

From molecules to human: a research on the 4th dimension of life.: Energy, material, information, meaning.

Sixia Liu

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Université de Limoges École Doctorale Cognition, Comportements, Langage(s) (ED 527) Centre de Recherches Sémiotiques, Limoges

Thèse pour obtenir le grade de **Docteur de l'Université de Limoges** Sciences de l'information et de la communication

Présentée et soutenue par **Sixia Liu**

Le 14 décembre 2017

De la molécule à l'homme : recherche sur la quatrième dimension de la vie. Energie, matière, information, sens.

Thèse dirigée par Gérard Chandès

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To my grandfather, Shujin Wang, and to my grandmother, Huifang Xue



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Introduction

This thesis stands at the conjunction of disciplinary boundaries: on one hand, biology generally ignores the semiosis of living beings which it considers foreign to its objectives and methods; on the other hand, semiotics, in its original state, ignores the possibility of a form of semiosis produced by living systems without a psychic system. Our basic hypothesis is that semiotics can and should be involved in the functioning of the elementary system that constitutes the cell or the cellular being. Obviously, we are not talking about the semiotics of discourse, but the work carried out in this discipline entitled "biosemiotics", which is likely to broaden the field of the competence of semiotics in its most general sense, as the science of signs. We devote a development to the possibility of taking into consideration the exchange of matter and energy between a cell and its environment as an act of semiosis that gives rise to meaningful information. We are aware of the risk of using the concepts and the lexicon of current semiotics as simple metaphors, whereas it is our intention to attest, on the basis of the present work, of the reality of a semiosis in the living realm.

An introduction to biosemiotics

The studies of semiotics see things in the world in a conveyed nature – *"aliquid stat pro aliquo,* 'something stands for something else'" (W. Nöth, 1995, p. 84) – the first thing is a sign for the second. The process of relating the two things gives rise of meaning. Take the example of human spoken language: by conventions, a sound is connected to a concept. Therefore, hearing a word is related to knowing the meaning of this word, rather than receiving sound waves.

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Although some semioticians, such as Charles Sanders Peirce and Charles Morris, have been inspired by biology in formulating their theories (Santaella, 1999; Petrilli, 1999 as cited in Kull, 2015, p. 525), the concept of biosemiotics was first used by Friedrich Rothschild in his studies of brain processes (Rothschild, 1962; 1968 as cited in Kull, 2015, p. 525). Thomas Sebeok, then, studying animal communication and ethology, has invented the term of zoosemiotics (Sebeok, 1977 as cited in Kull, 2015, p. 525).

Meaning is the main topic of this thesis. More particularly, it is the meaning of life that is being discussed. From the point of view of biologists, adaptation is a quantitative event characterized by self-replication; however, it is argued by biosemioticians that the process is based on history and meaning, thus concerning the use of signs (K. Kull, 2009; Sharov, Maran, & Tønnessen, 2015). An example of a flowering apple tree is given by Hoffmeyer (2011), suggesting that the tree has "some kind of agency" because it exhibits "end-directed behaviors" – the flowers attract bees to help with pollination which can lead to the successful reproduction of the tree (pp. 44-45). Also, the traditional approaches of semiotics based on human languages show an evident limitation especially when it comes to explaining pre-linguistic sign processes, their relations to languages being used today, as well as non-linguistic semiosis observed in other species (K. Kull, 2012; Sharov et al., 2015).

It is important to bear in mind that, in this work, the definition of meaning is not limited to the realm of human cognition and life does not equal to the sum of activities (physiological and cultural) of all human beings in the society. In fact, the definition of meaning is given from two perspectives: one is semiotics, which provides the logical framework and the other is biology, which extends "what can be meaningful" to the molecular and the cellular levels of the natural world, thus including all forms of life as we know. Biosemioticians postulate the coexistence of life and semiosis:

"[...] life has a semiotic nature because it is based on endless interpretation of environmental cues and transfer of life-related functional meanings vertically across generations and horizontally to neighboring organisms" (Sharov et al., 2015, pp. 1-2).

To conclude, biosemiotics offers a way to understand life so that physics and chemistry are considered the preconditions for sign actions; at the same time, the role of signs conveyed and related to other signs is an intrinsic part of the biological nature of all living beings.

The four dimensions of life: energy, matter, information, and meaning

1. Energy and matter: the thermodynamic feature of life

There are numerous attempts in the scientific world to distinguish the characteristics of living things from the non-living ones. One of the most fundamental features of life is related to the sciences of thermodynamics. In 1943, Erwin Schrodinger noted in his book *What is Life*? that there is a fundamental process of life – "order from disorder" (Schrödinger, 1948, p. 82).

According to the first law of thermodynamics, in an isolated system (e.g. the Universe), the amount of energy does not increase or decrease (Ji, 2012, pp. 10-11). In other words, energy cannot be created or destroyed; it can only be converted from one form to another (Ji, 2012, pp. 10-11). For example, energy in carbohydrates and lipids can be converted to energy in the form of adenosine triphosphate (ATP); this energy can be used to do mechanical work, such as

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muscle contraction (Purves, Sadava, Orians, & Heller, 2004, p. 108). The second law of thermodynamics states that, when energy is converted from one form to another, some of that energy becomes unavailable to do work; it is lost to a form associated with disorder measured by entropy (Purves et al., 2004, p. 109). It is also claimed by the second law that, because of energy conversions taking place inside the isolated system, disorder tends to increase (Purves et al., 2004, p. 109).

On the other hand, living organisms made of highly orderly molecular structures appear to be a violation of the second law of thermodynamics (Schneider & Kay, 1994). In fact, different from isolated thermodynamic systems, living organisms are the open ones that can exchange energy or matter with their environment; and the order of living organisms is maintained because they can import usable energy (i.e. free energy) from the environment (Ji, 2012, p. 8). Most importantly, "order from disorder" of life is not a contradiction to the second law because while the imported order is used in metabolic processes, far more disorder is created and exported to the environment – therefore, in the bigger system made of organisms and their environment, disorder always increases (Purves et al., 2004, p. 109).

The thermodynamic feature of living organisms creates, automatically, the recognition of the boundary between living organisms and their environment (Deacon, 2006; Schneider & Kay, 1994). Open systems that can maintain themselves away from thermodynamic equilibrium is called by Ilya Prigogine and his colleagues as "dissipative structures" because the entropy is continuously dissipated out of the systems (Prigogine & Stengers, 1984, pp. 143-144).

2. Information and meaning: semiotic control is needed in the selfmaintenance of living organisms

Unlike non-living things, organisms have the goal of self-maintenance¹ to achieve. That is, organisms must make sure that they gain order from the environment, not lose it to the environment – this is right where a system of control is needed. This control system should be capable of monitoring, evaluating, and regulating of the on-going exchanges of matter and energy between an organism and its environment; and essentially, control requires information.

Information is constantly retained, measured, and compared to the constraint of the system yielding an assessment of the result. The constraint represents the general needs of an organism to satisfy to maintain alive. In the discussion of life's thermodynamic feature, it especially means the import of usable energy and the order maintained inside the living organism. After comparing the received information and the constraint, the system reacts: if the result is judged to be beneficial to the self-maintenance of the organism, the concerned energy/matter exchange will be allowed; if it is not, it will be stopped and corrected.

It is argued that living systems are distinguished from non-living ones because the former is adaptive based on their previous experiences (Kull, 2003). For example, genes as a "heritable memory" evolve under the pressure of natural selection (Pattee & Kull, 2009, p. 317). Generally, following Heylighen (1991) and

¹ Following V. N. Alexander (2013), in this thesis, we use the term "self-maintenance" (para. 8) to refer to the ability of living organisms to survive and reproduce thus counteracting to the entropic effect. Self-maintenance is applied to both individual organisms and their species – when the genetic information of an organism is transferred to the next generation, this organism is self-maintained.

Grandpierre (2013), here we consider information as a kind of knowledge that a cell has on its functional status reacting to various perturbations from the environment. In the same sense, living organisms are goal-serving "autonomous agents" (Kauffman, 2000 as cited in Deacon, 2012, p. 163). The control mechanism of life is by nature semiotic – a living organism does not react to information, but signs – as it realizes the connection between received information and the satisfaction of the goal – its self-maintenance.

From molecule to human: sign actions are involved in every level of life events

Sign actions – defined in this thesis as the creation of meaning, the transmission of meaning, and the construction of biosemiotic living sphere – are involved in every level of life events. Regarding the biological part of this work, we have taken an evolutionary point of view: starting from the fundamentals – macromolecules, to something more complex – the pathways for metabolic and informational exchanges enabling the organism's homeostasis, and finally to the sophisticated behaviors toward a psycho-linguistic world. Eventually, it is shown that cognition can exist from and at the cellular level; and a clear cut between the natural and the cultural aspects of life does not necessarily exist.

The biological facts examined in this thesis are:

Macromolecules: genes (1.2.1.4 the genetic code; 2.3.2 the genetic code extended; 5.3.2 alternative RNA splicing); proteins (2.2.2.1 protein structures).

Cellular functions: membrane transport (3.2.2; 3.3.2); metabolism (4.2.2; 4.3.2; 5.2.2); cellular signal transduction (6.2.2; 6.3.2).

Organismic functions: immune responses (7.3.2); homeostasis (8.2.2); the endocrine and nervous systems (8.3.1; 8.3.2); cognition and behaviors (1.3.1.2; 7.3.1.2; 7.3.1.3; 8.2.1); self-consciousness and intelligence (7.3.1.4; 9.2.1; 9.2.2; 9.3.1; 9.3.2).

The structure of the thesis

This thesis consists of three parts; each part is made of three chapters. In every chapter, semiotic theories are first presented; then, analysis of biological phenomena based on these theories are given. A review of the previous chapter and the presentation of the present one can be found at the beginning of every chapter. The three parts are arranged in a logical order: the models of biosemiotics signs and the definition of semiotic control in life can be found in Part I; the interactions between sign-using agents and the coordination of their selfmaintaining actions are discussed in Part II; finally, the development of complex cognitive mechanisms endowed with remarkable creativity and flexibility is addressed in Part III. As an interdisciplinary approach covering semiotics and biology, this thesis contains introductory content of both domains. Some concepts are explained in the text; the others are provided in the footnotes throughout as needed.



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PART I

THE SEMIOTIC NATURE OF LIFE

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CHAPTER 1

A BIOLOGICAL DEFINITION OF SIGN

1.1 INTRODUCTION

1.1.1 Review of Introduction

In Introduction, the characterization of life starts from its thermodynamic features. Life is a defiance of the increase of disorder in the Universe (Deacon, 2006; Schneider & Kay, 1994). The maintenance the orderliness of an organism requires the exchange of energy and matter between itself and its environment; order is imported from the environment to the organism and more disorder is created in the bigger system made of the organism and the environment (Ji, 2012, p. 8; Purves et al., 2004, p. 109).

Information is closely associated with the exchange of energy and matter. There are many types of information biologically relevant: the genetic sequence, protein structures, signaling pathways, sensorial stimulus, thoughts in language, etc. They are descriptions of an organism's self-maintaining actions, thus can be used to control and regulate these actions. Information becomes meaningful when it is connected to a self-maintaining action. Meaning is an important component of life. The aim of this thesis is to show that self-maintaining actions of organisms not only rely on causal relations imposed by the natural laws, they are also placed inside semiotic frameworks that specify the ways in which chemical and physical

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changes can take place. If self-maintaining actions are messages, life is a language as a system of rules which is responsible for the production of these messages. This is exactly the focus of biosemiotics as an emerging interdisciplinary science.

1.1.2 Presentation of Chapter 1

Semiotics is the study of signs. Briefly presented in Introduction, a sign is made of two different things where there is a connection between them, or simply put, "something stands for something else" (Nöth, 1995, p. 84). Here in Chapter 1, at the beginning of this work, it is necessary to start from a thorough definition of the sign in the biological context.

The first sign model may already be formulated in Aristotle, which has three components: "pragmata ('the things to which the sign refers'), the expressive element ('that which is in the voice'), and thoughts ('that which is in the mind')" (Violi, 1999, p. 744). In the contemporary time, the term "semiotics" is first used by John Locke (1690) in *Essay Concerning Human Understanding* where semiotics is considered as a science on the mental ability to use signs to acquire knowledge (Rattasepp & Kull, 2015). Semiotics is related to human mental life from its historical roots, but our study is not limited to human cognitive abilities. It should be noted that the sign models proposed in this thesis expand semiotic theories on the level of sign users – besides humans, there are cells, unicellular organisms (prokaryotic and eukaryotic), and non-human animals. The aim is to provide perspectives in redefining cognition from a developmental point of view.

Starting from the late nineteenth century, there appeared to be two main directions in semiotic research: interpretative semiotics inspired by the work of Charles Sanders Peirce, and structural semiotics, also referred to as "semiology" by Ferdinand de Saussure (Rattasepp & Kull, 2015). In Chapter 1, we start from introducing the classic sign models of Peirce and Saussure: the components, the definitions of "mediation through signs", and the characteristics of these theories. Then, two other sign models are presented and compared with the classic ones. One is the code model proposed by Marcello Barbieri showing that a sign is "two independent worlds that are connected by the conventional rules of a code" (Barbieri, 2008a, p. 578); the other is the teleological model from Victoria N. Alexander emphasizing that the creation and the use of sign is closely connected to a purpose (Alexander, 2013).

The first chapter of the thesis is about concepts – the definitions of information and meaning, as well as the definitions of the purpose-satisfying actions in the biosemiotic context. In Chapter 2 and Chapter 3, respectively, theories related to the code model and the teleological model are presented and discussed, with examples of their applications in analyzing biological facts.



1.2 SIGN AS INFORMATION-MEANING COMPLEX1.2.1 Saussure's theory of sign and the theory of code semiosis

1.2.1.1 Saussure's semiotics

Saussure's sign model was first elaborated to analyze linguistic signs; then, the model was transferred to the study of nonlinguistic signs. The Saussurean sign is dyadic, made of Signifier – a sound-image, and Signified – a concept (Figure 1.1) (Nöth, 1995, p. 59).

Saussure has emphasized that Signifier and Signified together form one sign²; they cannot be separated one from the other (Noth, p. 59). The inseparability between Signifier and Signified is compared to which between the two sides of a sheet of paper:

"Thought is the front and the sound the back; one cannot cut the front without cutting the back at the same time" (Saussure, 1916b: 113 as cited in Nöth, 1995, p. 59).

It is argued by Saussure that the relation between Signifier and Signified is an arbitrary one since it is determined by a social convention, not a material connection between the sound-image and the concept: "the idea of 'sister' is not

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² In this thesis, when modeling a sign, the components are written with the first letter in uppercase. For example: according to Saussure, a sign is made of "Signifier" and "Signified". Also, "sign" is distinguished from "Sign"; the latter is a component of a model of sign.

linked by any inner relationship to the succession of sounds s-ö-r which serves as its signifier in French" (Saussure, *CLG*, 100, 67 as cited in Holdcroft, 1991, p. 52)



Figure 1.1 Saussure's Sign Model. A sign is made of a Signifiant which is a sound-image and a Signified which is a concept.

In Saussure's semiotics, a sign is a mental entity which is independent of any external object – not even the sound-image represented by Signifier: "The latter is not the material sound, a purely physical thing, but the psychological imprint of the sound, the impression that it makes in our senses" (Saussure, 1916b: 66 as cited in Nöth, 1995, p. 60). Also, Saussure's mentalist conception of sign has ruled out the connection to the physical reality reflected as the differences between individual uses of sign (Nöth, 1995, pp. 60-61). Explicitly rejecting the existence of a referential object in his dyadic sign model, Saussure believes that nothing exists beyond the Signifier and the Signified in a sign system. His sign system is not used to mediate between thought and reality: "the linguistic sign unites, not a thing [chose] and a name, but a concept and a sound-image" (Saussure, 1916b: 66 as cited in Nöth, 1995, p. 60). In conclusion, Saussure's sign is created inside a system of collectively agreed conventions in the form of psychological institutions that are (relatively) independent of the reality; meaning appears when concepts coincide with sound-images in the human mind.


Moreover, Saussure has associated the economics-inspired concept of value with meaning (Holdcroft, 1991, p. 109) It is proposed by Saussure that there are two aspects of value: (1) dissimilar things that can be exchanged based on a given value; (2) similar things that can be compared based on a given value (Saussure, CLG, 159, 115 as cited in Holdcroft, 1991, p. 109). The first aspect is referred to as the process of signification - the association between Signifier and Signified to produce meaning - a sign is seen as the counterpart of other signs. The second aspect suggests that the relationship between a sign and other signs determine the value of the sign. Saussure claimed that: "Language is a system of interdependent terms in which the value of each term results solely from the simultaneous presence of the others" (Saussure, CLG, 159, 114 as coted in Holdcroft, 1991, p. 108). An example used by Saussure to explain value is comparing French "mouton" to English "sheep": The value of the English word is different from the French one because English "sheep" can only mean the animal, given there is an opposition between English "sheep" and English "mutton"; while French "mouton" can mean both the animal and its meat (Saussure, 1916b: 11415 as cited in Nöth, 1995, p. 61). The differentiated use of "sheep" in the English language system accounts for the difference in meaning (when it is opposed to "mutton"). Central to the Saussurean structuralism, the syntagmatic and associative relations between linguistic units play an important role in the determination of their meaning (Holdcroft, 1991, p. 112).

1.2.1.2 The theory of code semiosis

As a major contributor to the theory of code semiosis, Barbieri (2008a, 2008b) has built a sign model made of Sign, Meaning, and Code (Figure 1.2). Barbieri (2008a) explained that, "a semiotic system, is always made of at least two distinct

worlds: a world of entities that we call signs and a world of entities that represent their meanings" (p. 578); also, "a bridge between the two worlds can be established only by conventional rules, i.e., by the rules of a code" (p. 578).

Nevertheless, the most important concept in Barbieri's semiotics is that these three components of sign do not come into existence by themselves; they are produced by the same agent named a codemaker (Barbieri, 2008a). The concept of sign making by a codemaker fits right in the biological context; for example, proteins, essential to a variety of functions in living organisms³, are considered "manufactured" molecules (Barbieri, 2008a). By introducing the concept of codemaker, Barbieri (2008a, 2008b) emphasized that there cannot be semiosis without an act that connects Sign and Meaning by establishing rules. According to Barbieri (2008b) "an act of semiosis is always an act of coding" (pp. 25-26).



Figure 1.2 The Model of Code Semiosis. A sign is made of entities from two worlds – Signs and Meanings – connected by a code.

Saussure's Signifier and Signified as mental entities are evidently different from Barbieri's Sign and Meaning which can correlate to macromolecules inside a cell (DNA and protein) (Barbieri, 2008a, 2008b). Barbieri's semiosis focuses on a more generic level of living organisms – the level of the cell. On the level of human

³ Citing Purves, Sadava, Orians, and Heller (2004): "The functions of proteins include structural support, protection, transport, catalysis, defense, regulation, and movement." (p. 38).

mental life, Barbieri (2008b) suggested that signs are used in a mediated manner for humans to know the reality. "[Humans] have a built-in drive to make sense of the world [...] when we give a meaning to something, that something becomes a sign for us" (p. 25).

In Saussure's semiotics, the relationship between Signifier and Signified is characterized as arbitrariness, namely the result of an outside system of rules collectively obeyed (Holdcroft, 1991, p. 52). Barbieri (2008a, 2008b) acknowledged the mutual independence between Sign and Meaning by suggesting a system of arbitrary conventions that is responsible for connecting the two: in protein production, for example, the sequence of DNA determines, arbitrarily, the sequence of amino acids in a produced protein. However, the arbitrariness defined by Barbieri is different from the one defined by Saussure (Barbieri, 2008a, 2008b). For linguistic signs, the codemaker (i.e. humans) of the grammatical rules is outside the system (i.e. language); thoughts are inevitably separated from the reality. For signs involved in the production of proteins, the codemaker (i.e. RNA) of the genetic code is a part of the system (i.e. the cell); the symbolic and the material aspects are integrated into the same living system.

1.2.1.3 The attention on the "third entity"

On the "third entity" – named as rules, conventions, or code in the sign models of Barbieri and Saussure, the difference is remarkable. In the linguisticsinspired Saussurean model, a Signifier is always connected to a Signified in the sense that this connection is random and stable within the given (linguistic) system. It implies, to some extent, that anything can be a sign of something else. On the other hand, postulated by the code model of Barbieri, the connection between Sign and Meaning should not be seen as something that already exists and keeps existing without any effort of coding – the act of rule-establishment. This connection (i.e. code), in this sense, is neither random nor stable. The Sign is only meaningful to the agent (i.e. codemaker) who created and constantly maintains the connection. Although Barbieri (2013a, 2013b) explicitly distinguishes between code semiosis and interpretative semiosis, that is, semiosis based on code is not an act of interpretation, his code is nevertheless reality-based. Barbieri (2013b) argued that: "[...] the names are no longer arbitrary labels but true 'observables' because they describe characteristics that we observe in Nature." (para. 17).

In the biological reality, as many examples can show, without rules, there are only things, not signs: (1) In eukaryotic genes, non-coding sequences (introns) are interspersed with coding ones (exons); they cannot be converted into proteins (Purves et al., 2004, p. 285); (2) Humans with their sensory organs cannot perceive magnetic field, but homing pigeons can. The pigeons use it for navigation (Bookmam, 1977). We believe that Barbieri's statement "signs do not come into existence on their own" (Barbieri, 2008b, p. 26) should not be understood as an implication of the ability to interpret⁴, but a distinctive feature of living organisms, which is the creation and the use of sign. As Battail (2009) suggested:

Biosemiosis in Barbieri's meaning implies the existence of natural conventions, a seeming oxymoron. This existence has far-reaching consequences, tending to blur the frontier between culture and nature, and suggesting that the truly significant divide lies between the living and the inanimate. (p. 325)

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⁴ The issue of interpretation is addressed by Alexander in formulating the teleological model of sign, according to which semiosis can include both mental and non-mental instances (see 1.3.1.2).

