortaya çıkma durumunun dereceleri vardır. Bir sistemi meydana getiren parçaların sayısız şekilde bir araya gelme şansı vardır. Bir özellik, bu bir araya gelme şekillerinden bir veya bir kaçına özel ise o özelliğin ortaya çıkma seviyesi yüksektir denilebilir. Fakat bu özellik, bu bir araya gelme şekillerinden pek çoğunda bulunuyorsa, bu özelliğin ortaya çıkma seviyesi düşüktür. Örneğin bir sistemin kütlesi, onu oluşturan parçalar ne şekilde birleştirilirse birleştirilsin parçaların kütlelerinin toplamıdır. Bu durumda sistemin kütle sahibi olma özelliği, ortaya çıkma seviyesi düşük bir özelliktir. Tersi durumda, örneğin bir amplifikatörin yükseltme özelliği, kendisini oluşturan parçaların özel bir düzenlenişi ve ilişkileri sonucu ortaya çıkar. Bu durumda, amplifikatörün bu fonksiyonunun ortaya çıkma seviyesi yüksektir.

Örneğin, Benard hücreleri olarak tanımalanan altıgen hücrelerin ortaya çıkma seviyesinin yüksek olduğu söylenebilir. Bu fenomen, derin olmayan dairesel bir kapta bulunan bir sıvıya sürekli olarak belli seviyenin üzerinde enerji aktarılması sonucu oluşur. Sıvıyı oluşturan moleküllerin dinamik ilişkileri sonucunda ortaya çıkar ve ortaya çıkması kabın derinliğine ve şekline bağlıdır. Bu fenomenin, kendini oluşturan parçalar ve aralarındaki dinamik ilişkiler sonucunda ve belirli bir düzenlilikte ortaya çıktığı söylenebilir.

Fakat, Benard hücreleri fenomeni pek çok farklı sıvıda oluşabileceği gibi, dünyanın atmosferi gibi daha da farklı ortamlarda oluşabilir. Yani bir fenomen olarak pek çok farklı materyal altyapının dinamik ilişkileri sonucunda Benard hücreleri oluşabilir. Öyleyse bu fenomen, moleküllerin ne çeşit moleküller olduğundan ziyade, daha soyut bir kavram olan "*molekül*" seviyesinde moleküller arası dinamik ilişkiler vasıtası ile açıklanabilir.

Bu bağlamda, yaşam pek çok farklı materyal altyapı tarafından sergilenen bir fonksiyonel özellik olarak düşünülebilir. Bu fonksiyonel özellik, kendisini oluşturan parçaların düzenliliğine oldukça bağımlıdır. Yani ortaya çıkma seviyesi oldukça yüksektir. Bir canlı varlık sınırsız şekilde parçalarına ayrılabilir ve bunların parçalarına ayırmaların pek çoğunda yaşam fonksiyonunu kaybeder. Canlı varlıklar özelinde, yaşamı oluşturduğu varsayılan parçaların kendileri de fonksiyoneldir ve yine kendilerini oluşturan parçaların özel bir düzenlenişine bağlı olarak yüksek ortaya çıkma seviyelerine sahiptir. Dolayısıyla, yaşam birbiriyle hiyerarşik olarak ilişkili ve dolaşık pek çok fonksiyonun bir arada işlemesi olarak düşünülebilir.

Yaşamın fonksiyonel ilişkiler ağı olarak düşünülmesi ve bu ilişkiler ağının matematiksel olarak formalize edilebileceği; dolayısıyla canlılığın formalizasyonlar üzerinden çalışılabileceği fikrine "ilişkisel biyoloji" veya "biotopoloji" denebilir ve Nicholas

Rashevsky tarafından önerilmiştir (Rashevsky, 1954). Rashevski'ye göre yaşam fenomenin ne olduğu, yaşamın fiziksel altyapısından ziyade, fonksiyonel ilişkiselliği vasıtasıyla incelenmelidir (Rashevsky, 1954). Bu bağlamda, yaşam birbirine yol açan bir fonksiyonel ilişkiler ağı ise yaşamı modellemekte kullanılan aracın da başarılı bir model olabilmesi için bu fonksiyonel ilişkiselliği sadık bir şekilde temsil edebiliyor olması gerekmektedir.