Signifier and Signified are defined by Saussure as mental entities (Nöth, 1995, p. 60), implying that human mind is a premise of semiosis. The subjects of biosemiotics studies, however, are not limited to human nor human psychology. This difference is addressed by Barbieri as the determining role of codemaker. According to Barbieri (2008a, 2008b), Sign, Meaning and Code are brought into existence by the same codemaker, thus, the nature of the codemaker determines the nature of the sign. If there is a boundary between culture and nature, despite that biosemiotics does not seem to support such separation, the distinction is made during the process of coding. When the codemaker is the human mind, mental entities as Signifier and Signified are created and connected to each other; when the codemaker is RNA-based molecular machines, the sequence of genetic information stored in DNA is correlated to the sequence of amino acids in a protein (Barbieri, 2008a, 2008b).

1.2.1.4 Code semiosis exemplified by the genetics

In 1957, Francis Crick suggested a model for information flow that is known as the central dogma of molecular biology (Tropp, 2012, pp. 22–23). By the mid-1960s, the central dogma was extensively supported by experimental evidence; the enzymes that catalyze the "flows" of genetic information were discovered (Tropp, 2012, p. 23). Simply put, the central dogma states that "the genetic information flows from DNA to DNA (DNA replication), from DNA to RNA (transcription), and from RNA to a polypeptide (translation)" (Figure 1.3) (Tropp, 2012, p. 23).⁵

⁵ The central dogma of molecular biology may be too simple to describe the complex cellular mechanisms of information processing. For example, the primary transcripts of the eukaryotic genes (pre-mRNA) contain both coding and non-coding regions and the coding regions should be spliced

The genetic code required in the production of proteins is used by Barbieri to illustrate the semiotic nature of life (Barbieri, 2008a, 2008b, 2013b).



Figure 1.3 The Central Dogma. As indicated by the arrows, information flows from DNA to RNA to proteins; DNA can replicate itself. Adapted from *Encyclopedia of genetics, genomics, proteomics, and informatics* (Entry *Central dogma,* p. 309) by G. P. Rédei, 2008, Springer Science & Business Media. Copyright 2008 by Springer. Adapted with permission.

It is proposed and confirmed by Crick that an RNA molecule forms as a complementary copy of one DNA strand of a gene; this produced RNA, called messenger RNA (or mRNA), serves as a template to produce proteins (Purves et al., 2004, p. 236). Then, Crick proposed the existence of an adapter molecule that binds a specific amino acid while recognizing a sequence of nucleotides carried by mRNA; these adapters, called transfer RNA (or tRNA), were also experimentally identified (Purves et al., 2004, p. 236). Summarily, a gene is transcribed to produce a mRNA; then, the mRNA is translated by tRNA into linked amino acids of a corresponded sequence.



together to make a functional transcript (mature mRNA) for the synthesis of proteins (Purves et al., 2004, p. 285-290). RNA splicing is addressed in 1.2.2.1 and 5.3.2. For more information, See Shapiro, J. A. (2009). Revisiting the central dogma in the 21st century. *Annals of the New York Academy of Sciences*, *1178*(1), 6-28.

Before examining the genetic code, it is necessary to know that: (1) DNA molecules are made of linear chains of nucleotides and proteins are made of linear chains of amino acids (Purves et al., 2004, p. 38; 54). (2) The four types of nucleotides of DNA (i.e. deoxyribonucleotides) are distinguished by their nitrogenous bases – adenine (A), guanine (G), cytosine (C), and thymine (T) (Purves et al., 2004, p. 54). In RNA, there are also four types of nucleotides (i.e. ribonucleotides). Three of the four bases are the same as in DNA; except thymine (T) is replaced by uracil (U) in RNA (Purves et al., 2004, p. 55). (3) According to the principle of complementary base pairing, in double-stranded DNA, adenine always pairs with thymine (A-T) and cytosine always pairs with cytosine (C-G) (Purves et al., 2004, p. 55). Also, following the same principle, RNA can pair with single-stranded DNA, except adenine pairs with uracil, not thymine (A-U) (Purves et al., 2004, p. 55). (4) There are 20 different amino acids found in protein (Purves et al., 2004, p. 39). Then, the question is: What is the corresponding relation between the sequences of nucleobases and amino acids? In fact, a real code is responsible for relating the genetic message carried by mRNA to a specific sequence of amino acids.

The genetic message in a mRNA molecule can be seen as "a series of sequential, non-overlapping 'words'"; each word (called a codon) is made of three "letters (i.e. nucleobases)" and corresponds to a specific amino acid (Purves et al., 2004, p. 239). The correspondence between codons and amino acids are shown in the table below (Figure 1.4). Accordingly, Barbieri (2008a, 2008b, 2013b) suggested that genes and proteins, as two individual words, are connected by an arbitrary code brought into existence by the codemaker – RNA.

[U		с		A		G		
ł	U	UUU	Phenyl-alanine	UCU	Serine	UAU	Tyrosine	UGU	Cysteine	U
		UUC		UCC		UAC		UGC		С
		UUA	Leucine	UCA		UAA	STOP	UGA	STOP	Α
		UUG		UCG]	UAG		UGG	Tryptophan	G
	С	CUU	Leucine	CCU	Proline	CAU	Histidine	CGU	Arginine	U
		CUC		CCC		CAC		CGC		С
		CUA		CCA		CAA	Glutamine	CGA		Α
		CUG		CCG		CAG		CGG		G
	Α	AUU	Isoleucine	ACU	Threonine	AAU	Asparagine	AGU	Serine	U
		AUC		ACC]	AAC]	AGC		с
		AUA		ACA		AAA	Lysine	AGA	Arginine	Α
		AUG	Methionine; START	ACG		AAG		AGG		G
	G	GUU	Valine	GCU	Alanine	GAU	Asparagine	GGU	Glycine	U
		GUC		GCC]	GAC		GGC		с
		GUA		GCA		GAA	Glutamic acid	GGA		Α
		GUG		GCG		GAG		GGG		G

Figure 1.4 The Universal Genetic Code. Genetic information is encoded in mRNA in codons – the three-lettered unit made up of the bases uracil (U), cytosine (C), adenine (A), and guanine (G); each condon corresponds to an amino acid. Adapted from "Mechanism of expanding the decoding capacity of tRNAs by modification of uridines" by A. Weixlbaumer, F. V. Murphy IV, A. Dziergowska, A. Malkiewicz, F. A. Vendeix, P. F. Agris, & V. Ramakrishnan, 2007, *Nature Structural & Molecular Biology*, 14(6), para. 8.

From the table, we can see that there are more codons than different amino acids in proteins: the combinations of the four "letters" – the nucleobases of RNA – U, C, A, G give 64 (4³) different three-letter codons, but these codons determine only 20 amino acids (Purves et al., 2004, p. 239). In fact, the codon AUG not only codes for the amino acid methionine but also functions as the initiation signal for translation (i.e. a start codon); three of the codons – UAA, UAG, and UGA – all signal for the termination of translation (i.e. stop codons); besides, an amino acid is coded by different codons (Purves et al., 2004, pp. 239–240). The phenomenon is referred to as redundancy (Purves et al., 2004, p. 240).



As a matter of fact, many people experience redundancy in their daily lives by using their languages. English, for example, there is an evident mismatch of quantity between the 26 letters of the alphabet and the concepts to signify. The problem is solved with the creation of words, as combinations of different letters in different orders, to correspond to various concepts. Usually, the correspondence is not of a one-to-one type – a word may have several different meanings. The situation is addressed in Saussure's concept of value (see 1.2.1.1): the opposition between concepts makes the sign semantically different. Furthermore, the rules by which letters are combined and arranged can be considered code defined in Barbieri's semiotics. In other words, it can be postulated that codes are created as solutions to maintain a qualitative match between Signs and Meanings (Neuman & Nave, 2008). This issue is discussed in detail in 2.3.1.

1.2.2 Defining information and meaning

1.2.2.1 Distinguishing natural and conventional signs

Barbieri (2008a) believes that the way in which protein is produced separates it from "inorganic" molecules ⁶. In the "inorganic" world, the structure of molecules is determined by the chemical bonds⁷ that exist between their atoms – by internal factors. In living systems, instead, proteins are made by molecular machines (represented by RNA) which bind amino acids in the order prescribed

⁶ We believe that the term "inorganic" is used by Barbieri to refer to chemical compounds of a nonbiological origin. The absence of carbon in their compositions should not be considered a criterion here. ⁷ It is defined that: "A chemical bond is an attractive force that links two atoms together to form a molecule." (Purves et al., 2004, p. 20) Several kinds of chemical bonds are addressed in 2.2.2.1.

by an external template of nucleotides – the reason why Barbieri (2008a) calls proteins "manufactured molecules" and considers life as "artifact-making" (p. 579). The two types of connection are addressed by Barbieri as the distinction between symptoms and symbols – natural and conventional signs (Barbieri, 2008a). A physical link exists between Sign and Meaning in natural signs, while in conventional signs, the relation between Sign and Meaning is determined by arbitrary rules.

At the molecular level, DNA replication⁸ and the transcription from DNA to mRNA (pre-mRNA) are cases where natural signs are involved: the processes are based on the complementary mapping of nucleobases⁹ between the template and the produced molecule. The relation between them is physically causal. On the other hand, conventional signs are involved in the translation of mature mRNA to amino acids. The correspondence between mature mRNA base triplets (i.e. codons) and amino acids of a given protein is by nature arbitrary, no other than the rules used to connect sound-images and concepts in a linguistic system. Kjosavik (2014) considers the code as a "reading frame" imposed upon the mRNA transcript (p. 386). More precisely, the convention is used to create the "higher order of organization (into triplets)" to realize a qualitative match between genetic information and amino acids (Kjosavik, 2014, p. 386).



⁸ The division of a cell requires that the genetic information of the parent cell to be replicated and distributed to the daughter cells (Purves et al., 2004, p. 165). The replication of DNA, considered "semiconservative", takes place in two steps – the two strands of DNA are seprated so that each can serve as a template for base pairing; nucleotides are connected to form a new strand with its sequence determined by the template strand based on the principle of complementary base pairing (Purves et al., 2004, p. 222).

⁹ Complementary base pairing is involved in both DNA replication and the transcription from DNA to mRNA.

In both cases presented above, DNA provides the information needed for the assembly of the second molecule (a replicated DNA/a pre-mRNA, or amino acids); however, as the production rules are different, it is suggested by Barbieri that the meaning of this information is also different in each case (Barbieri, 2008a). Barbieri (2008a) believes that information (Sign) and meaning (Meaning) are not intrinsic properties of the molecules that carry them; they are produced by a codemaker during the process of coding (semiosis).

1.2.2.2 Information and meaning

Comparing words as a sequence of letters and genetic information as a sequence of nucleotides, both are combinations of subunits arranged in a specific order. The specificity for the arrangement of a sequence of letters or nucleotides is evidently important – a misspelled word is meaningless to the readers; a change of one nucleotide in DNA (i.e. point mutations) may result in a different or non-functional protein (Purves et al., 2004, pp. 251–252). Barbieri (2013b) concluded two characteristics of sequence information: (1) A sequence is a syntactic entity which can be connected to different meanings under different rules. (2) The specificity of a sequence cannot be measured quantitively or qualitatively; the natural order of the subunits can only be named – it is a "nominable entity" (para. 17-18). Barbieri (2013b) has emphasized that nominable entities are not names because they naturally exist in the physical reality and susceptible to observations; for instance, the specificity according to which molecular machines build proteins from DNA. Therefore, it indicates that the semiotic aspect of life is not a metaphor, but something that concretely exits.



Information and meaning, defined by Barbieri (2013b), correspond to sign components - Sign and Meaning. An important feature of Barbieri's definition of sign is that Sign and Meaning are not properties of sequences, but something brought into existence by a codemaker (Barbieri, 2013b). In other words, sequence information cannot be qualified as information; not until it is connected to meaning by a code (i.e. the process of semiosis). Barbieri's definitions of information and meaning are used as a theoretical basis for this thesis in analyzing biological phenomena. The distinction between sequence information and information, in fact, indicates that semiosis in the biological world is without doubt reality-based. Artmann (2009) argued that sequence information, the relational order of the subunits of biological signal/message, only counts for the syntax of the system; information, on the other hand, concerns the semantics – the "standing for" relations, the exploitation of sequence information by the cell based on codes that are "chemically arbitrary¹⁰", the manufacturing of biologically important molecules (p. 32). The pragmatic aspect of the system relates to the "purpose" of the mapping/exploitation/manufacturing (Artmann, 2009). It is discussed in the presentation of the second model of the biological sign (see 1.3.1.2).

Remember that Barbieri distinguishes between two types of signs – natural and conventional signs (see 1.2.2.1). They are different one from the other because of the nature of the connection between Sign and Meaning – a physically causal one for the former and an arbitrary one for the latter. Barbieri (2013b) does not qualify the connection in natural signs as a code; he used the term "copying" instead of "coding" to describe the creation of natural signs. Yet, Barbieri (2013b)

¹⁰ It is written in the original text in French "chimiquement arbitraire" (Monod, 1970 as cited in Artmann, 2009, p. 32) for "chemically arbitary" in English.

suggested that during the process of "copying", as the sequence information is used to create a copy of itself, it becomes information which is endowed with both the syntactic and the semantic dimensions. In this thesis, we made a slight modification on Barbieri's distinction between copying and coding: copying can be seen as a special case of coding – when the code used to build the connection happens to be a physical one; thus, coding is used here to denote the building of any kind of connection between Sign and Meaning (or between information and meaning). The meaning of a natural sign and a conventional sign is respectively specified as internal meaning and external meaning.

1.3 SIGN IN A GOAL-ORIENTED MODEL

1.3.1 Peirce's theory of sign and the theory of teleological semiosis

1.3.1.1 Peirce's semiotics

Different from the Saussurean semiotics which characterizes signs as strictly conventional, independent from external objects and individual uses, Peirce's theory of signs represents a phenomenological approach as it defines signs as something that can be experienced by its users and through which the reality is known to them (Rattasepp & Kull, 2015). The sign model of Peirce is made of three elements: Representamen ("sign [Sign]"), Object ("thing signified"), and Interpretant ("cognition produced in the mind") (Figure 1.5) (Peirce, § 1.372 as cited in Nöth, 1995, p. 42). In a more elaborated definition of sign, Peirce stated that:



A sign [Sign], or representamen, is something which stands to somebody for something in some respect or capacity. It addresses somebody, that is, creates in the mind of that person an equivalent sign, or perhaps a more developed sign. That sign which it creates I call the interpretant of the first sign. The sign stands for something, its object. It stands for that object, not in all respects, but in reference to a sort of idea. (Peirce, § 2.228 as cited in Nöth, 1995, p. 42)



Figure 1.5 Peirce's Sign Model. A sign is made of Representamen, Object, and Interpretant. The Representamen evokes the Interpretant defining the Object.

Although both involve the mental life of humans, Peirce's sign model is different from the one of Saussure. Based on Peirce's definition of sign, generally, Representamen can correspond to Saussure's Signifier, and Object to Signified; the third component, Interpretant, which is the understanding that an individual sign user has on the Representamen-Object relation, however, indicates that signification is an instance of interpretation, not the pre-determined result of a set of arbitrary rules as what is suggested by Saussure (Atkin, 2013). According to Peirce, the meaning of a sign is conveyed through the interpretation of its users (Atkin, 2013). Barbieri (2008b) suggested that:



The real difference between Saussure and Peirce, therefore, is not between a dyadic and a triadic model of semiosis. It is between a model based on coding and a model based on interpretation. More precisely, between a model based on external coding and a model based on internal interpretation. (p. 24)

Central in Peirce's semiotics, there are at least two features of Interpretant: (1) Interpretant characterizes the understanding of a sign user on the relationship between a Representamen and an Object and in fact, this understanding is not static, it can be completed by more acts of sign use; therefore, it is better to think that Interpretant provides an interpretation of the Representamen that enriches the knowledge of the represented Object (Atkin, 2013). (2) The way in which Representamen signifies the Object shapes the understanding of the users on their relationship; for example, the way in which smoke (Representamen) represents fire (Object) is by focusing people's attention on the physical connection between them (Atkin, 2013). It is important to note that the connection between a certain set of Representamen and Object may not be known to some people (thus they are not the users of these signs), or the understanding of this connection may change (Atkin, 2013). In other words, the meaning of a sign depends on the interpretation(s); and interpretation(s) are constrained by both the user and the physical reality.

The role played by Interpretant in connecting Representamen and Object does have some resemblance to the role of Codemaker defined in Barbieri's sign model. Both models consider that for something to represent something else, there should be a process of connection in which the meaning of the sign is determined. The difference between the two, however, is also on the connection. It appears that interpretation manifests great unpredictability when it comes to the determination of meaning. On one hand, the ability of interpretation varies among users. On the other hand, the nature of Object constrains the nature of the sign – as the constraint can be qualitative, existential or physical, and conventional or law-like, signs are classified as indexes, icons, and symbols (Atkin, 2013). The code semiosis acknowledges the particularity of the connector (called a codemaker), but strictly speaking, the connection is considered an arbitrary one. Thus, signs created by a code are symbols.

In Peirce's theories of signs, he distinguished between Objects understood at a given point and at the end of the inquiry – the former is called "immediate object" and the later "dynamic object" (Atkin, 2013). Sign using is considered an inquiry – a chain of signs is generated leading to a full understanding of an Object (Atkin, 2013). An immediate object can be given any moment when the sign is used; while the dynamic object represents when "our scientific knowledge is complete" (Hookway, 1985 as cited in Atkin, 2013). It is suggested to consider the dynamic object as "the goal and end point that drives the semiotic process", and the immediate object as "our grasp of that object at any point in that process" (Atkin, 2013).

As an inquiry can be divided into different steps, in Peirce's theories, there is also a distinction between Interpretants – the immediate interpretant, the dynamic interpretant and the final interpretant (Atkin, 2013). The immediate interpretant is a "general definitional understanding" of the relationship between Representamen and Object (Atkin, 2013). The dynamic interpretant is the understanding of this relationship at some actual instance in the chain of signs (i.e. during the process of inquiry) – thus, "an incomplete understanding, or interpretation, of the dynamic object" (Atkin, 2013). The final interpretant marks the completion of our understanding of the dynamic object, thus "where the immediate object and the dynamic object coincide" (Atkin, 2013). According to



Peirce, the final interpretant as "an ultimate opinion" on a given matter can be used to decide whether an interpretation is true (Peirce, 1958, Volume 8, 184(1909) as cited in Atkin, 2013). In other words, at the end of an inquiry, normativity is established, conventionalizing the creation of meaning.

1.3.1.2 The teleological model of sign

The teleological model of sign proposed by Alexander is inspired by the Peircean semiotics, Thomas L. Short's teleology, as well as theories from other biosemioticians such as Stanley N. Salthe, Claus Emmeche, Søren Brier, Alexei A. Sharov, etc. (Alexander, 2013). It is made of Sign, Response, and Objective (Figure 1.6).

Sign using is defined by Peirce as an interpretation-generating process in which sign users develop the knowledge of a certain matter (Atkin, 2013). Alexander (2013) agrees with Peirce on that reality can be known through signs, but puts forward that: (1) Interpretant which prerequires a human mind cannot be the case for all living organisms; a more generic term, "Response", is proposed to replace it. (2) For living organisms, the acquirement of knowledge or the learning of the truth should be a means to an end, which is, ultimately, the survival of individuals and the species. As a result, Object in the Peircean sign model is replaced by Objective. In conclusion, according to Alexander (2013), meaning is created when an organism responds to a Sign to realize an Objective.



Figure 1.6 The Model of Teleological Semiosis. A sign is made of Sign, Objective, and Response; the Sign is recognized as a means to achieve the Objective thus evokes the Response accordingly. Adapted from "Creativity: self-referential mistaking, not negating" by V. N. Alexander, 2013, *Biosemiotics 6*(2), para. 4. Copyright 2012 by Springer Science & Business Media B.V. Adapted with permission.

Alexander (2013) suggested that the term Response is accurately used because not only the range of the studied subject is expanded comparing to classic semiotics – from human mental life to the cellular activities of all living organisms – but also it highlights the semiotic nature of life by distinguishing semiotic processes from the mechanical ones. Alexander (2013) emphasized that a response is purposeful as it answers to the organism's need of self-maintenance. A reaction, on the other hand, can be the consequence of material changes. Citing Alexander (2013): "The response must be a purposeful one, one that is done because it always or usually leads to a self-maintaining effect. This distinguishes a response from a mechanical reaction." (para. 6).

It should be noted that purposefulness defined by Alexander (also adopted in formulating the theoretical basis of this thesis) cannot be confused with intentionality, the latter is characterized by mental states directed upon an object, such as beliefs, desires, regrets, etc. (Lycan, 1999). Both Alexander (2013) and Short (2007) have used examples of the behavior of non-human animals to show that the responses to signs are goal-oriented. Short (2007) noted that whatever the type of responses, deliberate or automatic, the capacity to respond exists for the purpose of producing such responses, that is, survival, growth, or self-replication; and those responses are always constrained in a purposeful program of behaviors. It appears that the teleological semiosis proposed by Alexander and Short operates on common features of living organisms leading to the direction of selfmaintenance and it does not distinguish between the perspectives of study – cellular biology, zoology, social sciences, etc.

Short (2007) has proposed a sign model made of Sign, Response, Object, and Purpose. He explained it with an example: A dear flees (Response) after being startled by a sudden noise (Sign) is based on an experienced correlation between noises and predators (Object); although the correlation may not stand true in that moment, the deer avoids the fate of becoming the meal of a predator (Purpose) (pp. 156-157). Alexander (2013) suggested, then, to "fold" Object into the dimension of Purpose (termed as Objective in her own model) (para. 7). Alexander (2013) argued that it is extensively agreed in Short's work that the ultimate purpose of living organisms is their self-maintenance. This is, in fact, a "general type" of objective that can be realized in many ways – "many-to-one mappings" (para. 8). Therefore, an organism encounters many Signs in life associated with the opportunities to realize the Purpose of self-maintenance, despite the variety of the actual Objects that correspond to these Signs. Modifying Short's model, Alexander (2013) proposed that it is rather the Objective that determines the nature of a Response to a Sign, not the Sign-Response relationship. Also, by saying that "the more dissimilarity is tolerated, the more complex the responding system" (para. 8), Alexander (2013) believes that creativity is generated through teleological semiosis.

Alexander's sign model is illustrated by an example like the one of Short (Figure 1.7): After detecting an odorant of rabbit (Sign), a wolf runs to the direction of that odorant and getting ready for the hunt (Response) (Alexander, 2013, para. 8). The Response is not determined by the Sign-Object relationship – rabbits smell, but the Purpose of self-maintenance. In other words, the wolf does not respond to a particular rabbit, but to the possibility of having its goal realized, be it successful preying, food consummation, securing the intake of free energy, or ultimately, the survival of the animal and its offspring. Alexander (2013) said that "rabbits are only meaningful to wolves insofar as they are a means of survival" (para. 8).



Figure 1.7 Survival as the Ultimate Objective. The wolf responds to the odorant of rabbit not to achieve the purpose of catching a specific rabbit but to achieve the purpose of survival. Adapted from "Creativity: self-referential mistaking, not negating" by V. N. Alexander, 2013, *Biosemiotics 6*(2), para. 8. Copyright 2012 by Springer Science & Business Media B.V. Adapted with permission.

Alexander's distinction between Object and Objective can be related to the distinction between immediate object and dynamic object in Peirce's semiotic theories. A physical thing, a rabbit preyed by a wolf, is an immediate object mediated through a sign in a chain of signs, leading to the objective of the wolf's self-maintenance, which is the dynamic object. An immediate object is referred by Alexander as an immediate sign to a semiotic objective – to survive, the wolf must respond to a sign rather "semiotically" than "mechanically" (Alexander, 2013).

The wolf chased after the odorant of rabbit but ended up finding no rabbit in that place, its hunting response can only be explained with semiotic causation (not material causation)¹¹ – the wolf responds to an Objective instead of an Object (Alexander, 2013). The wolf should eventually realize that another food item (a chicken, for example) can also satisfy its purpose of survival.

While the use of signs is considered the way to reach a full understanding of something in the Peircean semiotics (Atkin, 2013), Alexander (2013) agrees on this point by suggesting that "Responses to signs are based on past experiences" (para. 14). As it is shown in the example given above, responding mistakes are inevitable. However, living organisms can learn from their mistakes in an active manner: Usually, more trials lead to an increase of successful results; or by accident, new Sign-Object relationships can be learned and categorized as new types of Response. A detailed analysis of the role played by "mis-responses" (Alexander, 2013, para. 13) in the survival of an organism can be found in 3.3.1.2. In conclusion, to cite Alexander (2013),

If the mistaken response turns out to be advantageous, the agent will develop greater flexibility insofar as it has acquired a new goal, a new way to survive or self-affirm. [...] Every semiotic response is based on what has happened before. A response to a present situation can be 'wrong,' but better. (para. 13)



¹¹ The Four Causes Doctrine of Aristotle (384 – 322 B. C.) formulated based on the daily experiences of humans question the causes of the changes in the macroscopic world (Ji, 2012, p. 191). They are: the material cause (What is it made out of?); the efficient cause (How does it work?); the formal cause (What is it?); and the final cause (What is it for?) (Ji, 2012, p. 191).

1.3.1.3 Making use of the code model

Comparing the code model and the teleological model of semiosis, one of the major differences is the connection between Sign and the mediated content. According to Barbieri (2008a, 2008b, 2013b), the connection between Sign and Meaning is determined by Code resulted from the effort of a codemaker. Alexander (2013) proposed that, on the other hand, the Response to a Sign is driven by a Purpose as a "general type" of objective (para. 8), which for living organisms, should be their self-maintenance. In teleological semiosis, a Response marks an instance of the inquiry of a given matter which may or may not successfully achieves the Purpose of the sign user. If it does not, the sign user can adjust to another response while learning and/or discovering something new from the mistake. However, the arbitrary Code proposed and defined by Barbieri does not seem to allow such fallibility; because mistakes are considered semiotically invalid and they cannot exist in the sign system in the first place.

Barbieri (2012) has argued that the problem with learning and creativity can be naturally taken care of because the cell is autopoietic¹². What is referred by Barbieri as "codepoiesis" is that after the genetic code gave rise to the first cells, the subsequent evolution operates as two complementary processes – one for the generation of new codes and the other for the conservation of the existing ones (Barbieri, 2012, para. 2). The appearance of a new code is described by Barbieri (2008a) as a "sudden event" in the history of life and the new code does not abolish the previous ones (p. 592). Barbieri (2008a) has concluded the discovery of several codes in the work of code semiosis: the splicing codes, the signal



¹² Autopoiesis: the concept was introduced in 1972 by Humberto Maturana and Francisco Varela to describe the self-producing patterns observed in living cells (Di Paolo, 2005). A detailed presentation of autopoiesis can be found in 7.2.2.2.

transduction codes, the cytoskeleton codes, and the compartment codes¹³. What Barbieri emphasized is that the genetic code is stable and has stayed that way for billon of years – "While morphological structures did rise and fall countless times, the 'deep' organic codes have never been removed. This tells us that they truly are the fundamentals of life, the invariants that persist while everything else is changing." (Barbieri, 2008a, p. 592).

One qualified as stable, while the other as flexible, however, it is possible to integrate code semiosis and teleological semiosis. Alexander (2013) has suggested that the genetic code can be operating for the purpose of "the continued survival of the codemaker" via the production of protein (para. 12). A similar point of view is issued by Richard Dawkins in his book The Selfish Gene (2006). According to Dawkins (2006), an organism is the "survival machine" for its genes and the evolution of genes is essential under the pressure of natural selection (p. 21). As a matter of fact, mutations spontaneously appear in the replication, the transcription and the translation of DNA at a very low rate - usually much lower than one mutation per 10⁴ base pairs per DNA duplication (Purves et al., 2004, p. 254). Mutations do not promote evolution; the outcomes can be harmful, beneficial, or neutral to the fitness of the concerned organism or species (Purves et al., 2004, p. 254). However, mutations are responsible for providing the raw material needed for the evolution of genetic complexity; if random mutations lead to the production of useful proteins, the new gene is more likely to be kept by natural selection (Purves et al., 2004, p. 254). In this sense, with the two types semiosis combined, a system is both reliable and resourceful in achieving goals. Such models are presented and disused in 4.2.1.1 and 4.3.1.1.

¹³ In this thesis, the semiotics of RNA splicing is addressed in 5.2.2; the semiotics of signal transduction can be found in 6.2.2 and 6.3.2.

1.3.2 Defining purpose

1.3.2.1 Directionality and originality

In Alexander's model of the teleological sign, Objective which determines the Response to a Sign is defined as a general one, meaning that there can be a variety of ways to achieve it. According to Short (2007), a purpose is "a type of outcome for which an agent acts or for which something was selected as a means" (p. 110). Agreeing with this point of view, Alexander (2009) suggested that Responses are selected by agents based on the Objective. Then, Alexander (2009) continued that when biological system continuously responds under an Objective, it shows "self-organized emergent order" (p. 87), which she named as directionality. The term "self-organization" ¹⁴ is used to describe a teleomatic character or a kind of directedness observed in some of the general properties of bodies studied in physics (Emmeche, 2004). The directedness can be either the tendency towards disorder in an isolated system characterized by the second law of thermodynamics, or the tendency opposing the first one (i.e. the one toward the equilibrium) of a system (e.g. living organisms) open to its environment from which it imports free energy to maintain its dissipative structure (Emmeche, 2004).

Short (2007) suggested that although purposeful actions may appear mechanical, they are distinguished from the mechanical ones because when they fail to realize the purpose, they can be modified. Besides acknowledging the



¹⁴ Self-organization is refered to as the appearance of structure or pattern without an external agent imposing it (Heylighen, 2001). It is believed that dissipative structures (presented in Introduction) are self-organizing (Prigogine & Nicolis, 1985). A detailed presentation of self-organizing complex systems can be found in 7.2.2.1.

fallibility of responses, Short (2007) also implied that, for living organisms, parallel mechanisms are involved in the selection of responses:

Potential selection for a type of effect is built into purposeful action. But, in addition, to be purposeful an action must be a mode selected for the type of effect it selects for. And that selection must either have been natural, in the evolution of the agent's species or by the agent itself (in that case, we speak of the agent as choosing the purpose for which it acts). (p. 111)

In this thesis, we believe that the directedness as the self-organizing effects of living organisms results from both natural selection and their adaptive behaviors while the former select genetic variants mechanically, the latter represents a semiotic means to increase fitness. The analysis on the roles of the two mechanisms and their interplay can be found in 3.2.1. Indeed, among the various ways that a living organism adopts to reach a goal, some may be genetically preprogrammed and some others may have to be learned. The ability to learn new ways to respond purposefully is important for the organism facing changes in their internal and external environments. Alexander (2009) suggested that the interaction between a directional system and an Object that leads to a new functionality of the system can be qualified as originality. Original actions are necessary "mis-responses" based on the existing Sign-Object relationships, yet Alexander (2009) believes that original and directional signs are not completely irrelevant – "Originality occurs when effectual, but accidental, indexical or iconic relationships are found between distinct thoughts/responses/signs." (p. 88.). As a result, the original signs are selected by a system based on the directional ones; inevitably, there is a causal relationship between the two.

In the example of the rabbit-hunting wolf, sensing the odorant of rabbit and succeeding in capturing the rabbit is directionality; while sensing the odorant, finding out that there is another animal, and learning that it can also satisfy the goal of having a meal, or ultimately, the survival of the wolf, is originality. The newly learned sign enriches the wolf's repertory of purposeful responses.

1.3.2.2 Existing for a purpose and serving a purpose

In Short's teleology, "existing for a purpose" (or "having a purpose") is distinguished from "serving a purpose" (or "acting for a purpose") (Short, 2007, pp. 110–111). The first case, "existing for a purpose", it does not qualify the initiator of certain actions as an agent who is able to respond purposefully, because the actions are mechanical, passive, and incapable of adjustments (Short, 2007). Short (2007) gave an example as a rock being placed on the desk to weigh down papers; although the placement of the rock is selected for that effect, the rock itself is not a purposeful agent (p. 111). On the other hand, the second case, "serving a purpose", is characterized by the susceptibility of modifications when certain actions fail to fulfill a purpose; comparing to the first one, the actions in the second case are semiotics-based, active and flexible (Short, 2007).

Short's distinction between "existing for a purpose" and "serving a purpose" is used by Alexander to outline the different and complementary roles played by directionality and originality (Alexander, 2009). Alexander (2009) believes that there is directionality when something exists for a purpose and there is originality when something serves that purpose. Then, she argued that it is in the middle of a directional course that original actions occur, because "[...] the individual exercise of a capacity that exists for a purpose always serves the purpose afresh, even if within the context it is directional." (Alexander, 2009, p. 88).

Individuality is clearly rejected in the Saussurean semiosis – a sign system is highly conventional. In contrast, it is greatly appreciated by the Peircean one – the knowledge of something depends on individual acts of interpretation. Barbieri, the author of the code model of sign, is indeed inspired by Saussure by suggesting that signs are only valid when there are arbitrary conventions; but he does not exclude the possibilities for mistakes to appear, which can result from other types of code (yet to discover). While manifesting remarkable flexibility, it appears that Alexander's teleological signs are created on a stable and mechanic basis. Adaptation is not achieved out of the blue; it is better to be understood as a type of adjustment, as causal connections (indicial and/or iconic) are presumed to exist between the responses that already exist and the new ones.

According to Alexander (2009), a directional system reacts to mistakes in a retroactive way (i.e. by feedback control) – the detection and the correction of specific errors, but the system is not adaptive because the responses are fixed. To serve a purpose, the original signs come from the selection of "formal properties of likeness and nearness" based on the old ones (Alexander, 2009, p. 90). The idea is illustrated with the example of music composing:

"A musician is trying to compose a melody. He looks out the window to see birds sitting on electrical wires in a way that he interprets as the right musical notation." (Alexander, 2009, p. 90).

In the example, the positions of the birds are iconically perceived by the musician. Alexander (2009) explained that it is not luck that has led the musician to find the right note; originality can only come into existence after that directionality made it purposeful. "Luck and randomness are everywhere and uninteresting, uninteresting until bent to a purpose." (Alexander, 2009, p. 91).



Chapter 2 MEANING AND LIFE

2.1 INTRODUCTION

2.1.1 Review of Chapter 1

Chapter 1 is about definitions. First, two classic models of sign – one from Saussure and the other from Peirce – are presented to define the basic components of a sign and the creation of meaning. Then, we present two other models – one is called the code semiosis and the other is based on teleology; both are specifically designed to describe signs and their actions in the biological context.

The theory of code semiosis is explained with the example of the central dogma of molecular biology which is the one-way flow of genetic information from DNA, to RNA, then to protein (Barbieri, 2008a, 2008b, 2013b). The definitions of information and meaning used in this thesis are given by the code theory – information and meaning can only simultaneously exist by an act of coding (Barbieri, 2013b). According to the teleological model, semiosis is defined as a goal-oriented process (Alexander, 2013). The example used to illustrate the theory is a hungry wolf searching for a rabbit based on the perception of an odor (Alexander, 2013, para. 8). Alexander (2013) suggested that the goal of an organism, ultimately, is the survival of itself and its species which can be realized in a variety of ways; therefore, the hungry wolf does not respond to the odor of a specific rabbit but its purpose of staying alive.



The classic models are compared to the new ones; through the comparisons, it is shown that semiotics can be applied to analyzing phenomena in not only the cultural world but also the natural one. The two new models, when compared one to another, show different but complementary points of view on the semiotic nature of life. Together, they are the fundamental models of signs that are used to describe the biological facts studied in this thesis. Examples of an integrated model of the two are given in 4.2.1.1 and 4.3.1.1. In Chapter 2 and Chapter 3, we respectively discuss and further develop the theories proposed in the two new models.

2.1.2 Presentation of Chapter 2

In code semiosis, Sign and Meaning are connected by a code; there cannot be signs without codes (Barbieri, 2008a, 2008b). As the example of the genetic code shows, a code is a system of conventions, external to and independent from the physical reality, which is used to build one of the most important macromolecules of life – protein (Barbieri, 2008a). In other words, there cannot be life without codes. By contrast, such codes are not involved in the case of "inorganic" molecules because they are made of components held together by and only by chemical bonds determined by natural laws (Barbieri, 2008a). These rules, however, are internal to and dependent on the physical reality. Presented in the first part of Chapter 2, the argument of Howard H. Pattee (2008) that both codes and natural laws are required in the construction of life. This characteristic is named by Pattee as the "matter-symbol complementarity" (Pattee, 2008).

In 1.2.1.1, Saussure's concept of value is presented: Signs exist inside a structuralist system. A sign is meaningful not only because there is a conventional connection between Signifier and Signified; also because a sign is differentiated

from other signs. In other words, a code not only connects Sign and Meaning; it also makes sure that this connection is specific. Presented in the second part of Chapter 2, by incorporating new findings of the genetics and using mathematics language, Yair Neuman and Ophir Nave (2008) showed that value exists in a codebased system of signs. Furthermore, Neuman and Nave (2008) suggested that value is, in fact, responsible for the creation of code. The concept of value is also discussed in 8.3, in the presentation of a neuron-based motivational system used by organisms for the prioritization of their actions (Spruijt et al., 2001).

2.2 CONNECTING INFORMATION TO MEANING

2.2.1 The theory of matter-symbol complementarity

2.2.1.1 Both internal and external codes are needed in the construction of organic materials

In Introduction, the thermodynamic feature of life is presented as a process of the exchanges of energy and matter between an organism and its environment to import free energy (Deacon, 2006; Schneider & Kay, 1994). It is also explained that during this directional process, information needs to be retained by the organism to monitor and control the on-going exchanges (Grandpierre, 2013; Heylighen, 1991). Therefore, on one hand, there is energy in the form of matter; on the other hand, information is used as a means of regulation. Together, they contribute to the organism's self-maintaining actions in the form of biochemical changes. This phenomenon is characterized by Pattee as "the matter-symbol complementarity" (Pattee, 2008).



Presented in 1.2.2.1, according to Barbieri (2008a), natural signs are distinguished from conventional signs as there are two types of codes establishing the connection between Sign and Meaning – an internal code and an external one¹⁵. Using the example of the genetic code, Barbieri (2008a) explained that the internal code which is involved in DNA replication and the transcription from DNA to mRNA and determines the way molecules interact (obviously in a causal manner) belongs to natural laws; the external code, on the other hand, is represented by the transcription from mRNA to proteins, where the correspondence between genetic information and amino acids cannot be reduced to natural laws – such correspondence exists outside the chemical nature of both genes and proteins (i.e. arbitrariness). Pattee (2008) suggested that matter is formed by internal codes, while the forming process of matter is controlled by external codes which are symbol-based.

Biosemiotics distinguishes life from inanimate matter by its dependence on material construction controlled by coded symbolic information. [...] This type of subject/object distinction is reestablished at many levels throughout all of evolution. In physics this becomes the distinction between material laws and symbolic measurements/models. (Pattee, 2008, p. 115)

Comparing to the code theories of Barbieri, Pattee's theory of matter-symbol complementarity advanced the distinction between physical reality and arbitrary conventions by proposing that there is also a relation of control between the two. Arbitrary conventions exist outside the physical reality, but it can apply to understanding and even manipulating the physical reality. It is explained by

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¹⁵ It should be noted that, different from the use proposed by Barbieri, in this thesis, the term "code" is referred to signs based on both physical causation and arbitary conventions.

Pattee that, first, physical or/and chemical changes take place regardless of observers – "physical laws are universal and must apply to all conceivable systems"; then, however, for these changes to be described and controlled, information is required in defining a system's initial conditions (Pattee, 2008, p. 116).

"All living organisms exist by virtue of hierarchies of control by informational constraints. This is the case at all levels, from the genes, to development, to sensorimotor controls, to abstract thinking, and to our technical artifacts." (Pattee, 2008, p. 116).

The measurement of the initial conditions – a mathematical one, for example, including parameters such as space, time, matter and energy, is indispensable for the prediction of any consequence of the laws of a system (Pattee, 2008). The separation between informational constraints and physical laws is called by Pattee as "the epistemic cut" (Pattee, 2008, p. 118). This separation is evident, as Pattee (2008) puts, "If we can speak of knowledge about something, then the knowledge representation, the knowledge vehicle, cannot be in the same category of what it is about." (p. 119). The internal code and the external code, in this sense, are fundamentally different one from the other because the external code provides possibilities to know or/and to manipulate the functioning of the internal one. The external code makes the construction of matter directional to serve the purpose of living organisms. This is clearly an evidence to support the main argument of this thesis: There is truly a semiotic aspect of life.

Pattee (2012) suggested that studying the phenomena of self-organization in living organisms, informational constraints and physical laws, respectively, represent the biologist's approach and the physicist's approach: the former has a history of selecting and evolving symbolic structures for more than 3 billion years, whereas the latter does not include memory nor symbols. Then, Pattee (2012) argued, for physicists to describe physical laws (i.e. measurement), the use of symbols is unavoidable. Crnkovic (2012) suggested that, in fact, measurements do not compromise the objectivity of the reality – they are not "an agreed upon imagination" (p. 751); instead, they are how (human) agents interact with the world, discovering laws and patterns. Naturally, the measurements made by different agents on the same matter are most likely to be different. Crnkovic (2012) explained that it is exactly because cognitive agents are a part of the world being measured in the formation of knowledge – "The reality of an amoeba or a robot differs from the reality of a human." (p. 752).

Pattee (2008) has made another important distinction between informational constraints (i.e. external code) and physical laws (i.e. internal code): the measuring device must indeed obey the physical laws, yet the results of measurement are independent of the laws. For example, the meaning of a symbol does not depend on the rate at which it is written or read; in contrast, physical and chemical changes are rate-dependent (Pattee, 2008, p. 120). This point of view is consistent with Saussure's definition of natural language as a system of symbols existing beyond the reality - referential objects are excluded in the Saussurean sign model. In fact, this independence enables a symbol-based system to exploit physical laws for its own benefits. It should be noted that such system has a huge advantage in the growth of complexity – it can develop a variety of ways to manipulate the laws, including error-controlled perception, model-based anticipation, evolution by the creation of new codes, etc. It is extensively shown by the examples in this thesis that semiotic patterns are built to control biological processes. For instance, the synthesis of proteins (see 1.2.1.4), metabolic reactions (see 4.3.2), signaling pathways (see 6.2.2; 6.3.2), etc.