Kategori teorisi, fonksiyonel ilişkisellikleri temsil etme bakımından güçlü bir araçtır. Kategori teorisi temel olarak matematiğin yüksek soyutlama seviyesine sahip bir alanıdır. Burada yüksek soyutlama seviyesine sahip olmak ile kastedilen şey kümeler, gruplar, topolojik alanlar gibi pek çok farklı matematiksel yapının kategori teorisi içerisinde kategori teoretik kavramlarla ifade edilebiliyor olması ve aynı temsil biçimi ile ifade edilebildikleri için birbirleri ile karşılaştırılabiliyor olmasıdır.

Kategori teorisinde, bir kategori, objeler ve bu objeler arasındaki morfizmler yani objeler arasındaki ilişkilerden oluşur. Bu bağlamda, örnek olarak kümeler birer obje ve küme fonksiyonları birer morfizm, topolojik alanlar birer obje ve sürekli fonksiyonlar birer morfizm, gruplar birer obje ve grup homomorfizmleri birer morfizm olarak kategori teorisi çerçevesinde temsil edilebilirler.

Kategori teorisi, yüksek soyutluk seviyesi ile bir fonksiyonel ilişkiler ağı olarak düşünülebilecek yaşam fenomenini başarı ile modelleyebilir. Birkaç örnek vermek gerekirse, kategori teorisinde objeler arası morfizmlerin belli koşullar altında birleştirilebiliyor olması özelliği yaşamı oluşturan fonksiyonel parçaların, içinde bulunduğu bağlam ile bağımlı karakterini yansıtabilmektedir. Örneğin aspartokinaz enzimini, fonksiyonu aspartat molekülünden lizin molekülü üretmek olan bir enzim olarak f ile tanımlanan bir morfizm olarak $f: O \rightarrow B$ şeklinde temsil edebiliriz. Yine fonksiyonu lizin molekünü bir protein molekülüne çevirmek olan bir başka enzimi g ile tanımlanan bir morfizm olarak $g: B \rightarrow S$ olarak temsil edebiliriz. Kategori teorisi aksiyomları çerçevesinde, f morfizminin varış kümesi (codomain) ile g morfizminin tanım kümesi (domain) ortak olduğundan, bu iki fonksiyon birleştirilebilir ve $gof: O \rightarrow S$ olarak ifade edilebilir. Yaşamı oluşturan parçaların içinde bulundukları bağlama bağlı olarak farklı fonksiyonellikler kazanabildiği bilinmektedir. Örneğin bir genin fonksiyonu, içerisinde bulunduğu çevresel faktörlere, transkripsiyon faktörlerine, şaperonlara, diğer genlere vb. bağlı olarak değişiklik gösterebilir. Bir genden kopyalan aynı mRNA'dan çevresel koşullara göre farklı proteinler sentezlenebilir veya üretilen proteinler ancak ortamda bulunan şaperon proteinleri vasıtasıyla aktive edilebilir. Kategori teoretik temsil biçiminde örneğin f morfizmi ile tanımlanan fonksiyon ve g morfizmi ile tanımlanan bir diğer fonksiyon, birbirlerinin varlığında bir araya gelerek gof ile ifade edilen daha farklı bir fonksiyona sahip daha büyük bir fonksiyonel parça oluşturabilmektedir.

Yine kategori teorisi aksiyomları çerçevesinde, iki obje arasındaki morfizmlerin oluşturduğu bir küme bulunur. Kümeler kategorisinden bahsediliyor ise kümeler birer objedir ve kümeler arası morfizmlerin oluşturduğu küme de bir objedir. Yani kategori teorisinde, objeler ve objeler arasındaki morfizmler birbirlerinden tamamen ayrı varlıklar değildir ve birbirleri cinsinden ifade edilebilir. Kategori teorisinin bu özelliği, yaşayan varlıkların fonksiyonları arasında bulunduğu söylenebilecek bazı fonksiyonların bazı diğer fonksiyonlara yol açıyor olması gibi ilişkisel özelliklerini modellemede kullanılabilir. Örneğin, yine f ile tanımlanan bir fonksiyon olarak $f: O \to B$ morfizmini varsayalım. Yine bir diğer fonksiyon olarak g morfizmini $g: B \to hom\ (O \to B)$ olarak ifade edelim. Burada $hom\ (O \to B)$ ifadesi, O ile B objeleri arasındaki morfizmlerin kümesi anlamına gelmektedir. f morfizmi de O ile B objeleri arasındaki bir morfizm olarak bu kümenin bir elemanıdır. Dolayısıyla, iki fonksiyonun birleşimini $gof: O \to hom\ (O \to B)$ olarak ifade edebiliriz. Bu bağlamda, gof ile ifade edilebilen parçanın fonksiyonu f fonksiyonuna yol açmaktır denilebilir.