2.2.1.2 Semiotic control in von Neumann's logic of self-reproduction

Self-reproduction is defined as "the process by which a given system produces a copy of itself in a given space" (Etxeberria & Ibáñez, 1999, p. 297). For example, during cell division, DNA is replicated and can be transmitted to offspring cells during reproduction (Purves et al., 2004, p. 166). There is a relation of similarity between the parent and the offspring which should only be referred to as the degree of resemblance; it does not matter whether the similarity results from a causal link or not – the causal link may not be exploited by the entity being replicated, but an external agent - for example, the machines in a factory make identical copies of a type of product (Etxeberria & Ibáñez, 1999). Pattee's theory of matter-symbol complementarity is inspired from John von Neumann's logic of self-reproduction (von Neumann, 1966 as cited in Pattee, 2008), which is formulated based on artificial models but biologically applicable¹⁶. The selfreproducing automaton proposed by von Neumann is controlled by "an entanglement of construction and computation (i.e. the complementarity of matter and symbols in Pattee's terms)" (p. 312) and it allows evolvability by including historical variations occurred during the process (Etxeberria & Ibáñez, 1999).

Fundamentally, the process of self-reproduction requires that the reproduced entity is identical to the original (Pattee, 2008). In DNA replication, a DNA molecule is a structure made of parts (i.e. nucleotides distinguished by 4 nitrogenous bases) that are arranged in a specific order (i.e. DNA sequence based on the order of nucleotides) (Purves et al., 2004, p. 220). Its replication is, in fact, a question of how to construct a copy of an organized structure from a reservoir of



¹⁶ According to Etxeberria and Ibáñez (1999), there are many froms of self-reproduction in the biological world, while the logic of von Neumann's inspiration only refers to the asexual reproduction of unicellular organisms.

these parts (Pattee, 2008). Pattee (2008) has explained that, in von Neumann's logic, there are two ways to ensure the accuracy of self-reproduction: (1) by inspection – first identifying the parts of the original structure, then, assembling the corresponding parts to form a copy; (2) by description – first describing the original structure with symbols, then, using its symbolic description to guide the assembly of a copy with parts in the reservoir.

The distinction between inspection and description corresponds to the distinction between internal code and external code defined in Barbieri's terms. Inspection, on one hand, indicates that there exists a physical resemblance between the original structure and the copy for that the latter should be made identical to the former. This physical connection is an internal code. On the other hand, description means coding (i.e. the transformation from materials to symbols), as well as decoding (i.e. the transformation from symbols to materials) if a copy needs to be made based on the original structure. These transformations between materials and symbols are determined by the code used during the processes, not any physical connection between the two. This arbitrary relationship is an external code.

Both internal and external codes (i.e. inspection and description) are needed in von Neumann's logic of self-reproduction. It is because, as Pattee (2001) argued, that there is an irreducibility between material with its structure dynamically maintained by physical laws and symbol-based measurement made by an outside system – the function of measurement cannot be explained solely by physical laws, and measurement alone is not enough for the construction of materials. Pattee (2008) explained it with the help of von Neumann's formal model: When the description $\varphi(A)$ is fed to a material constructor A – it seems that A would construct a copy of itself A' ($\varphi(A) \rightarrow A = A'$), but this process is not selfreproduction because the description $\varphi(A)$ has not been replicated. This problem, however, cannot be resolved by the mode of description because feeding a description of the description $\varphi(\varphi(A))$ to the constructor will lead to an infinite regress of description making. Therefore, another component, B, is added to the system, to be the copier of the description of A: after A is described, its description $\varphi(A)$ is not further described, but inspected and copied. Formally, there is: " $\varphi(A + B) \rightarrow (A + B) = \varphi(A' + B') \rightarrow (A' + B')$ " (von Neuman, 1966 as cited in Pattee, 2008, p. 122).

Von Neuman (1966) suggested adding an equipment for control, C, to the automaton of self-reproduction, A+B. The function of C lies in guiding and executing between the two modes needed in self-reproduction (von Neumann, 1966). The function of C is called by Pattee (2008) as "housekeeping details" (p. 122) such as starting and terminating a cycle of self-reproduction where the separation between the old constructor and copier from the newly produced ones is required. However, the combination of A, B and C is auto-reproductive but not creative; to be evolvable, the automaton should be able to reproduce when any new structure or function (D) is added to the original "blueprint" (von Neumann, 1966). The evolvable model is: " $\phi(A + B + C + D) \rightarrow (A + B + C) = \phi(A' + B' + C' + D') \rightarrow (A' + B' + C' + D')"$ (von Neuman, 1966 as cited in Pattee, 2008, p. 122). Von Neuman (1966) has specified that D is an inheritable and non-lethal mutation because if mutations happen to any one of A, B and C, the automaton cannot self-reproduce anymore.

Concluding von Neumann's logic of self-reproduction and Pattee's readings, the complementary relation between matter and symbols is evident: (1) The construction of materials requires both internal and external codes; they have different roles: one for inspection and the other for description. In other words,
symbols are used to build matter; and matter is used to preserve symbols. (2) The external code controls the construction of materials in the sense that it determines how the internal code is used in the process. It can be speculated that using descriptions is a better choice in maintaining the accuracy for self-replication because symbols are rate-independent (thus stable). In contrast, inspecting a structure is a rate-dependent (thus unstable) process; the results of inspections of the same structure in different moments may not be the same. (3) External codes are stable but open to evolution. It is exactly because a symbolic description is not limited by physical laws that make the creation of novelties and even adaptations possible. As physical causation is required by internal codes, they are not capable of creating something entirely new.

2.2.2 The semiotic control in protein structures

2.2.2.1 The internal and the external codes in the four-leveled protein structure

In this section, with the example of protein structure, it is shown that material construction requires both internal and external codes. The determinant role of the external code, as Pattee (2008) characterized, is "a time-independent passive memory that by means of a coded description controls the dynamical rates of specific constructions or chemical syntheses" (p. 123). Also, the external code can make material construction evolvable because the code can apply "to an open set of potential descriptions" (Pattee, 2008, p. 123).

A protein consists of a single unbranched polymer of amino acids and is folded into a specific three-dimensional shape (Purves et al., 2004, p. 38). According to Pattee (2008), folding is, in fact, the process of decoding from the description as a sequence of amino acids into a chemically reactive structure: "Folding transforms what are essentially rate-independent syntactically coded sequences into rate-dependent functional controls." (p. 125). In protein folding, Pattee (2008) suggested that the roles of external and internal codes are respectively played by strong and weak chemical bonds because: strong bonds are responsible for holding together amino acids in the sequence determined by the corresponding DNA sequence based on an arbitrary code; while weak bonds are responsible for the dynamic chemical interactions between molecules in the polypeptide chain determined by strong bonds. Simply put, strong bonds are used as a description to build weak bonds; while weak bonds dynamically interpret strong bonds – "strong bonds that preserve the passive topological structure of what is folded, and weaker bonds that acting together hold the active folded structure in place" (Pattee, 2008, pp. 125–126).

A chemical bond is "an attractive force that links two atoms together to form a molecule" (Purves et al., 2004, p. 20). There are several kinds of chemical bonds, for example, covalent bonds which are strong bonds and result from the sharing of electrons; hydrogen bonds formed by the sharing of hydrogen atom, are weaker than covalent bonds but enormously important to biology; ionic bonds which come from the loss or gain of electrons by atoms (Purves et al., 2004, pp. 20–21). Covalent bonding is much stronger than hydrogen bonding, ionic bonding, hydrophobic interaction, and van der Waals interaction; therefore, in Pattee's terms, covalent bonding represents the external code, while the rest corresponds to the internal one.

The folding process of a protein gives rise to the four levels of its structure (Figure 2.1): Covalent bonding (i.e. the external code) is responsible for the primary structure which is the precise sequence of amino acids in the polypeptide chain (Purves et al., 2004, p. 40). The carboxyl group of one amino acid reacts



covalently with the amino group of another, undergoing a condensation reaction that forms a peptide linkage (Purves et al., 2004, p. 40). The primary structure determines how the protein coils and folds at higher levels, thus adopting a specific and functional structure (Purves et al., 2004, p. 41).

Protein's secondary structure is referred to as "regular and repeated patterns in different regions of a polypeptide chain" (Purves et al., 2004, p. 41). There are two main types of patterns: α helix and β sheet, both result from hydrogen bonding (i.e. the internal code) between the amino acid residues that make up the primary structure (Purves et al., 2004, p. 41). The determination of strong bonds over weak bonds as well as the interpretation of strong bonds by weak bonds are clearly shown with protein's secondary structure: The α helix has a structural pattern of 3.6 amino acids per turn with a hydrogen bond formed between every fourth amino acid residue; this repeated pattern of hydrogen bonding i + 4 \rightarrow i is the most prominent characteristic of an α helix (Creighton, 1999). At the same time, there are other types of hydrogen bonding patterns – 3¹⁰ helix with a pattern of i + 3 \rightarrow i, Pi helix with a pattern of i + 5 \rightarrow i, etc. (Creighton, 1999). In other words, hydrogen bonds are formed on the structural basis determined by covalent bonds; and different patterns of hydrogen bonding interprets the same structural basis differently.

Comparing to the secondary structure which is made of local patterns of a polypeptide chain, the tertiary structure is the global shape of the chain - it is "bent at specific sites and then folded back and forth" (Purves et al., 2004, pp. 41-42). The tertiary structure is determined by the chemical interactions between R groups – the amino acid side chains; many of these interactions are weak bonds (i.e. the internal code) such as ionic bonds, hydrophobic interactions, and van der Waals interactions (Purves et al., 2004, p. 42). Both secondary structure and

tertiary structure are derived from a protein's primary structure built by the external code. The stability of strong bonds necessarily secures the determinant role of an external code in guiding the process of material construction. For example, when lysozyme (a protein) is slowly heated, the heat energy will disrupt only the weak interactions and cause only the tertiary structure to break down; but the protein will return to its normal tertiary structure when it cools, demonstrating that all the information needed to specify the unique shape of a protein is contained in its primary structure (Purves et al., 2004, p. 43).

Many proteins are made of two or more polypeptide chains with each of them folded into a unique three-dimensional shape (Purves et al., 2004, p. 43). These polypeptide chains – referred to as subunits – bind to and interact with each other, resulting in the quaternary structure of protein (Purves et al., 2004, p. 43). A hemoglobin molecule, for example, consists of two α and two β subunits which are held together by weak bonds such as hydrophobic interactions, van der Waals forces, hydrogen bonds and ionic bonds (Purves et al., 2004, p. 43). These weak bonds (i.e. the internal code) are essential to the protein's major function which is to carry oxygen in red blood cells – as hemoglobin binds one O₂ molecule, the weak bonds break and the four subunits slightly shift their relative positions to enhance the binding of more O₂ molecules (Purves et al., 2004, p. 43). Comparing to the role of strong bonds, weak bonds with great flexibility make the constructed material functionally adaptable.





Figure 2.1 The Four-Leveled Protein Structure. A functional protein is folded into a threedimensional shape which exhibits four levels of structure. The primary structure of the protein gives rise to the secondary, tertiary, and quaternary structure. Adapted from *Amino Acids and Proteins*, in OpenStax CNX. Retrieved October 4, 2017, from https://cnx.org/contents/Ykhx0EAe@1/033-Amino-Acides-and-Proteins.



2.2.2.2 The interactions between the internal and the external codes

As it is shown in the four levels of protein structure, protein folding is the result of both strong and weak bonds, which are considered by Pattee as informational constraints and functional controls (Pattee, 2008), or external and internal codes based on Barbieri's theories of code semiosis (Barbieri, 2008a). Such correspondence is made essentially based on the determinant role of the external code over the internal one. In the folding process, the linear sequence of amino acids held together by strong bonds constrain the chemical interactions between weak bonds.

In protein folding, the "epistemic cut" – the separation between symbols and matter, therefore, is between a sequence of amino acids linked one to another by covalent bonds and a folded structure which is functional thanks to weak bonds such as hydrogen bonds, ionic bonds, hydrophobic interaction, and van der Waals interaction. It is strongly suggested by Pattee that although symbol vehicles must obey physical laws and they can have a physical description, it does not mean that this description is physically limited; instead, this description can be interpreted differently (Pattee, 2013). As the example of the variations of helix shows, as a type of hydrogen bonding pattern in protein's secondary structure, it can exist in several forms depending on the number of amino acid residues per turn.

In Pattee's early work of biosemiotics (Pattee, 1969), a significant attention is given to deciphering the linguistic features of molecules. Pattee (1969) believes that a molecule becomes a message not because of the physical structure of the molecule, but the context in which it is symbolically constrained. Then, according to Pattee's latest formula, it takes at least four elements for signs to exist in the biological world: a referent information (1) is endowed with a physical embodiment (2) while an interpreter (3) distinguishes the two and establishes the "stand-for relation" between them; interpretations act as informational vehicles that constrain the dynamics of local interactions (4) (Pattee, 2013, para. 1).

In fact, we believe that the "epistemic cut" provides an explanation on defining the connection between arbitrary code and the physical reality – they are not completely irrelevant one to another because a code can be interpreted. This point of view may be found in conflict with Barbieri's distinction between code semiosis and interpretative semiosis as it is suggested that interpretations are created by a (human) mind (Barbieri, 2009b). In this thesis, we argue that it is exactly because "errors" occur during coding and decoding, a code is provided with the raw materials to evolve. The essence of the theory of matter-symbol complementarity is: while arbitrary code and interpretation are distinguished one from the other, they coexist with each other.

The internal code dynamically interprets the external code. In protein folding, protein as a three-dimensional and rate-dependent structure which is biologically functional cannot be created without the weak bonds. The specificity of protein functions depends on the shape of a protein and the chemistry of its surface groups: (1) The binding of a substance to a protein involves a general fit between the three-dimensional structures of the two; it is by binding that a protein is activated to fulfill its functions (Purves et al., 2004, p. 44). (2) The surface of a protein presents R groups of the exposed amino acids to the substance to bind; weak bonds can tighten the binding or facilitate the interactions between inner regions of the protein (Purves et al., 2004, p. 44). Pattee (2013) has suggested that there are many levels of interpretation in making a functional protein: folding is the first level, followed by the second which is the binding between the protein and its substrate; the third level is the metabolic network in which the protein



to the ecosystem; finally, the last level of interpretation should be determined by natural selection. He also pointed out that, the levels of interpretation are supported by informational constraints and contribute to the structural complexity of organisms (Pattee, 2013).

2.3 A SYMBOLIC VALUE SYSTEM

2.3.1 The mathematic and semiotic definition of value

In Barbieri's model of semiosis, Sign is connected to Meaning by code (Barbieri, 2008a, 2008b, 2013b). We can think that there are two categories – one contains many Signs and the other contains many Meanings; then, the code is a set of conventions based on which specific Sign-Meaning mappings are defined. Here is a question: What are the relationships between the signs produced by the same set of conventions? In other words, is code responsible for creating a sign or a system of signs? Saussure with his semiotic theory founded on the understanding of natural languages believes that (linguistic) signs exist inside a structuralist system – they can be compared with each other (Holdcroft, 1991, p. 109); or more precisely, a Sign-Meaning mapping is specific because it is distinguished from other Sign-Meaning mappings.

Value is created when distinctions are made between signs. Saussure explained the concept of value by comparing English "sheep" with French "mouton" on the number of Signified that each Signifier is connected to (Saussure as cited in Nöth, 1995, p. 61). Neuman and Nave (2008), then, proposed a mathematic method to define value and to study the use of value. The genetic code, again, is used to illustrate the theory; this time, however, it is enriched with new scientific findings (Purves et al., 2004, p. 237; Tamarin, 2001, p. 276). Most



importantly, with value, Neuman and Nave (2008) elegantly explained why there should be codes in the first place.

In mathematics, a category is an algebraic structure that consists of "objects" linked by "arrows (morphisms)" (Awodey, 2006, p. 1). Ca1tegory theory is a way to study and characterize different types of mathematical structures by their "admissible transformations" (Awodey, 2006, p. 1). Neuman and Nave (2008) explained the logic: There are the set of objects (A, B, C ...) and the maps between these objects (f, g, h ...); each map connects one object to another in the same set, the mapping is represented as f: A \rightarrow B. Illustrated in Figure 2.2, if there are three maps as g: A \rightarrow B, h: B \rightarrow C, and e: A \rightarrow C, then the relationship between the maps can be represented as e = h \circ g (i.e. e equals to h following g) (Neuman & Nave, 2008).



Figure 2.2 A Composite Map. Given the collection of objects (A, B, C) and the collection of maps (g, h, e), the map from A to C equals to the combination of the map from A to B and the map from B to C. Reprinted from "On the semio-mathematical nature of codes", by Y. Neuman & O. Nave, 2008, *Biosemiotics*, 1(1), p. 101. Copyright 2008 by Springer Science & Business Media. Reprinted with permission.

As it is defined in Barbieri's code semiosis that a sign is made of two entities connected by a code (Barbieri, 2008a, 2008b, 2013b), then, maps such as g, h, and e can be considered signs. As map e establishes a relationship between h and g, the value of sign e is different from the value of sign h (or sign g) – the value of e equals to the value of h following g. In other words, these signs are organized in a structuralist system; and they can be compared one with another by their values. According to Neuman and Nave (2008), "e equals to h following g" (p. 100) describes the flow of value inside the sign system; value is defined as "the same abstract property that flows in a monetary system or in any other system – biological, psychological, or social – involving signs or codes" (p. 102).

Neuman (2008) has emphasized that living organisms are "meaning-making" systems rather than "information-processing" ones. Citing Bateson's famous argument of the effects of information on life – "difference that makes a difference", Neuman suggested that only when discrete physical states are differentiated by an observer that they can contribute to the building of the living realm (Bateson, 2000 as cited in Neuman, 2008, p. 48). This point of view agrees with the one held in Pattee's theory of matter-symbol complementarity (Pattee, 2008) – the construction of biological materials is a sign-mediated activity.

Then, Neuman (2011) proposed that the hierarchy of life is recursive in the sense that discrete physical states are transformed into information which is used to actively produce other discrete physical states. In other words, life which is considered autopoietic depends on: (1) the mapping relations between matter and symbols in both directions (i.e. both coding and decoding); as well as (2) the hierarchical composition of these relations. In fact, the linear flow of information (exemplified in the genetic code) only characterizes an instance of the semiotics of life – the use of a code. Neuman and Nave (2008) believe that codes themselves are first created in the flow of values where the specificity of a sequence is defined by differentiating from other sequences.



2.3.2 The genetic code and value-based semiosis

2.3.2.1 The values in the system of the genetic code

According to the central dogma of molecular biology, the genetic information flows linearly and irreversibly from DNA to RNA then to protein (Purves et al., 2004, p. 236). The process can be divided into two major steps: first, transcription – where the sequence of DNA is copied into a corresponding one of RNA; then, translation – where this RNA sequence determines the sequence of the produced amino acids (protein) (Purves et al., 2004, p. 236)¹⁷. Beside the central dogma, a DNA molecule can be replicated to produce two identical replicas (Purves et al., 2004, p. 222).

The relationships between DNA, RNA and protein can be interpreted in a semiotic way – as proposed by Barbieri in his theory of code semiosis: DNA and protein are Sign and Meaning connected by a codemaker which is RNA (Barbieri, 2008a, 2008b, 2013b). Here, Barbieri's sign can be further segmented into a transcription sign – DNA and RNA connected by the rule of transcription (i.e. complementary base pairing, which is an internal code based on physical connected by the rule of translation sign – RNA and protein connected by the rule of translation (i.e. the genetic code, which is an external code which has no physical connections with the encoded or the decoded entity). Then, according to Neuman and Nave (2008), signs "DNA \rightarrow protein", "DNA \rightarrow RNA", and "RNA \rightarrow protein" exist in a structuralist system, in which they can be

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¹⁷ It should be noted that, in eukaryotes, the primary RNA transcripts must go through splicing to be translated into proteins.

compared one with another based on their values (Figure 2.3) – the value of sign "DNA \rightarrow protein" equals to the value of sign "DNA \rightarrow RNA" following sign "RNA \rightarrow protein".



Figure 2.3 The Values in the System of the Genetic Code. The flows of genetic information specified by the central dogma are represented by the dark lines; other types of information flows that exist besides the central dogma are represented by the dashed lines. These directional flows give rise to the values in this system. Reprinted from "On the semio-mathematical nature of codes", by Y. Neuman & O. Nave, 2008, *Biosemiotics*, 1(1), p. 103. Copyright 2008 by Springer Science & Business Media. Reprinted with permission.

To understand the values created in the system of the genetic code, we need to explain the information flows (represented by the dashed lines) that are not included in the central dogma.

First, RNA self-replication, that is, RNA can serve as a template for its own replication. The genetic information of viruses such as tobacco mosaic virus, influenza virus, poliovirus is carried by RNA instead of DNA and can potentially be translated into protein (Purves et al., 2004, p. 237). As RNA is usually single-

stranded, its replication requires a RNA-to-RNA transcription that yields a complementary strand to the parent one; then, this strand is used to make more copies of the viral genome (Purves et al., 2004, p. 237).

Second, the flow of information from RNA to DNA suggests that RNA can act as a template for DNA synthesis. The human immunodeficiency virus (HIV) and certain rare tumor viruses have RNA as their genome which is not replicated by RNA self-transcription, but another process called reverse transcription (i.e. the synthesis of DNA from RNA) (Purves et al., 2004, p. 237). These viruses infect a host cell, then, they make a DNA copy of their genome to make more copies of the genome and mRNA to produce viral proteins (Purves et al., 2004, p. 237).

Finally, although direct translation from DNA to protein is not known to happen in nature, it is shown by B. J. McCarthy and J. J. Holland in the mid-1960s that under certain experimental conditions, single-stranded DNA could bind to ribosomes and be translated into proteins, thus without the mediation of RNA (Tamarin, 2001, p. 276).

Based on the types of information flow shown in Figure 2.3, Neuman and Nave (2008) suggested that a "determination problem" rises regarding the relationships between the maps: "given two maps f and h, what are all g, if any, for which $h = g \circ f$?" (pp. 103-104), where f: RNA \rightarrow DNA, h: RNA \rightarrow protein, and g: DNA \rightarrow protein. In other words, given that information stored in DNA needs to be delivered to the synthesis of protein, while there are only two paths available (Figure 2.4): (1) from RNA to DNA, and (2) from RNA to protein.



Figure 2.4 The Determination Problem. Given that information flows from RNA to DNA and from RNA to protein, the question is how to transfer information from DNA to protein.
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The types of information flow represented in Figure 2.4 (RNA \rightarrow DNA and RNA \rightarrow protein) are different from the ones defined by the central dogma (DNA \rightarrow RNA \rightarrow protein). If the arrow of map f is changed to the opposite direction, the two will be the same. This result of the change can be mathematically explained by isomorphism (Figure 2.5) (Neuman & Nave, 2008), defined as: In any category, an arrow f : A \rightarrow B is called an isomorphism if there is an arrow f⁻¹ : B \rightarrow A in the same category such that f⁻¹ \circ f = 1A and f \circ f⁻¹ = 1B; 1A and 1B are the identity arrows of A and B (i.e. 1A: A \rightarrow A and 1B: B \rightarrow B) (Awodey, 2006, p. 11).

In transcription and reverse transcription, the relation between RNA and DNA is an isomorphism because there is a one-to-one physical correspondence between the template molecule and the produced one based on complementary base pairing. For example, the coding region of DNA for arginine is 3'-GCC-5' is transcribed to the mRNA codon 5'-CGG-3' (Purves et al., 2004, p. 242).



Figure 2.5 The Isomorphism between DNA and RNA. As the nucleotides of RNA and DNA can be complementarily paired to each other, there is an isomorphism between them.
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The change from arrow f: RNA \rightarrow DNA to arrow f⁻¹: DNA \rightarrow RNA is used to form hypotheses on the evolutionary relevance between RNA and DNA, one of them is called "the RNA world" (Neuman & Nave, 2008). Suggested by Gilbert, RNA can assume the functions of information storage and catalysis so that there may be an RNA world at the beginning of evolution where RNA alone catalyzed the synthesis of themselves; then, DNA took over the role of the carrier of genetic information from RNA by reverse transcription, while proteins are responsible for major enzymic activates (Gilbert, 1986). Comparing to RNA, the double-stranded DNA is more stable for storing information and capable of correcting errors, yet allowing mutations and recombination (Forterre, 2005; Gilbert, 1986).

Meaning is created when RNA is translated into proteins, but the creation of value requires an isomorphic relationship to be established between RNA and DNA (Neuman & Nave, 2008). In fact, the flow of information forms a sign; the flow of value forms a system of signs. Value provides the common ground for signs to be compared and distinguished one from another – they are different

signs because they have different values. It can be speculated that, during evolution, establishing the isomorphism between DNA and RNA, values of different strategies for self-reproduction are distinguished and a better one – g: f⁻¹ \circ h (i.e. DNA \rightarrow RNA \rightarrow protein) – is selected in the end. Another example can be found in natural languages (e.g. English): the isomorphism between "dog" and "god" contributes to the distinction between their meanings and the expansion of the system's signifying ability (Neuman & Nave, 2008). We believe that value is a part of the code that is responsible for the creation of a specific sign.

2.3.2.2 Value and the creation of code

As Neuman and Nave (2008) have explained, the relationship between RNA and DNA can be mathematically characterized as an isomorphism because of their biological natures – complementary base pairing. On the other hand, the relationship between RNA and protein is not a "substitution" or "one-to-one" correspondence – evidently, there are fewer nucleobases (4 RNA nucleobases: A, G, C, and U) than amino acids (20 natural amino acids) – "This map involves a domain that contains fewer objects than its co-domain." (Neuman & Nave, 2008, p. 107). It is suggested that the solution to this problem can give rise to codes, which is "at the heart of every semiotic system" (Neuman & Nave, 2008, pp. 107–108).

In 1.2.1.4, the central role played by the genetic code in transforming information stored in the genes into proteins is shown in the phase of translation: each codon (made of three sequential nucleobases) on the mRNA specifies an amino acid to produce on the growing polypeptide chain (i.e. a protein) (Purves et al., 2004, p. 239). The combination of the four nucleobases give 64 different codons and they specify 20 amino acids with overlaps – the phenomenon is referred to as



redundancy (Purves et al., 2004, p. 240). Indeed, redundancy is the solution to the problem of representing a collection of objects with another collection of fewer objects (Neuman & Nave, 2008).

According to Neuman and Nave (2008), two maps are required to achieve redundancy: first, the objects in a domain are rearranged and combined to create "higher-order structural units" (p. 108); then, these units are mapped on the objects in the co-domain. Natural languages (e.g. English), for example, represent a system in which a limited number of letters in the alphabet are rearranged and combined to create tens of thousands of words; then, these words are associated with concepts. In fact, codes are indispensable if it is to establish a correspondence between two worlds in which "the domain is lesser in number than the co-domain yet has to cover the entire spectrum of the co-domain" (Neuman & Nave, 2008, p. 108).

Neuman and Nave (2008) explained, in the hypothesis of "RNA world", a self-replicating RNA "existed in and for itself" (p. 108); when it was connected to DNA by an isomorphic relationship, value is created as a comparison between the two is made. An isomorphic code, however, is not arbitrary because it describes a physical causation between two objects. On the other hand, when the relation between the two objects is asymmetric – DNA and protein, codes appear as a solution to build correlations between them. More precisely, the correlations as directional flows of information are built based on the values of objects in the same category. In other words, there cannot be codes without values.

Neuman and Nave (2008) have noted that, although the goal is to realize a quantitative match between two sets of objects, the transformation from a one-toone correspondence to the creation of code is, in fact, a "qualitative shift" (p. 108) – there is no longer a physical relationship to refer to; an arbitrary code is inevitable because one of the two sets contains composite units thus involving values. The idea is also illustrated with the example of "dog" and "god": If they are not considered as words but merely the collections of the letters g, o, and d, the two have the same value; by contrast, when they are recognized as words – for each one of them, the letters are combined in a specific order (the specificity of sequence information, see 1.2.2.2) – the two words can be differentiated one from another, thus correspond to different meanings (Neuman & Nave, 2008, p. 108).

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Chapter 3 PURPOSE AND LIFE

3.1 INTRODUCTION

3.1.1 Review of Chapter 2

In Chapter 2, the model of code semiosis proposed by Barbieri is further discussed: First, by Pattee's theory of matter-symbol complementarity (Pattee, 2008), it is suggested that the construction of materials in life requires both matter and symbols which can be respectively corresponded to an internal code and an external one. The process of material construction is controlled by the external code; while the result – the produced material – can exist in variations – as the dynamic interpretations of the external code by the internal one. Then, by Neuman and Nave's mathematical and semiotic definition of value, an elegant explanation on why there should be code in the first place is given: code is created to maintain an equal match of quantity between Signs and Meanings (Neuman & Nave, 2008). In other words, coding is a means to create more Signs: Signs that are originally letters in an alphabet are combined and arranged in a specific order to form words as new Signs (Neuman & Nave, 2008). Value is involved in composing new Signs; Signs are differentiated one from another because they are given different values.

The shortcoming of the code semiosis is addressed in 1.3.1.3: The Code denotes the arbitrary relationship between Sign and Meaning; it is determined by a codemaker, and theoretically, does not allow alterations. On the other hand, Alexander (2009, 2013) argued with her theory of teleological semiosis that the

connection between Sign and Meaning, or using her own sign model, between Sign and Response, should be susceptible to variations because such connection is established in the realization of a goal which is a "general type" of objective (Alexander, 2013, para. 8) – there are more than one way to realize the goal; and the sign users can learn from the successful responses as well as mistakes. This point of view is consistent with what the Peircean semiotics claims: semiosis takes place in a dynamic process of inquiry.

3.1.2 Presentation on Chapter 3

Chapter 3 is the further development and discussion of the theory of teleological semiosis (Alexander, 2009, 2013). First, it is the shortcoming of the code theory (Barbieri, 2008a, 2008b, 2013b) being addressed. The point of view that considers every aspect of life is determined only by inalterable codes is misleading. As it is explained in 2.2, the symbolic side of life is relatively stable; on the other hand, the material being controlled by the symbolic code has a contingent nature (Pattee, 2008). It is characterized by Alexander (2009) as "directionality" and "originality" of evolution (see 1.3.2.1) in the sense that the code-controlled yet dynamic material construction serves a purpose - for a living organism, the ultimate purpose is the survival of itself and its species. With his theory of "modulated stochastic causation", J. H. van Hateren (2015d) explained how organisms evolve through differential reproduction. The process relies on both codes and the dynamic interpretations of the codes, respectively named as the deterministic and the stochastic causes; and it is responsible for the emergence of agency based on which organisms control and regulate their actions (van Hateren, 2015d).



The teleological sign model proposed by Alexander is inspired by the one formulated by T. L. Short (see 1.3.1.2). Short (2007) has made the distinction between Object and Purpose in his sign model, while it is modified in Alexander's - Object and Purpose are integrated into Objective. Alexander (2009, 2013) argued that an Object is recognized only because it is supposed to serve a Purpose; therefore, organisms respond to a Purpose rather than a specific Object. Alexander (2009, 2013) agrees that while a sign user interprets the Sign-Object relationship based on his Purpose, he does make mistakes during the process; potentially, some of these misinterpretations can satisfy the original purpose, they are then integrated into the organism's repertoire of Response. To define interpretation and misinterpretation from a biosemiotic point of view, Andrew Robinson and Christopher Southgate (2010) also studied and modified Short's theory of teleology. They have distinguished two types of misinterpretation, then, proposed to divide the ultimate Purpose of living organisms (i.e. self-maintenance) into subgoals, and correspondingly, the sub-Responses to these goals (Robinson & Southgate, 2010). They showed that even for a misinterpretation that fails to satisfy the present goal, it may have an important impact on the survival of the organism and its species in the future (Robinson & Southgate, 2010).

3.2 AGENCY AND GOAL

3.2.1 The theory of deterministic and stochastic causation

As it is addressed in 1.3.1.3 and the presentation of this chapter, it may be suggested by the theory of code semiosis that life is a deterministic system: it appears to be a relation of determination between the genotype and the phenotype of an organism. Nevertheless, we believe that the point of view cannot stand true, because: (1) The genetic code is not perfectly followed all the time, spontaneous mutations occur at rates that can be influenced by natural selection (Drake, Charlesworth, Charlesworth, & Crow, 1998). (2) Organisms can react under stressful situations by replacing actions which are not beneficial to their survival – for example, it is showed that kittiwakes from the two populations switch between reproductive responses when facing stress (Schultner, Kitaysky, Gabrielsen, Hatch, & Bech, 2013). In this sense, semiosis is considered to serve a purpose through a process of inquiry or learning (as claimed by the teleological semiosis). This point of view is well portrayed with van Hatern's theory of modulated stochastic causation according to which agency is included in natural selection through differential reproduction (van Hateren, 2015d).

Ernst Mayr (1961) suggested that any causality should be able to (1) explain past events; (2) predict future events; and (3) interpret phenomena from a teleological perspective. Van Hateren (2015d) recognized the variable of time and defined causation as any relationship between a cause and its effect, which is, any changes (physical and mental) separated by temporal intervals. Then, on the goaldirectedness, van Hateren (2015d) suggested that there are two main types of causation: the deterministic causation and the stochastic causation.

First, the deterministic causation is referred to as the change of a variable which is caused by other variables can itself cause more changes in downstream variables inside or outside the original system (Figure 3.1 a.) (van Hateren, 2015d). The key characteristic of the deterministic causation is that "the change of state remains fully predictable" (para. 4); although in practice, no system is truly deterministic as there is always some noise (van Hateren, 2015d). Then, the stochastic causation describes the changes that arise spontaneously without being



caused by upstream factors; these changes may become the deterministic causes of downstream changes (Figure 3.1 b.) (van Hateren, 2015d). Finally, van Hateren (2015d) suggested that deterministic and stochastic causations are intertwined (Figure 3.1 c.): the change of a deterministic variable can impact on the change of a stochastic variable; then the stochastic change is passed on to the downstream variables deterministically. This chain of changes involving both types of causation is named the modulated stochastic causation (van Hateren, 2015d).



Figure 3.1 Three Types of Causation. a. deterministic causation: predictable changes of state caused by the change of an upstream variable; b. stochastic causation: changes of state that occur spontaneously; c. modulated stochastic causation: the combination of deterministic causation and stochastic causation that leads to both predictable and spontaneous changes of state.¹⁸ Reprinted from "The natural emergence of (bio) semiotic phenomena", by J. H. Van Hateren, 2015, *Biosemiotics*, *8*(3), p. 407.

Van Hateren (2015d) argued that evolution results from both deterministic and stochastic causations: On one hand, the number of offspring per unit of time is usually limited by an organism's own genetic and physiological conditions, thus

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¹⁸ Van Hateren (2015d) has noted that the temporal properties of deterministic causation and stochastic causation are made different only to be visually distinguished one from another in the graph; they do not imply that the stochastic variables change more rapidly than the deterministic variables.

by a deterministic cause. On the other hand, the rate of reproduction can decrease or increase depending on the rather unpredictable circumstances, such as availability of food and mates, as well as the potential occurrence of diseases and natural disasters. Van Hateren (2015d) characterized fitness as resulted from the interplay of deterministic and stochastic causes – "a complex dynamical process, with an intricate form (structure) involving many inputs and a single output" (para. 5).

The deterministic mechanism of evolution is represented by natural selection – the differential survival and reproduction of individuals due to differences in phenotype (van Hateren, 2015d). Organisms that adapt well their environments are more likely to succeed in reproduction (van Hateren, 2015d). In other words, they reproduce at a greater rate than those that adapt less well. As a result, genotypes of the better-adapted organisms are more likely to be distributed in the population. However, natural selection only accounts for half of the story; the other half is the stochastic mechanism represented by organisms' active role of control and regulation (van Hateren, 2015d). When organisms do not adapt the environment well, meaning that their on-going actions (genetic and behavioral) are not beneficial to the survival of themselves and the species, it is possible for them to change and look for actions that are (van Hateren, 2015d). In other words, an organism can act as an agency that selects actions which serve the purpose of survival.

In the model of evolution formulated by van Hateren (Figure 3.2), it is shown that fitness results from both the deterministic and the stochastic mechanisms.





Figure 3.2 Evolution through Natural Selection and Active Feedback. Organisms survive and evolve under the pressure of natural selection (the Darwinian evolution), represented by the R loop and by actively adjust their actions to increase the fitness, represented by the A loop. f_{true} is the actually outcome of fitness; f_{est} is the self-estimated outcome of fitness. Arrow p represents the environmental impacts on the organism; arrow s represents the distribution of genotypes under the influence of the environment. ~ 1/f_{est} indicates the magnitude of behavioral changes. Reprinted from "The natural emergence of (bio) semiotic phenomena", by J. H. Van Hateren, 2015, *Biosemiotics*, 8(3), p. 407.

On the left, the part "Loop of Reproduction (Loop R)" represents the mechanism of Darwinian evolution based on natural selection. Van Hateren (2015d) explained that: Organisms reproduce at a rate that corresponds to their fitness – named as "external fitness f_{true} " (para. 6). Through differential survival and reproduction, the genotypes of the better-adapted organisms are kept and spread within the population, while the genotypes of the organisms that do not adapt may face extinction. The distribution of genotypes (arrow s) and the changes of the environment (arrow p) will further affect the reproduction rate of the future generations.

On the right, the part "Loop of Active Feedback (Loop A)" represents the agency that is responsible for the selection of beneficial actions. First, as van Hateren (2015d) suggested, it requires the ability of evaluation, that is, the

measurement and the distinction between actions based on their degrees of benefits to the survival of the organism. Van Hateren (2015d) addressed the ability of evaluation by adding a variable to the loop of active feedback as the estimation of fitness by the organism - fest - named as "(self-)estimated fitness" (para. 6). It should be noted that the self-estimation of fitness has nothing to do with an intentional mind¹⁹. The self-estimation of fitness is an internal process that approximates the outcome (ftrue) of another process - differential reproduction under the influence of multiple factors (van Hateren, 2015d). In an example given by van Hateren, it is shown that toxins that disrupt the normal functioning of a cell are used by the cell as an indicator of low expected fitness (van Hateren, 2013). Elsewhere, van Hateren (2015a) has defined the estimation of fitness (fest) as "an evolved process that is implicitly present in the organism's physiology, presumably in a distributed form and depending on a large set of fitness indicators that are available to the organism" (p. 130). He has further suggested that nervous systems are the more advanced forms of indicators monitoring the organism's internal state (van Hateren, 2015a). Errors are inevitable in the selfestimation - the process can be interfered by irreverent parts of the environment or/and the agent, but for the measurement result to be useful in guiding the organism's regulatory actions, the perceived reality should ideally approximate the physical reality (van Hateren, 2015b).

In the loop of active feedback, the self-estimated fitness f_{est} is compared to f_{true} , or "the replacement level" – the level balancing reproduction and death

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¹⁹ The term "intentional" is referred to by philosophers as a kind of directedness toward an object; therefore, mental states such as beliefs, desires, and regrets are considered intentional (Lycan, 1999). In this thesis, we explicitly distinguish intentionality that is created by the human mind and the directedness as a result of the biosemiotic processes of self-maintenance.

within a species (van Hateren, 2015c, para. 6). If f_{est} is above the replacement level, it usually means that the organism's current actions serve the purpose of survival well and do not necessarily have to be changed; however, if fest is below the replacement level, it is more likely for the organism to change its actions to avoid reproduction failures or even premature death (van Hateren, 2015d). The changes of actions based on a low value of expected fitness, suggested by van Hateren, can be performed on the micro level of physiology as genetic mutations or on the macro level as different behavioral patterns (van Hateren, 2015d). In any case, he believes that as the environment can change unpredictably, the changes of actions also need to be random (van Hateren, 2015d). In fact, this type of control is indirect and it does not drive the changes of actions in any direction; it operates on the magnitude of (symbolized as $\sim 1/f_{est}$) changes rather than the changes themselves (van Hateren, 2015d). Van Hateren (2015d) explained that: Low f_{est} leads to large changes and high f_{est} to small changes. Large changes increase the probability of finding actions that yield high fest, which can later compensate the loss in trying out many different actions - the waste of time and energy, the encounter of dangers, etc. When the organism's f_{est} returns to a high one, the organism reproduces at a faster rate and the magnitude of changes decreases. Therefore, although the changes are random, probabilistically, actions will diffuse away from areas with high variability more quickly than from areas with low variability, and it will tend to stay in areas with low variability as it can be enhanced by natural selection - the fittest survive.

Two examples of random changes are given: (1) The mutation rate of a cell increases in response to toxins or unfavorable temperatures (Galhardo et al., 2007; Shee et al., 2011; Al Mamun et al., 2012; MacLean et al., 2013 as cited in van Hateren, 2013, para. 4); (2) After sensing low concentrations of chemical attractants, the frequency of changing direction of an E. coli is increased (Macnab and

Koshland, 1972 as cited in van Hateren, 2013, para. 6). Van Hateren (2013) pointed out that by combining the mechanisms of natural selection and active feedback, an organism harnesses and modulates randomness by a self-referential criterion: cycles of the control loop are built upon varying the magnitude of random changes, but the selection of the changes is not random; it is driven by continuous comparisons between the actual and the estimated values of fitness. In fact, the Loop of Active Feedback amplifies the intermingling between deterministic and stochastic causes (van Hateren, 2015d). The value of f_{est} determines the variability of actions, and the random action outcome leads to a new value of f_{true} , thus a new value of f_{est} ; then, the new value of f_{est} again determines the variability of actions, and so on and so forth (van Hateren, 2015d). Each time the loop functions, stochasticity (random actions) is added into the directional development of a high value of self-estimated fitness (van Hateren, 2015d).

Controlling the magnitude of changes as a "unique causal signature" (para. 6) is believed by van Hateren to be "a part of the standard equipment of any cell" (para. 7) that gives rise to the agency(van Hateren, 2015c). According to Cherniak (1981), it appears that goal-directedness is the necessary condition for a minimal rationality: "If an agent has a particular belief-desire set, he would attempt some, but not necessarily all, of those actions which are apparently appropriate." (p. 166). In 1.3.2.1, Alexander (2009) has characterized the purposeful actions of an agent as the combination of directionality and originality: On one hand, the system is modulated to serve a specific purpose; on the other hand, the system is evolvable through exploring different ways to serve the purpose. Attempting to define a "minimal molecular autonomous agent" (p. 505), Kauffman and Clayton (2006) suggested that the following criteria should be met: the system is distinguished from its surroundings by natural boundaries; it can grow and further define its boundaries in working cycles; it reproduces with heritable variation, and it

chooses between alternatives. Comparing the three definitions of agency, the last one is the closest to What van Hateren captured as the key to adaption: deterministic and stochastic factors intermingle and become inseparable in feedback loops; the possibility of creating novelties are made into use by the system (van Hateren, 2015d).