Yaşamın bütününün de kategori teoretik bir tanımı Robert Rosen tarafından yapılmıştır (Rosen, 1991). Bu tanımda yaşam bir metabolizma fonksiyonu ve bir onarım fonksiyonundan oluşur. Onarım fonksiyonu, metabolik fonksiyonun devamını sağlar. Burada kritik nokta, metabolik fonksiyonun devamını sağlayan bir onarım fonksiyonu mevcutken, onarım fonksiyonuna yol açan bir başka fonksiyon mevcut değildir. Metabolizma ve onarım fonksiyonundan oluşan sistemin kendi işleyişinin, belirli koşullarda onarım fonksiyonuna yol açabileceği Robert Rosen tarafından kategori teoretik çıkarım kuralları çerçevesinde gösterilmiştir (Rosen, 1991).

Kategori teorisi, hiyerarşik ilişkiselliklerin temsili açısından da güçlüdür. Bir kategorinin içerisindeki objeler arasındaki ilişkiler morfizmlerle temsil edilebilir. Bir üst seviyede, kategoriler arasındaki ilişkiler de funktor adı verilen morfizmler aracılığı ile temsil edilebilir. Yine bu funktorlar arasındaki ilişkiler de doğal dönüşüm (natural transformation) adı verilen morfizmler aracılığı ile temsil edilebilir.

Bir sistem, kabaca birbirleri ile ilişki içerisinde bulunan parçalar bütünü olarak tanımlanabilir. Örneğin, bir kap içerisinde bulunan gaz, birbirleri ile ilişki içerisinde bulunan moleküller bütünü olarak tanımlanabilir. Yine örneğin bir araba, bir bilgisayar, bir amplifikatör de birbirleri ile ilişki içerisinde bulunan parçalar bütünü olarak birer sistemdir. İnsan yapımı olan bu sistemler genelde bir fonksiyonu gerçekleştirmek üzere bir amaç dahilinde tasarlanmıştır. Dolayısıyla bu sistemler, fonksiyonel olarak tanımlanabilirdir. Öte yandan, kapalı bir ortamda bulunan gaz gibi sistemler genel olarak fonksiyonel olarak tanımlanmazlar.

Canlı varlıklar, kapalı bir gaz sistemi gibi birbirleri ile ilişki içindeki moleküllerden oluşan bir sistem olarak tanımlanabilmelerinin yanında, insan yapımı sistemler gibi fonksiyonel olarak tanımlanmaya da müsaittirler. Örneğin bağışıklık sisteminin fonksiyonu vücudu zararlı etkenlere karşı korumak olarak veya solunum sisteminin fonksiyonu, hücrelere oksijen sağlayarak ve karbondioksitin dışarı atılmasını sağlayarak hücre metabolizmasının devamını sağlamak olarak tanımlanabilir.

Sonuç olarak canlılık birbiriyle ilişki içerisindeki bir fonksiyonlar ağı olarak düşünülebilir. Bu tezin amacı, bu fonksiyonelliklerin materyal altyapılardan nasıl ortaya çıktığını ortaya koymak değildir. Bu fonksiyonlar ağının modellenmesi yönünde bir temsil biçimi önermektir. Başarılı bir modelin modellediği fenomenin ilişkisel yapısını uygun bir biçimde temsil edebilmesi beklenir. Bu bağlamda, canlı varlıkların ilişkisel yapılarının ana hatları ortaya konmaya çalışılmıştır. Bu ilişki biçimlerinin de kategori teoretik temsil araçları vasıtasıyla temsil edilebileceği gösterilmeye çalışılmıştır. Bu bağlamda, yapay yaşam alanında yaşamın ve yaşam ile ilintili diğer süreçlerin modellenmesinde kategori teoretik temsil araçları önerilmiştir.

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