3.2.2 The establishment of goal and agency: membrane transport I

3.2.2.1 Modulated stochastic causation in passive membrane transport

As it is shown in the previous section, a system that has incorporated both deterministic and stochastic causations can be qualified as an agency which can regulate its actions by feedback control. That is, the measurement of the current state, the comparison of the measurement with the normativity of the system, then based on the result of the comparison, the regulation if necessary. In this section, we study the transport of substances across the plasma membrane as a system capable of serving the goal of self-maintenance in a retroactive way while distinguishing between different situations. By this example, we aim to show that agency can exist at the cellular level.

The plasma membrane is composed of a lipid bilayer with associated proteins capable of regulating substances entering and leaving the cell (Purves, Sadava, Orians, & Heller, 2004, pp. 87–88). As it allows only some substances, not all, to pass through, the membrane is said to be selectively permeable (Purves et al., 2004, p. 94). There are two fundamental types of processes by which substances

pass across the membrane: (1) Passive transport. The process does not require any input of outside energy, but the energy in the substances themselves and the difference in their concentration on the two sides of the membrane (Purves et al., 2004, p. 94). (2) Active transport. The process does not use the intrinsic property of a concentration gradient and requires the input of chemical energy (Purves, p. 94). The process of passive transport can be further divided into two types – simple diffusion through the membrane and facilitated diffusion through protein channels or by means of carrier proteins (Purves et al., 2004, p. 94).

Diffusion is the net movement of molecules or atoms from a region of high concentration to a region of low concentration (Purves et al., 2004, p. 94). An example is used to explain the process: a drop of ink falls into a cup of water, the pigment molecules are initially very concentrated, and without stirring, they slowly spread through the water until eventually the concentration of pigment is the same in every drop of liquid in the cup (Purves et al., 2004, p. 94). A solution in which the particles are uniformly distributed is said to be at equilibrium because there will be no future net change in concentration (Purves et al., 2004, p. 94). In simple diffusion, the net movement of substances is directional – downward the concentration gradient – until equilibrium is reached (Purves et al., 2004, p. 95). The relationships involved can be put into the teleological sign model (Figure 3.3).





Figure 3.3 The Teleological Model of Simple Diffusion. The concentration gradient of a substance between the inside and the outside of the cell is recognized as a Sign to achieve the Objective of the even distribution of the solutes (Equilibrium) and is responded by the net movement of the solutes.

The Response "Net Movement" to Sign "Concentration Gradient" aims to serve the Objective "Equilibrium". The equilibrium of substance concentration in a closed system results from the thermodynamic characteristic of nature – the maximizing entropy (Purves et al., 2004, p. 109). In a solution without barriers, all the solutes diffuse at rates determined by the physical properties of the system – temperature, types of solutes, and concentration gradient of each solute (Purves et al., 2004, p. 95). In this sense, the course of development toward the Objective can be considered deterministic. On the other hand, if a biological membrane divides the solution into separate compartments, the movement of the different solutes can be affected by the properties of the membrane; that is, the cellular membrane is selective: substances to which the membrane is permeable diffuse from one compartments, and their concentrations are equal on both sides of the membrane; substances to which the membrane is impermeable remain in separate compartments, and their concentrations are hand ifferent on the two sides of the membrane (Purves et al., 2004, p. 95). In this case, as the Objective may or may not



be achieved, the developmental course of the system is also influenced by stochastic factors.

The selective permeability of the membrane is key to its role as an agency. The agent makes use of the deterministic part of the system – net movement downward the concentration gradient driven by the entropic effect – for its own benefits – the successful transport of substances across the membrane without the input of outside energy, which eventually contribute to the self-maintenance of the organism (i.e. the given substances are successfully transported). At the same time, the agent's own properties are stochastic regarding the diffusion of any solute – only some solutes are selected to pass through the membrane. In facilitated diffusion and active diffusion, the stochasticity increases when the selection becomes more specific. In this way, the functional possibilities of membrane transport are exploited.

3.2.2.2 Agency and the specification of membrane transport

The teleological sign model of simple diffusion (Figure 3.3) shows the connection between Sign "Concentration Gradient" and Response "Net Movement", but it does not specify whether it is the outside or the inside of the cell that has the higher or the lower concentration, thus whether the solute is entering or leaving the cell. Nevertheless, this type of information – if certain substances are supplied or evacuated – matters to the cell (and the organism); therefore, the cell should build its own model that can specify the direction of the solute's movement. This model building is an internalization of the external events which, according to the theory of matter-symbol complementarity (Pattee, 2008) (see 2.2.1), should be performed by an observer in order to make use of the



perceived phenomena to its own benefits. In the terms of van Hateren, then, it can be referred to as the estimation of fitness – an agent assessing the efficacy of the on-going actions to its self-maintenance (van Hateren, 2013, 2015d). In any theory, this observer or agent – the membrane, should be capable of measuring and comparing the solute concentrations inside and the outside of the cell.

The measurement as the estimation of the efficacy of membrane transport, f_{est} , exists in two forms: (1) the solute concentration is higher or (2) lower on the outside than the inside of the cell. On the other hand, for the actual outcome of membrane transport, f_{true} , correspondingly, there are: (1) the solute enters or (2) leaves the cell. In simple diffusion, the match between f_{est} and f_{true} – for example, higher solute concentration outside the cell and the entrance of the solute inside the cell – not only obeys the physical laws but also contributes to the cell's goal of membrane transport (and eventually self-maintenance). If mismatch appears, for example, there is a concentration gradient between the two sides of the cell, but no directional movement of the solute occurs, the transport is disrupted. However, the disruption of simple diffusion of certain solutes does not mean that they cannot pass through the membrane via other ways. The membrane as an agency is characterized by exploring different methods to realize its goal of effective substance transport.

For instance, charged or polar molecules such as amino acids, sugars, and ions do not pass readily through a membrane despite the presence of a concentration gradient; instead, they cross the membrane with the help of membrane proteins (Purves et al., 2004, p. 97). Naturally, the process is called "facilitated diffusion"; there are two types of proteins involved in facilitated diffusion – membrane channel proteins and carrier proteins (Purves et al., 2004, p. 97). Membrane channel proteins are proteins inserted into the plasma membrane that can bind to a polar or charged substance and allow it to pass through (Purves et al., 2004, p. 97). Most channels are gated – a channel opens when a stimulus happens to change the shape of the protein; the rate of substance diffusion by channel proteins depends on the concentration gradient of the substance between the inside and the outside of the cell (Purves et al., 2004, p. 97). Facilitated diffusion by carrier proteins, then, involves the actual binding of the transported substance to a membrane protein (Purves et al., 2004, p. 98). Different from simple diffusion, there are only a limited number of carrier protein molecules per unit of membrane area; the rate of diffusion reaches a maximum when all the carrier molecules are fully loaded with solute molecules (Purves et al., 2004, p. 98). When the system is saturated, further increases in the concentration gradient are not accompanied by an increased rate of diffusion (Purves et al., 2004, p. 98).

In both types of facilitated diffusion, the concentration gradient can be considered as a deterministic cause while the specificity of the substance-channel protein interaction which depends on many factors such as the physical nature of the substance, the binding specificity between the substance and the membrane protein, the saturation of the transport protein, temperature can be considered as stochastic causes. It should be noted that, from simple diffusion to facilitated diffusion, there is a transition of the magnitude of changes, from low to high, proposed in van Hateren's model of evolution as the active feedback of the agent facing situations unfavorable to the realization of its goal. We can understand the mechanism this way: the channel proteins and the carrier proteins are used by the cell to select the substances to pass through with several criteria; the more the criteria there are, the more specific the selection is, and the more stochastic for a random substance to diffuse through the membrane because it is less probable for it to fit all these criteria. Eventually, a high stochasticity for the solute, or correspondingly, a high specificity for the mechanisms of substance diffusion, which serves the cell purpose of self-maintenance better.

3.3 PURPOSE AND INTERPRETATION

3.3.1 Defining interpretation

3.3.1.1 A modified version of Short's definitions of purpose and interpretation

An organism as an agency is directional and evolvable. The organism's actions are driven by the goal of survival in the sense that they are measured and selected by the degree of benefits they can bring compared to the realization of the goal. In fact, as Short (2007) and Alexander (2013) have already addressed, this mechanism is only logical when the goal of survival is a general one – so there is room for comparisons and selections between the actions. In the same way, Robinson and Southgate (2010) argued that considering survival as a "general type of outcome" allows the distinction of actions apart from their mechanistic causes (p. 165). The "general type of outcome" is explained with Aristotle's example that a man walking for his health: "Health is the 'end' – the 'final cause' – which explains why the man is walking. [...] it could be instantiated in various ways and by various means (by swimming rather than walking, and so on)." (Robinson & Southgate, 2010, p. 165). Robinson (2015) has explained elsewhere, according to Short's interpretation, a final cause as a general type is a possibility rather than an actuality – a general type of outcome explains a particular action, but the former does not necessarily cause the latter. In other words, between a purpose and an action, there is a "many-to-one" relation (Alexander, 2013, para. 8).


A one-to-one relation – for example, the relation between the desire of an agent and its action – cannot be qualified as teleological, because the action does not respond to a purpose; it is conventionalized (by a code) to correspond to the desire.

Robinson and Southgate's study on the teleology of life starts from Short's definitions of purpose and interpretations (Robinson & Southgate, 2010). Purpose is defined by Short as "a type of outcome for which an agent acts or for which something was selected as a means" (Short, 2007, p. 110). Short (1983, 2002, 2007) argued that a teleological cause explains its effects rather than compelling them and semiosis takes place in a purposeful context. More precisely, a response is a part "purposeful course of behavior" which should be justifiable by the very purpose (Short, 2007, p. 158). Short (2007) considers Peirce's interpretation as a justification of a purposeful response:

R interprets X as a sign of O if and only if (a) R is or is a feature of a response to X for a purpose, P, (b) R is based on a relation, actual or past or apparent or supposed, of X to O or of things of X's type to things of O's type, and (c) O's obtaining has some positive bearing on R's appropriateness to P. (p. 158)

If we use the same example of the hungry wolf in Alexander's teleology (see 1.3.1.2.) (Alexander, 2013, para. 4–5), then: R "hunting" interprets X "an odor of rabbit" as a Sign of O "a rabbit" because (a) R "hunting" responds to X "an odor of rabbit" for a purpose P "the wolf's survival"; (b) R "hunting" is based on a physically causal relation between the odor and the rabbit which can be unreliable sometimes – for example, the rabbit has already gone, but its odor stays in the same place; and (c) the presence or the absence of the rabbit has a bearing – positive or negative – on the appropriateness of R "hunting" to P "the wolf's survival".



Robinson and Southgate (2010) accept the general concept of Short's definitions while proposing two improvements. First, they argued that the word "purpose" should not be confused with intentionality where psychological implements are involved; they believe that purposeful responses exist in living organisms with or without a conscious mind (Robinson & Southgate, 2010). The same concern is articulated by Alexander for which she proposed to use "response" instead of "interpretation" to describe an agent's purposeful actions (Alexander, 2013). Second, Robinson and Southgate (2010) do not believe that Short's distinction between "existing for a purpose (or having a purpose)" and "serving a purpose (acting for a purpose)" is necessary. According to Short (2007), "existing for a purpose" is considered imposed by natural selection onto the organisms while "serving a purpose" depends on the organisms' active and variable responses to increase their fitness (pp. 110-111). Robinson and Southgate (2010) do not propose to clearly distinguish between the two; instead, they have created an intermediate concept to characterize the name of a purposeful response - "a change of state that occurs for a purpose" (p. 167). As it is addressed by van Hateren in the theory of modulated stochastic causation (see 3.2.1), the mechanisms of natural selection and an organism's active feedback function in an intermingling way; the deterministic and stochastic properties of an organism are always continuously entangled thus difficult to be separated (van Hateren, 2015d).

Further developing Short's definitions of interpretation, Robinson and Southgate (2010) defined interpretation as (Figure 3.4):

A response, R, of an entity [(organism)] is a proper interpretation of X as a sign of O if and only if: (1) The entity has a property, Q, of undergoing change of state Δ S in response to sign X, where R is any actual instance of such a response; (2) (a) R tends to increase the probability of an effect of a certain general type, P; (b) This tendency of R depends on a relation between X and O, where the occurrence of X does not necessarily imply the occurrence of O; (3) The property Q has been selected for the tendency of instances of R to actualize effects of general type P. (p. 168)



Figure 3.4 The Definition of Interpretation. A response is a proper interpretation of the Sign of an Object when an agent responds based on the understanding of the Sign-Object relation with a property selected for the achievement of a general type of Purpose. Adapted from "A general definition of interpretation and its application to origin of life research", by A.
 Robinson & C. Southgate, 2010, *Biology & Philosophy*, 25(2), p. 168. Copyright 2009 by Springer Science & Business Media. Adapted with permission.

Again, we use the example of the hungry wolf (Alexander, 2013, para. 4–5) to illustrate the definition of interpretation. The action of hunting properly interprets the odor as a sign of a rabbit because: (1) The wolf has a property Q, "sensory receptors and motor effectors" capable of responding to sign X, "an odor of rabbit", by undergoing change of state Δ S, "tracing the rabbit in the direction of the odor and getting ready for the catch", where R is any actual instance of the hunting process. (2) (a) R, an instance of the hunting, tends to increase the probability of an effect of a general type, P, "the wolf's survival"; (b) this tendency of R depends on



a relation between X and O which may not stand true in the situation where the rabbit is gone but its odor still remains. (3) Q, the "sensory receptors and motor effectors" responsible for the tracing and the catching, have been selected for the tendency of R "hunting" to realize P "the wolf's survival".

Comparing Robinson and Southgate's definition of interpretation and Alexander's teleological model of sign, both agree that a response for a purpose may not actually succeed in achieving that purpose. According to Alexander (2013), Response is determined by the purpose, not the Sign-Object relation; as the purpose is a general type of outcome, there can be different responses (based on different Sign-Object relations), including the wrong ones. The fallibility of Sign-Object relation is indeed included in Robinson and Southgate's definition – there is room for errors. The next section is about the classification of the errors.

3.3.1.2 Misinterpretations and their relations to the survival of the organism

Short (2007) has concluded three features of his definition of interpretation: (1) A purpose is achieved when an object signified by the sign is obtained, but the definition does not entail that the object can always be obtained. There are times when an agent fails to obtain the object. (2) A purpose can be achieved by different objects while each one of them is specific. (3) An object is not perfectly specific as it can be mistaken for another object. The second object might as well be used to achieve the purpose. Short's conclusion brings up the discussion on the fallibility of a response based a particular Sign-Object relation. As Robinson and Southgate's definition shows, an interpretation can be fallible, thus being a misinterpretation (Robinson & Southgate, 2010). They categorize misinterpretations into two main



types based on the element concerned in the occurrence of a purposeful response: R-level error and Q-level error (Robinson & Southgate, 2010).

An R-level error is referred to as the situation in which a response fails to realize the Purpose because the Sign-Object relation does not hold in this instance, although the pairing between the recognition of the Sign and the type of Response is selected for the realization of the Purpose (Robinson & Southgate, 2010). For example, a hungry wolf senses an odor of rabbit but in fact, the rabbit has already gone, and the wolf's purpose of survival cannot be realized in this instance. The connection between Sign "an odor of rabbit" and Object "a rabbit" may be evident but in this instance, it does not hold. On the other hand, a Q-level error occurs when an organism fails to respond in the presence of a Sign, or it responds while the Sign is absent (Robinson & Southgate, 2010). In other words, the property Q responsible for the recognition and the responsiveness to a certain Sign is impaired. For example, the hungry wolf does not have any hunting actions although there is an odor of rabbit, or it hunts although there is no odor of rabbit at all. In fact, if a Q-level error occurs with a response, it cannot be qualified as an interpretation because it is not selected to realize a specific purpose (Robinson & Southgate, 2010).

Furthermore, Robinson and Southgate (2010) suggested that the errors, or misinterpretations, are relevant to the evolution of purposeful responses. They proposed to consider that as a general type of outcome, a purpose can "collapse" into a series of responses while each instance of response may or may not be a proper interpretation of the purpose (Robinson & Southgate, 2010). For example, we know that the hunting actions of a hungry wolf to the detection of an odor of rabbit are related to the animal's ultimate purpose of survival; it can be segmented into "catching a rabbit", "having a meal", "obtaining nutrition", and "increasing



the chance of survival" by their generality as a type of outcome, or more precisely, by their temporal and spatial reach to the realization of the purpose of survival. At the same, it is noted by Robinson and Southgate that although a response can be close to the purpose, the two should be distinguishable one from another because there cannot be response without purpose; otherwise, the action is not interpretative but mechanic (Robinson & Southgate, 2010).

Then, as the purpose can be segmented into individual responses, Robinson and Southgate (2010) suggested that there is also a segmentation of object correspondingly. For example, if the purpose is "catching a rabbit", then the object is "rabbit"; if the purpose is "having a meal", then the object is "edible items (including animals other than rabbits)"; and if the purpose is "obtaining nutrition", then the object is "nutritious food". The correspondence between a purpose and an object is important in the veridiction of the interpretation (Robinson & Southgate, 2010). Considering the case that a hungry wolf catches a chicken, it is a proper interpretation if its purpose is "having a meal", but a misinterpretation if its purpose is "catching a rabbit"; if the chicken is ill because of an infectious disease, then, eating it should be considered a proper interpretation if the purpose is "having a meal", but a misinterpretation if the purpose is "having a meal", but a misinterpretation if the purpose is "obtaining nutrition". In other words, whether an interpretation is proper or not can only be defined in the particular instance of the response.

Dividing the response, then the object proposed by Robinson and Southgate resembles the division of Interpretant and Object in Peirce's theories of sign. The Peircean one, in fact, is made to distinguish different stages in the development of knowledge on a certain matter (Atkin, 2013). In this sense, misinterpretations do occur and they enrich an agent's set of knowledge. It is strongly argued by Robinson and Southgate that misinterpretations can be beneficial in the long run,



which is why the responding mechanism is kept in natural selection – "it is successful often enough to increase the chances of survival and reproduction" (Robinson & Southgate, 2010, p. 174). In fact, misinterpretations make organisms adaptable: the wolf can learn that chickens or other animals are as edible as rabbits, thus expanding its food choice and increasing its hunting targets; the wolf can also learn that consuming disease-infected animals bring great risks to its life, thus adding them to the list of food items to avoid.

3.3.2 The veridiction of interpretation: membrane transport II

In 3.2.2., the process of membrane transport by simple diffusion is explained with the theory of modulated stochastic causation. It is shown that the cell has the ability to control and regulate the transport of substances to achieve the goal of self-maintenance. Therefore, being goal-oriented, simple diffusion can be considered an interpretation defined by Robinson and Southgate (Figure 3.5).

A cell interprets the concentration gradient of a given solute between the inside and the outside of the cellular membrane as a sign (X) of the net movement across the membrane of the solute (O) because: (1) The cell has a property Q, "cellular membrane", which is embedded with various mechanisms responsible for the transport of substance. (2) An instance R, "membrane transport", aims to increase the probability of a general type of outcome P, "self-maintenance of the cell", based on a relation between X and O which may not hold in this particular instance – for example, we have learnt that charged or polar molecules do not pass readily the membrane despite the presence of a concentration gradient. (3) Q, "cellular membrane", has been selected for the tendency of R "substance transport"



in realizing P "cell's self-maintenance"; and as it is shown in 3.2.2.2, different mechanisms are evolved to transport substances of different natures.



Figure 3.5 The Definition of Interpretation in Membrane Transport by Simple Diffusion. The cell's response is a proper interpretation to the concentration gradient of a solute between the two sides of the membrane signifying the net movement of the solute across the membrane because the response aiming to achieve the cell's self-maintenance is based on the natural tendency of the solute to reach equilibrium and the cell is endowed with the membrane which is selectively permeable to execute such response.

In their modified definition of interpretation, Robinson and Southgate (2010) have distinguished two types of errors: (1) R-level error occurs when the Sign-Object relation is properly interpreted, but a particular instance of response fails to fulfill the purpose. (2) Q-level error occurs when the organism fails to respond or it responds while interpreting the Sign-Object relation wrongly. These types of errors can be illustrated with different mechanisms involved in membrane transport²⁰.

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²⁰ Presented in this chapter, the mechanisms for membrane transport are simple diffusion, facilitated diffusion, and active transport.

For example, it is presented in 3.2.2.2 that the rate of substance transport by carrier proteins depends on not only the concentration gradient but also the availability of the proteins at a given moment (Purves et al., 2004, p. 98). When all the carrier proteins are loaded with solute molecules, the rate of diffusion reaches a maximum, and there will not be net movement (O) although the concentration gradient is present (S) – an R-level error occurs.

A Q-level error means something is wrong with the organism's sensibility or/and responsiveness in using a given Sign-Object relation to realize the purpose of survival. Considering the case that a certain type of substance needs to be transported into or out of the cell against the concentration gradient, the Sign-Object relations used in passive transport (i.e. the mechanisms of simple diffusion and facilitated diffusion) evidently cannot hold; the process responsible for this type of substance transport is called active transport (Purves et al., 2004, pp. 98–99). Since substances can across the membrane against the concentration gradient only in active transport, it is considered a Q-level error for the interpretative system of passive transport.

As it is proposed in Introduction, living organisms are characterized by the ability to import free energy from the environment for their self-maintenance (Deacon, 2006; Schneider & Kay, 1994). Regarding membrane transport, life cannot solely rely on concentration gradients which lead to an equal distribution of substances between the cell and the environment after equilibrium is reached; there is another process which moves substances against their natural tendencies to diffuse with an input of chemical energy – active transport. From passive transport to active transport, the property by which the cell can respond for self-maintenance is changed: active transport is achieved with the presence of membrane proteins, a specific binding between solutes and membrane proteins, as



well as an input of outside energy (Purves et al., 2004, pp. 99–100). Comparing the two processes, active transport is highly specific as it creates an even greater stochasticity for any solute to pass through the membrane (Purves et al., 2004, p. 100).

The increasing ability of purposeful responses represented by active transport can be understood as an adaptation. Kull (2014, 2015) has suggested that adaptation is a problem-solving process in which an agent turns certain incompatibility into compatibility, while the effect can be amplified by natural selection. Problem-solving, according to Kull (2015), is a semiotic process, not a computational one. The process is related to the Peircean concept of abduction by which an agent selects between alternatives ways to respond, but there is no room for selection when it comes to the formalized procedures of deduction and induction (Kull, 2015). Indeed, in membrane transport, options exist as different types of mechanisms and the possibility to select any one of them gives rise to the specificity of the process of transport. In other words, the cell (and the organism) can effectively control the directional movements of specific substances to achieve its purpose of self-maintenance.



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PART II

THE INTERACTIONS BETWEEN BIOSEMIOTIC SYSTEMS

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Chapter 4 THE TRANSMISSION OF MEANING

4.1 INTRODUCTION

4.1.1 Review of Part I

In Part I, we have discussed the creation of meaning in the biological world. Two sign models are studied and compared to each other in Chapter 1: the model of code semiosis from Barbieri made of "Sign and Meaning connected by a Code" (Barbieri, 2008a, 2008b, 2013b) and the model of teleological semiosis from Alexander made of "Sign and Response for the realization of a Purpose" (Alexander, 2009, 2013). Both models concern the tendency and the evolvability of the life-sustaining actions at all levels that an organism is capable of – molecular, cellular, organismic, psychological, etc. The code model focuses on the aspect of symbolic information processing, while the teleological model places its interest on the efficacy in realizing the goal of self-maintenance. In Chapter 2, the theory of code semiosis is further developed starting with the necessity of symbols in the construction of organic materials, argued by Pattee with his theory of "mattersymbol complementarity" (Pattee, 2008). It is shown that proteins are made based on both the law of physics (internal code) and the law of symbolic descriptions (an external code). Then, Neuman and Nave (2008) explained the creation of code with the concept of structuralist value: a sign is defined by being differentiated from other signs with their values. In Chapter 3, the purposefulness in biological

evolution is discussed. It is argued by van Hateren that evolution results from the entanglement of deterministic and stochastic causes; that is, together with natural selection, an organism' active role in error-control regulation makes it an agency responding for the purpose of survival (van Hateren, 2015d). However, not all responses can lead to the achievement of the purpose. Robinson and Southgate (2010) studied the veridiction of a purposeful response (i.e. an interpretation). They defined the conditions under which an organism interprets for a purpose; then, they categorized the errors which occur in the process, and point out the significance of misinterpretations to survival, at the present moment and in the long run.

After studying the mechanisms responsible for the creation of meaning, in Part II, we move on to the transmission of meaning. Or we can see it this way: Part I is about the use/action of sign by a single entity (a cell; an organism); Part II is about the communication based on sign use/action between the entities (cells; a population of organisms).

4.1.2 Presentation of Chapter 4

From Part I, we have learned that code semiosis and teleological semiosis address different aspects of the same process of meaning creation and they complement each other. In Chapter 4, two models are proposed – Meaning Generator System (Menant, 2003) and Self-Regulatory System (De Beule & Stadler, 2014); both have integrated the aspect of information processing and the aspect of goal-directedness.

According to Christophe Menant (2003), meaning is created in and by a system capable of evaluating incident information based on the satisfaction of the



system's needs of self-maintenance and responding to the evaluation. Then, Menant (2003) suggested that meaning can be communicated between systems, but whether a system responds to the transmitted meaning or not depends on the relation of this meaning to the needs of the receptor system. Menant's theories of meaning generator system and the transmission of meaning are applied to the studies of mechanisms of metabolism.

Proposing the model of self-regulatory system, Joachin De Beule and Kevin Stadler (2014) consider that the process of meaning creation forms a self-referential closure. A system is self-regulatory when it is capable of detecting and correcting deviations of the causal relations that sustain the system's capacity of regulation (De Beule & Stadler, 2014). In other words, the system regulates itself to maintain regulatory. De Beule and Stadler (2014) also agree on that a self-regulatory system can interact with other systems – either a tool or another self-regulatory system, leading to the integration of these systems with an increase in the self-regulatory capacity – the process is known as metasystem transition (V. F. Turchin, 1977, p. 55). De Beule and Stadler's theories of self-regulatory system are used to examine the catalytic activities of enzymes.



4.2 THE CREATION AND THE TRANSMISSION OF MEANING IN SELF-MAINTENANCE

4.2.1 The theories of meaningful information

4.2.1.1 Meaning Generator system

In Chapter 1, definitions of information and meaning in the biological world are given by Barbieri (1.2.2.2.) a sequence becomes information when it is used in a process of coding which is the establishment of a connection between the sequence and another entity being the meaning (Barbieri, 2008b). Barbieri's definition of information has captured the symbolic nature of information, despite that the sequence can exist as physical or chemical signals, written language or thoughts; meaning is considered as the output of a code-based mechanism of information processing. According to Barbieri (2008a, 2008b), the nature of the code is determined by the codemaker: linguistic signs are made by the human mind; while signs defined in the flow of genetic information are made by the molecular machines (1.2.1.3.).

In his theory of meaning creation, Menant (2003) first addressed the concerns on the usual definitions of information and meaning: (1) Meaning is considered irrelevant in cybernetics because it is not determined by the machine for information processing but the designer/user of the machine. (2) The ability to connect information to meaning is usually considered belonging to human beings. On the other hand, in biology, meaning is required in the construction of organic materials, and eventually used by the organism to realize the purpose of survival; also, meaning is created not only at the levels of (human) psychology and behaviors, but also the ones of molecules and cells. Therefore, Menant (2003) chose an example that illustrates the role of meaning in life's self-maintaining activities while disconnecting the creation of meaning from the human mind: a drop of acid in the water at the vicinity of a paramecium will make it move away, looking for a location where there is less acid.

Menant (2003) suggested that the reaction of the paramecium is based on its recognition of the acid as a hostile environment; in other words, the paramecium has the ability of connecting Information "the increased acidity of the environment" and Meaning "the hostility of the environment to its survival". Once the connection is established, an action of regulation occurs – "moving away from the area with high acidity" – in the purpose of the organism's survival (Menant, 2003). Thus, using this example, Menant (2003) defined the creation of meaning combining features of both code semiosis and teleological semiosis:

A meaning that 'has sense of', that 'wants to say': 'the environment is becoming hostile versus the satisfaction of vital constraints'. And this meaning is going to trigger within the paramecium an action aimed at putting it at distance from the acid environment. (p. 196)

Based on Menant's definition, there are three components essential to the creation of meaning (Figure 4.1): (1) the measurement, that is the reception of the incident information; (2) the comparison between the system's current condition and the goal to realize, that is the processing of the received information); and (3) based on the result of the comparison, if necessary, the regulation of the system to realize the goal of self-maintenance, that is the reaction of the system. Menant (2003) called the goal to realize as the "vital constraint" of the system in the sense of organisms' self-maintenance (p. 196). The received information becomes meaningful (i.e. "meaningful information", pp. 196-197) when it is connected to



the system's vital constraint and participates in the continuous maintenance of this constraint; the system is named a "Meaning Generator System" (Menant, 2003).



Figure 4.1 Meaning Generator System. Meaning is created when incident information is identified and connected to the constraint of the system; meaning is used to determine the actions to satisfy the constraint of the system. Reprinted from "Information and meaning", by C. Menant, 2003, *Entropy*, *5*(2), p. 197.

Furthermore, Menant (2011) suggested considering the embedment of an agent in its environment based on a "network of meanings" (para. 2), which is the superposition of many meaning generator systems to form the cognitive reality. Menant (2011) explained that a single entity in the environment represents information of various types; once received, it is used by the organism to generate different meanings to satisfy different constraints. The network of meanings is made of real-time information exchanges between the agent and the environment as well as regulatory actions as past experiences and anticipated simulations (Menant, 2011). In other words, information is transmitted across meaning generator systems to guide specific regulations. It should be more accurate to consider the network of meanings as a hierarchy of meanings. Earlier, Menant (2005) gave the example that the constraint of "staying alive" can be divided into sub-constraints "find food" and "avoid danger"; sometimes the sub-constraints



are in conflict (para. 6). He suggested that there should be a function at a higher level to assign priorities and solve the conflict (Menant, 2005). The transmission of information also takes place between agents (Menant, 2011). Menant (2011) has argued that although there can be an incompatibility between individual constraints in a group of agents, the group constraint is always the strongest. In the next section, we talk about the transmission of information and the subsequent generation of meaning; in 4.3.1.2, we discuss the compatibility between agents integrated into one group.

4.2.1.2 The transmission of meaningful information

Studying the transition from non-communicative behaviors to communicative ones, Quinn (2001) suggested that there are two basic requirements of communicative behaviors: (1) a set of behaviors potentially designated as signals; and (2) dedicated sensory channels for the perception of these signals. In short, communication appears with the necessity and the infrastructure. Menant (2003, 2005, 2011) believes that meaningful information can also be transmitted to another system whose own constraint may or may not be satisfied by the original information. In other words, meaning can be communicated. There are many examples in the world of animals: for instance, the specific sound as a call for reproduction made by a male cicada is meaningful information transmitted to the females and this information can be used by both the male and the female in the satisfaction of their vital constraint required by the survival of the species; however, if this information is received by a predator of cicada and the male cicada is hunted for it, the life of the male cicada is in danger while the vital constraint of the predator is more likely to be satisfied (Menant, 2003, pp. 201, 203).

Menant's meaning generator system is made of three components – the reception of the incident information, the processing of the received information and the reaction of the system – which are essential but not indispensable in the creation of meaning. For example, the system may not be able to react after measuring and evaluating the current condition, which is the case of a Q-level error when the system fails to respond (3.3.1.2) (Robinson & Southgate, 2010). In this case, the information is still meaningful because it is connected to the system's vital constraint; but as it cannot actually satisfy the constraint, it is considered by Menant (2003) as "non-efficient" (p. 202). Menant (2003) defined that the system in which meaningful information can determine the actions relating to the satisfaction of the system's constraint is the "domain of efficiency" for that information (p. 202).

According to Menant (2003), the transmission of meaning occurs between two meaning generator systems one as the transmitter (T) while the other as the receiver (R) (Figure 4.2): Once transmitted, usually, the information is meaningful (T) but non-efficient (T) in the receiver system R. If a connection between the received information and the constraint of system R is established, then meaningful information (R) and efficiency (R) can be created. In other words, this information can participate in the actions satisfying the constraint of the receiver system R. From then on, normally, the transmitted information is no longer efficient to the transmitter system T. However, if the constraints of the transmitter system T and the receiver system R are identical, meaning that they share the same domain of efficiency, then the transmitted information can still be efficient to the transmitter system T. By distinguishing between the situations, Menant (2003) showed that the same information can generate different meanings in different systems receiving it; and constraint-satisfying actions also vary among systems.





Figure 4.2 The Transmission of Meaning. Meaningful information defined in one system can be transmitted to another system and it may or may not be useful in satisfying the constraint of the receiver system. Reprinted from "Information and meaning", by C. Menant, 2003, *Entropy*, 5(2), p. 203.

Returning to the example of a male cicada calling the females for reproduction (Menant, 2003, pp. 201, 203), the call is meaningful information for both the male and the female who happen to have the identical vital constraint – the survival of the species; this information is thus efficient in determining the actions of both organisms. On the other hand, when the predator of the male cicada hears his call, the hunting can result in the cicada's death which is obviously against the satisfaction of its vital constraint. The meaning and the efficiency of the call is differently defined for the male cicada and the predator of cicada.

4.2.2 Meaning is created and communicated in metabolic reactions

Menant (2003) presents the meaning generator system with the example of paramecium reacting to drops of acid in the environment. The purpose of its reaction can be generally concluded as self-maintenance. More specifically, acid denatures proteins, endangering the orderly biological structure of the organism²¹. In Introduction, we have learned that one of the most important characteristics of living is the way that they use energy to maintain their orderliness; and in this section, we discuss the use of energy by organisms in Menant's frameworks of the creation and the communication of meaning.

In biological systems, the total energy is called enthalpy (H); the energy that can do work is called free energy (G)²²; the unusable energy is represented by entropy (S), which is a measure of the disorder of the system, multiplied by the absolute temperature (T) (Purves et al., 2004, p. 109). Thus, there is: H = G + TS (or G = H - TS). Metabolism is the total chemical activity of a living organism: reactions can be classified as either the building up of complexity in the cell, using energy to do so, or the breaking down of complex substances into simpler ones, releasing energy in the process (Purves et al., 2004, p. 109). To tell whether free energy (G) is released or consumed by a chemical reaction, the change in total energy (ΔH) and the change in entropy (ΔS) must be determined: $\Delta G = \Delta H - T\Delta S$. If ΔG is negative ($\Delta G < 0$), free energy is released; if ΔG is positive ($\Delta G > 0$), free energy is consumed (Purves et al., 2004, p. 109).

²¹ Denaturation is referred to as the situation that proteins lose the three-dimensional folded shape thus the normal biological functions (Purves et al., 2004, p. 45).

²² Free energy is required for "cell growth, cell division, and the maintenance of cell health" (Purves et al., 2004, p. 109).

The change of energy – being released or consumed has a determinant role in the tendency of the reaction to run to completion – the point at which all the reactants are converted to products (Purves et al., 2004, p. 110). The reactions that release free energy (- Δ G) are called exergonic reactions and tend to run toward completion without any input of energy (Figure 4.3 a.) (Purves et al., 2004, p. 110). As reactants break apart into smaller molecules, that is, the structure of a substance transforms from order to disorder, exergonic reactions can occur spontaneously in the natural world simply because of the entropic force (Hamori & Muldrey, 1984). On the other hand, the reactions that run toward completion only with an input of free energy (+ Δ G) are called endergonic reactions (Figure 4.3 b.) (Purves et al., 2004, p. 110). As the reactants are building up into bigger and more complex compounds, endergonic reactions represent the structural transformation from disorder to order which cannot take place in the natural world unless energy is supplied (Purves et al., 2004, p. 110).



Figure 4.3 Exergonic Reaction and Endergonic Reaction. a. An exergonic reaction releases energy; b. Energy is required for an endergonic reaction to take place.



In the case of life, the input of free energy required by an endergonic reaction can be provided by the energy released by an exergonic reaction on the condition that the overall change of free energy – the sum of the Δ G values of all the reactions involved – is a negative one, thus respecting the second law of thermodynamics (i.e. the decrease of free energy and the increase of entropy) (Purves et al., 2004, p. 112). In other words, an unfavorable reaction with a positive Δ G1 can be driven by a second, highly favorable reaction with negative Δ G2 if the magnitude of Δ G2 is greater than the magnitude of Δ G1. For example (Figure 4.4), the reaction synthesizing glutamine (an amino acid) has a positive Δ G (+3.4 Kcal/mol) and cannot proceed without the input of free energy from ATP hydrolysis, which has a negative Δ G (-7.3 Kcal/mol). The total Δ G for the coupled reactions is negative (the two Δ Gs added together: -3.9 Kcal/mol) (Purves et al., 2004, pp. 112–113).



Figure 4.4 The Synthesis of Glutamine. The reaction synthesizing glutamine is an endergonic one and it needs to be driven by an exergonic reaction – ATP hydrolysis.

The self-maintenance of an organism relies on the construction of biologically important molecules. In the synthesis of glutamine, as it is just shown, the amount of free energy required by this endergonic reaction is compared with the amount released by the exergonic reaction of ATP hydrolysis; then the overall change of energy – a negative one – favors the coupling of the two so that glutamine is synthesized. As the very process consists of the detection of difference and the reaction upon such difference, it can be seen as the



establishment of a connection between the current state (incident information) and the desired state (the constraint of the system), accompanied by a reaction to realizing the desired goal. In other words, meaning is created in this process. We use Menant's Meaning Generator System to model the synthesis of glutamine (Figure 4.5):



Figure 4.5 The Creation of Meaning in the synthesis of glutamine. Energy released from ATP hydrolysis is recognized as meaningful to the successful synthesis of glutamine because the former provide the energy needed in the latter.

The successful synthesis of glutamine – the maintenance the system's constraint – requires energy, which makes the received information – energy released from ATP hydrolysis relevant. The connection between this information and the constraint of the system needs to be identified before being considered "meaningful" to the system: the amount of energy released should be greater than the amount of energy required. If this condition holds, the system can react to this meaningful information by coupling the exergonic reaction (ATP hydrolysis) with the endergonic reaction (the synthesis of glutamine).



If this process can be considered involving a primary form of cognition, this cognition has nothing to do with any mental abilities. With the examples of paramecium and the use of energy on the cellular level, it is showed that cognition does not necessarily require a brain or/and nervous systems to process information and to generate meaning. At the same time, it is also shown that organisms react to incident information when it is connected to meaning which has a great significance to their survival. Bourgine and Stewart (2004) argued that cognition is required in the management of metabolic interactions between the organism and the environment. Meacham (2016) especially noted that metabolic relations between an organism and its environment are cognitive because they are not chemically necessary but involve a selection process based on recognition and reaction. He then added that cognitive interactions are distinguished from chemical ones by their temporal and historical dimensions that can serve as the basis for future selections (Meacham, 2016).

After explaining the creation of meaning in metabolism, here is another example of the use of energy by organisms, which requires the transmission of meaning. Glycolysis is the metabolic pathway by which organisms harvest the energy inside glucose; in this process, glucose is converted into pyruvate, releasing free energy which is then used to form the high-energy compounds ATP and NADH (Purves et al., 2004, p. 130).

Glycolysis, the energy harvesting (releasing) process consists of two phases – the preparatory phase in which energy is invested and the payoff phase in which energy is released (Figure 4.6) (Purves et al., 2004, p. 130). In the preparatory phase, the reactions are endergonic – that is, the cell is investing free energy into the glucose molecule, rather than harvesting energy from it (Purves et al., 2004, p. 130). With the investment of 2 ATPs, the first five reactions of glycolysis rearrange the



six-carbon sugar glucose and split it into two glyceraldehyde 3-phosphates (G3P) (Purves et al., 2004, p. 130). Then, in the pay-off phase, each reaction occurs twice per glucose molecule, yielding 2 NADH molecules and 4 ATP molecules (Purves et al., 2004, p. 131). Therefore, in the end, there is a net gain of 2 NADH molecules and 2 ATP molecules from the glycolytic pathway per glucose.



Figure 4.6 Two Phases of Glycolysis. Glycolysis consists of a preparatory phase where energy is consumed and a pay-off phase where energy is released.

The preparatory phase and the pay-off phase can be considered, respectively, a transmitter system and a receiver system of meaningful information. In the transmitter system, two G3P are formed from glucose; while in the receiver system, they are converted into pyruvate. Therefore, the G3P molecules can be seen as the meaningful information being transmitted (Figure 4.7). The formed G3P molecules in the preparatory phase are meaningful (T) and efficient (T) in this very system defined by the tendency of energy consummation – its constraint (T). After that the G3P molecules are "transmitted" to the system of the pay-off phase, they remain meaningful (T) but no longer are efficient (T) to the process of energy



consummation. However, as G3P can be used to satisfy the constraint of the receiver system – the release of energy, they are meaningful (R) and efficient (R) once again.



Figure 4.7 The Transmission of Meaning in Glycolysis. G3P is the meaningful information transmitted from the energy-consuming phase of glycolysis to the energy-releasing phase.

4.3 BIOSEMIOTIC SYSTEMS EVOLVE AND INTERACT WITH EACH OTHER

4.3.1 The theories of self-regulation

4.3.1.1 Self-regulatory system

In Menant's model of meaning generator system (Menant, 2003), the system's constraint is characterized as "vital" thus essential to its self-maintenance. The constraint can be used as a reference in determining the connection between the incoming information and the system's needs for self-maintenance. On the other hand, Menant (2011) has noted that the reference should result from the system's



self-maintaining actions, including the ones from the past and the ones in the anticipated future. In other words, there is a functional closure – comparing the received information to the constraint that aims in maintaining the constraint. The self-referential aspect of Menant's model is specially examined in this section. De Beule (2012b) believes that a closure is formed between the organism and its environment as the former makes use of the latter for its self-maintenance. Studying Ashby (1956), De Beule (2014) specifies that the process is self-regulatory: the system constantly maintains its physiological limits – the "essential parameters" (para. 9) – to be independent of the environment; therefore, it becomes its own basis of regulation.

Modeling a self-regulatory system, first, De Beule and Stadler (2014) defined the form of regulation as "error-controlled" and "end-directed" (para. 5): the system responds to incidents considered deviating from the system's purpose. In a diagram (Figure 4.8), they showed that the effect caused by a disturbance is evaluated by the target of regulation (the goal of the system); if it is qualified as an error, regulation occurs so that this type of effect will not be caused again (De Beule & Stadler, 2014, para. 5).



Figure 4.8 An Error-Controlled and End-Directed Regulation. Both living systems and artificial systems can detect and correct errors based on their purpose to achieve. Reprinted from "An evolutionary cybernetics perspective on language and coordination", by J. De Beule & K. Stadler, 2014, *New Ideas in Psychology, 32*, p. 121. Copyright 2013 by Elsevier Ltd. Reprinted with permission.



Then, De Beule and Stadler (2014) proposed that the causal nature of Disturbance and Effect – the rules by which causation is determined between two entities (material or conceptual) is, in fact, arbitrary. They suggested that physical causation can be reduced to arbitrariness: "Even in physics, speaking of a cause-effect relation implies that without the cause, something else would have happened." (para. 6). Therefore, a specific set of "cause-effect" determined by a specific physical law can be considered as a "category" or a "distinction providing information" (De Beule & Stadler, 2014, para. 6). Furthermore, they propose that, as the law is not fixed, it is specified by some other law (De Beule & Stadler, 2014). In figure 4.9, it is shown that Law L which specifies the causal relation between Cause C and Effect E is itself specified by Law R as the Effect L of Cause A, and the specification of laws goes on infinitely.



Figure 4.9 The Infinite Set of Cause-Effect. A law – physical or conventional – specifies the relation between a cause and an effect and the law itself is the effect of another cause specified by another law. Reprinted from "An evolutionary cybernetics perspective on language and coordination", by J. De Beule & K. Stadler, 2014, *New Ideas in Psychology, 32,* p. 122. Copyright 2013 by Elsevier Ltd. Reprinted with permission.

Reviewing the process of self-regulation defined (Figure 4.8), the effect caused by an incident actually causes the reaction of the system to stop the occurrence of the effect; therefore, by identifying an effect as the cause of its regulation, the specification of laws is limited inside a functional closure (Figure

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4.10 a.) (De Beule and Stadler, 2004). De Beule and Stadler (2014) suggested that the law by which the first effect causes the second should be understood as the qualification of the incident information by the target of regulation (Figure 4.10 b.), which is, in turn, defined as "the capacity to sustain categories, to qualify them, and to make informed decisions in order to persist or 'survive' as a system with such capacities" (para. 7). In other words, the system regulates to exist and it exists to regulate.



Figure 4.10 The Functional Closure of a Self-Regulatory System. a. Inside a functional closure, the effect of a cause becomes the cause of the law that specifies itself; b. In a self-regulatory system, the effect specified by a law can cause regulations of the law based on the preset reference. Adapted from "An evolutionary cybernetics perspective on language and coordination", by J. De Beule & K. Stadler, 2014, *New Ideas in Psychology, 32*, p. 122. Copyright 2013 by Elsevier Ltd. Adapted with permission.

It should be noted that the functional closure in the process of self-regulation defined by De Beule and Stadler is different from its inspiration – the closure defined by Ashby, which excludes the creation of novelties, thus adaptations, because the transformations between operands take place in a closed set (Ashby, 1991). In this thesis, we believe that new elements can be added to the system's



category of actions in the cycles of self-regulation. According to Froese and Stewart (2010), adaptive behaviors are originated from the interactions between the environment and the organism: the environment not only perturbs the boundary-defining essential parameters of the organism but also triggers selections of random organizational changes of the system when the boundary is exceeded. The same logic is expressed by von Neumann in his formal model of self-reproduction (see 2.2.1.2) (von Neumann, 1966); the physical closure required in the replication of oneself is nevertheless open to heritable alterations.

4.3.1.2 The interactions between self-regulatory systems

It is presented in 4.2.1.2 that, according to Menant (2003), meaningful information can be communicated between meaning generator systems. De Beule and Stadler (2014) agree that interactions can exist between self-regulatory systems and influence on their regulatory capacities. The first condition of the occurrence of these interactions is the independence of each system. A self-regulatory system is considered a subsystem in a larger system with "essential parameters" which are the "physiological limits" that distinguish the subsystem from the environment (De Beule & Stadler, 2014, para. 9). For example, the temperature of an organism should be maintained within the range that its biological functioning requires, despite that the temperature of its environment favors the need or not (De Beule & Stadler, 2014, para. 9). In Figure 4.11, it is shown that inside system U, a self-regulatory system O and its environment E. e is the essential parameters of O influenced by E and determines O's control C and regulation R. R interacts with E in order to regulate e so that O is distinguished from E (De Beule & Stadler, 2014, para. 9).



Figure 4.11 The Essential Parameters of a Self-Regulatory System. Self-regulation means that the achievement of self-maintenance is a self-referential process. As two subsystems of U, a system O interacting with the environment E that can maintain the independence and the stableness of its essential parameters (e) is considered a self-regulatory one (De Beule & Stadler, 2014, p. 9). The control part (C) commands the reacting part (R) to manipulate the environment to regulate the essential parameters of the system. Adapted from "An evolutionary cybernetics perspective on language and coordination", by J. De Beule & K. Stadler, 2014, *New Ideas in Psychology*, 32, p. 124. Copyright 2013 by Elsevier Ltd. Adapted with permission.

Then, through regulation, a system can evolve to be better adapted to its environment. De Beule and Stadler (2014) suggested that, among error-controlled regulations, some are judged to be more beneficial than others to the maintenance of the system's essential parameters, that is, the target of regulation; these moments will be selected and kept in the category of the system's future responses. The increased adaptability is, in fact, the increased capacity of self-regulation. De Beule and Stadler (2014) believe that this capacity can be extended by using tools. The definition of tool naturally implies functional interactions between two systems taking place in a goal-directed way, yet it is important to note that the tool system is not necessarily self-regulatory – self-regulation requires the control of a system's own essential parameters, maintaining the independence of this system from its environment (De Beule & Stadler, 2014). Through tool using, the selfregulatory capacity of a system increases in complexity and diversity; eventually, it is possible that the system and the tool integrate into one single larger system – the process is called a metasystem transition (De Beule & Stadler, 2014).

Introduced by Valentin Turchin, cybernetic scientist, in his book *The Phenomenon of Science* (1977), the concept of metasystem transition is referred to as the creation of a higher level of organization and control by integrating subsystems at the level below; major steps in evolution such as the origin of life, multicellularity and the beginning of culture are seen as the results of metasystem transition is considered as a "quantum of evolution", a "discrete jump to a higher level of complexity" (Francis Heylighen, Joslyn, & Turchin, 1995, para. 1). Using the cybernetic concept – control and regulation, Turchin studied the hierarchical organization, differentiation, and functionality of metasystems leads to the specialization of their functions:

Specialization is seen particularly clearly where whole organisms are integrated. Each subsystem being integrated into this case contains a great deal which is 'superfluous' – functions necessary for independent life but useless in the community, where other subsystems perform these functions. Thus, specialized muscle and nerve cells appear in the multicellular organism. (p. 56)

De Beule and Stadler (2014) explained metasystem transition with the example of using fire: "since the 'invention' of fire, humans have gradually 'outsourced' digestive functions to cooking, a likely advantage of which was an enhanced supply of protein, allowing an increase in brain size" (para. 11). As a result, humans in modern times no longer consume food the same way as their ancestors did; cooking has already become an indispensable part of their lives. In the example, fire as a tool is not self-regulatory but fully controlled by the tool user,



humans. De Beule (2014) suggested that through tool usage, the operations of tools involve more specialized interfaces and the interdependency between the operator and the tool is strengthened. Tools that are selected for their functions tend to be repeatedly manufactured and the operators become more dependent on those tools as their functions are irreplaceable (De Beule, 2014).

On the other hand, the case in which two self-regulatory systems interact is more complicated. In the theory of meaning transmission (see 4.2.1.2) (Menant, 2003), the concept of "domain of efficiency" states that the transmitted information can cause purposeful responses of the receiver system (thus being efficient) only when it is redefined as meaningful in and by the new system; also, meaningful information can be efficient in both the transmitter and the receiver systems at the same time if the two systems share the same vital constraints. In the same logic, De Beule and Stadler (2014) categorized the interactions between self-regulatory systems as the compatible and the incompatible ones.

The compatibility between two self-regulatory systems depends on the relation between their essential parameters: If no likeness exists between the two, then only one system can benefit from the interactions by the increase of its self-regulatory capacity; if their sets of essential parameters contradict one with another, then one of the systems will end up extinct (De Beule & Stadler, 2014). De Beule and Stadler (2014) explained that incompatible interactions are driven by "the simplifying power of natural selection" which amplifies the proliferation of the more adapted systems and eliminates the failing ones (para. 12). If similarities are shared between the essential parameters of the two systems, then both can benefit from the interactions. In this case, the partnership is more likely to be favored by natural selection and the two systems integrate into a larger whole – a qualitative change of functional organization which is characterized as


metasystem transition. Specifically, De Beule (2012a) conclude that the interactions between compatible systems bring about two types of benefits: (1) Joint control can be achieved as the two systems share remarkable similarities between their essential parameters. For any system, thus, the regulatory capacity per parameter is increased; (2) Integration of subsystems may cost each one of them some of its freedom toward the environment, but it gains the power to control other organisms to make use of their specialties. In this way, the whole system becomes a more efficient regulator as every subsystem is specialized.

Based on the definition of self-regulatory systems (Figure 4.10 b.), their integration means the acquisition of new causal relations – learning. They are indeed considered as agents with "a regulatory capacity to make and maintain arbitrary 'choices', to try out things and to see whether they 'make sense' through learning" (De Beule & Stadler, 2014, para. 13). In a Figure 4.12, two compatible self-regulatory systems O1 and O2, sharing some of their essential parameters, interact with each other and the same environment E (De Beule & Stadler, 2014, para. 12). In each self-regulatory system, the part responsible for regulation R – made of cause and effect, determined by an arbitrary rule – is further interpreted as the establishment of connection between the received signal S and the defined meaning M realized by an adapter A. More importantly, the part for control C can change the adapter A in order to learn new signal-meaning (or cause-effect) relations from the interacting system.





Figure 4.12 Learning Between Two Self-Regulatory Systems. Inside the system U, subsystems O1 and O2 interact with the environment E as well as each other. The reacting part of a self-regulatory system is made of a module for the input S (signal) and a module for the output M (meaning); the computational part A adapts S to M. The control part C can change the computational part A. As the two self-regulatory systems (O1 and O2) share some of their essential parameters (e), the regulatory capacity of each system increases by expanding its category of Cause-Effect relations with the ones learned from the other system. Reprinted from "An evolutionary cybernetics perspective on language and coordination", by J. De Beule & K. Stadler, 2014, *New Ideas in Psychology*, *32*, p. 126. Copyright 2013 by Elsevier Ltd. Reprinted with permission.

Metasystem transition leads to not only the integration of compatible selfregulatory systems but also the creation of rules for their interactions. According to De Beule and Stadler (2014), there are at least two reasons that protocols of interaction are needed: (1) For coordination – "the total self-regulatory capacity of two systems does not increase by itself (para. 13)". In the larger system, there should be a set of rules that specify the tasks of regulation of each subsystem in order to optimize the regulatory capacity of the whole. (2) For development – several self-regulatory systems integrate into a larger one and the growth continues. An expanding category of meaningful cause-effect relations characterizes the process of metasystem transition. The matching between causes and effects, in turn, depends on arbitrary rules.



In fact, Heylighen (1995) suggested that coordination and development, together, characterize the circular process of metasystem transition: the metasystem constrain the variety of subsystems to promote specialization and coordination among them; when the existing constraints become insufficient to guarantee the stableness of the metasystem, the variety of the subsystems tends to increase by integrating more of them – Turchin (1977) named the process as "the branching growth of the penultimate level" (p. 57). Simultaneously, coordination stimulates development and development strengthens coordination (V. F. Turchin, 1977). Defined as the two modes of a metasystem transition cycle, protocol-based coordination and development (Karatay & Denizhan, 2005) are specially discussed in 5.2.1.

4.3.2 Self-regulation and intersystem relations in enzyme catalysis

4.3.2.1 Enzymes as a means of self-regulation

In 4.2.2, we have learned that an exergonic reaction releases free energy, thus can spontaneously occur in the natural world (Purves et al., 2004, p. 110). However, the reaction may take place very slowly because there is an energy barrier between the reactants and the products; in this case, an input of energy is needed to change the reactants into their unstable forms (Purves et al., 2004, p. 113)²³. Heat, for example, can increase the average kinetic energy of the reactant molecules; but this

²³ The unstable forms of reactants are called "transition-state species" that have higher free energies than either the reactants or the products (Purves et al., 2004, p. 113) .

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non-specific method cannot be used in living systems: while one particular reaction is accelerated, so are the destructive ones including the denaturation of proteins (Purves et al., 2004, p. 114). For cells, reactions are speeded up by enzymes, which do not provide more free energy but can lower the energy barrier (Purves et al., 2004, p. 114). Most enzyme catalysis is specific – a reactant (called a substrate when it is bound to an enzyme) can only bind to the active site of an enzyme if there is fitness between their three-dimensional shapes; after the substrate is converted into the product, it is released from the enzyme²⁴ (Purves et al., 2004, p. 115).

Indeed, enzyme catalysis is one of the means by which cells regulate the use of energy for the purpose of self-maintenance. The general process can be formalized with the model of self-regulatory system (Figure 4.13): the reactant and the product are Cause and Effect connected by the Law of chemistry; when there is an energy barrier preventing the reaction – an Error, the cell accelerates the rate of the reaction by binding the reactant to an enzyme – Regulation; after the energy barrier is overcome by enzyme catalysis, the chemical law is reconditioned to the successful unfolding of the reaction at the rate required by cellular activities.

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²⁴ The process: the binding of a substrate to an enzyme produces an enzyme-substrate complex; the enzyme-substrate complex gives rise to product and the enzyme is free again; $E + S \rightarrow ES \rightarrow E + P$ (Purves et al., 2004, p. 115)



Figure 4.13 Self-Regulation in Enzyme catalysis. Enzymes are used by a cell to accelerate the unfolding of chemical reactions in the goal of self-maintenance.

On the other hand, if we consider a cell as a self-regulatory system, then enzymes can be seen as tools used by the cell for an increased self-regulatory capacity. The "essential parameters" of an enzyme should be what is related to its catalytic activity, which can be made use of by a cell in need of enzyme catalysis. The sharing of their essential parameters depends on the binding between the reactant (i.e. substrate) and the enzyme. This binding is specific – "a precise interlocking of molecular shapes and interactions of chemical groups at the binding site"; however, as proteins, many enzymes can change their structures, exposing the active sites while reacting with their substrates (Purves et al., 2004, p. 117). In this case, as the binding is realized by the structural change of the enzyme, it is called an induced fit (Purves et al., 2004, p. 117). For example, hexokinase, an enzyme, can catalyze the reaction between glucose and ATP: glucose + ATP \rightarrow glucose 6-phosphate + ADP; induced fit brings the enzyme's active site into alignment with the substrates – glucose and ATP, facilitating the catalytic mechanisms (Purves et al., 2004, p. 117).

As the case of induced fit shows, tool using results from the manipulation of the essential parameters of the interacting system. In other words, self-regulatory capacity does not increase just by chance – waiting on the perfect match between what the system needs and what the tool can offer; instead, a system makes choices or take trials to test the compatibility of itself and the tool, giving rise to a robust regulation. The closure of self-regulation is functionally closed but open to novelties. The evolvability of a self-regulatory system can be understood with van Hateren's theory of modulated stochastic causation (van Hateren, 2015d): the system actively selects actions that can better serve the purpose of self-maintenance while the results, both positive and negative ones, are amplified by natural selection. In 8.2.1, the ability to create possibilities for goal-oriented actions are addressed in the presentation of the theory of cognitive niche construction (Magnani & Bardone, 2008).

4.3.2.2 Interactions of systems in the control of metabolic pathways

By metabolism, energy from food is harvested to fuel cellular processes and it is done through sequences of enzyme-catalyzed chemical reactions called metabolic pathways in which the product of one reaction is the substrate for the next (Purves et al., 2004, p. 119). While the rate of a sequence of reactions can be promoted by enzymes, it can also be slowed down by inhibitors (Purves et al., 2004, p. 119). Some inhibitors inactivate the enzyme by permanently binding to it – the inhibition is irreversible; others can be unbound from the enzyme – the inhibition is reversible (Purves et al., 2004, p. 119).

In irreversible inhibition, the inhibitor covalently binds to the enzyme, permanently inactivating the enzyme's capacity of interacting with its substrate (Purves et al., 2004, p. 119). On the other hand, reversible inhibition can be categorized as competitive and non-competitive ones: Competitive inhibitors bind to the active site of an enzyme non-covalently, preventing the binding of the



substrate to the same site; when the competitive inhibitor is detached from the active site, the enzyme is active again (Purves et al., 2004, p. 119). Non-competitive inhibitors bind to the enzyme at a site different from its active site; the binding causes a conformational change in the active site which can no longer be fitted by a substrate (Purves et al., 2004, p. 120).

Previously in 4.3.2.1, we have studied the role of enzymes as tools used by the cell to regulate chemical reactions by forming a complex with the substrate. Here, after explaining the reversible and the irreversible binding of inhibitors to enzymes, it can be considered that inhibitors are used as tools to regulate the activity of the enzyme-substrate complex. The exact process varies depending on the case (Figure 4.14): in competitive inhibition, competing with the substrate for the same active site, the inhibitor is used to regulate the substrate, then to influence the enzyme; in non-competitive inhibition, the inhibitor is used to regulate the enzyme by causing the change of the enzyme's shape, which in turn influences on the binding of the substrate. Therefore, in a cell's plan of selfregulation for metabolic reactions, there are at least two levels of organization which require tool usage: (1) between the inhibitor and the enzyme-substrate complex; (2) between the inhibitor and the enzyme.





Figure 4.14 Inhibitory Regulation. In competitive inhibition, as presented by the solid lines, the inhibitor targets at the substrate to change the functions of the enzyme; in non-competitive inhibition, as presented by the dashed lines, the inhibitor targets at the enzyme to change its functions.

More commonly, enzymes exist in the cell in more than one shape – an active form that allows the binding between an enzyme and its substrate as well as an inactive form for the binding between the enzyme and the inhibitor - the two forms can constantly interconvert (Purves et al., 2004, pp. 120-121). This type of non-competitive inhibition with conformational changes of the enzyme is called allosteric regulation (Purves et al., 2004, p. 121). In this case, we can see that the enzyme plays the role of a self-regulatory system; it uses inhibitors as tools and interacts with substrates as other self-regulatory systems for an increased capacity of self-regulation. For an allosteric enzyme, each of its two forms specializes in a type of regulation – inhibition or promotion – interacting with an inhibitor or a substrate; in fact, these two types of regulations exist in a complementary manner. Therefore, the inhibitory regulation by tool using (the tool is the inhibitor) coexists in a larger system with the acceleratory one which also requires the use of tool (the tool is the enzyme). More importantly, the two types of regulation can no longer be separated one from another as they share the same set of "essential parameters" defined by the same shape-shifting enzyme (Figure 4.15).





Figure 4.15 Acceleration and Inhibition by Allosteric Enzymes. The active form and the inactive form coexist with each other in a complementary way: when the enzyme binds to the substrate, it cannot bind with the inhibitor and vice versa. Reactions that can take place are marked by solid lines; reactions that cannot are marked by dashed lines.

As it is previously explained, metabolic reactions happen in sequence (Purves et al., 2004, p. 119). It means that once the catalysis starts, other intermediate reactions happen in sequence, leading to the end product. How does the cell regulate this process? For example, how does the cell stop the reaction when there is an excess of the end product? One of the solutions is called end-product inhibition (or feedback inhibition) (Figure 4.16): when there is a high concentration of the end product, some of it binds allosterically to the enzyme at the start of the sequence, functioning as an inhibitor causing the inactivation of the enzyme (Purves et al., 2004, p. 142). While the excess of the end product of a reaction restrains the catalysis of another reaction in the earlier step of the sequence, it can also promote the catalysis of the third reaction in a different branch of the same sequence; in this case, the reaction being speeded up diverts the supply away from the synthesis of the first product (Purves et al., 2004, p. 142). That is, the excess of this product can be regulated by both negative and positive feedback controls.





Figure 4.16 Negative and Positive Feedback Controls of Catalytic Reactions. When the excess of a product inhibits its synthesis, there is negative feedback control; when the excess of a product stimulates the synthesis of other products, there is positive feedback control.

Metabolic pathways are made of interconnected reactions, enabling the whole process to be controlled at each point (Purves et al., 2004, p. 142). Therefore, regulating this composite system is more effective and efficient than regulating individual pathways one at a time. At the same time, as the reactions are connected one to another, they should be coordinated to fulfill their roles in the larger system. With the establishment of these "protocols", metabolic reactions are regulated within a framework based on the means of regulation (codes) and the target of regulation (purpose). This coordination consists of levels of control – for a certain reaction, the conversion of the reactants depends on the "choices" made by the precedent reactions; at each level, there are (at least) two types of control – the inhibition or the promotion of a given reaction. Furthermore, the control is retroactive (self-referential) thus relying on the estimation of past experiences – the excess of the end product can inhibit the reaction at an earlier step; it can also promote another reaction at a different branch of the sequence.

The growth on the scale of complexity as well as the increase of the selfregulatory capacity of a system by integrating another system is called metasystem transition (De Beule & Stadler, 2014, para. 10; Turchin, 1977, p. 55). For example, as it is shown in Figure 4.17, the process of (aerobic) cellular respiration is made of several pathways: glycolysis, pyruvate oxidation, citric acid cycle, and respiratory chain. The reactions in one pathway can be regulated by not only the reactions of this particular pathway but also the reactions in another pathway within the whole system (Purves et al., 2004, p. 142). In the citric acid cycle, the reactions are mainly regulated by the enzyme isocitrate dehydrogenase, which can be inactivated by ATP or NADH (Purves et al., 2004, p. 142). At the same time, the inhibition of citric acid cycle leads to an excess of citrate, causing the inhibition of glycolysis, the previous pathway (Purves et al., 2004, p. 142). In consequence, with an additional negative feedback inhibition, the given pathway is effectively regulated beforehand and the whole process of cellular respiration is kept in balance.



Figure 4.17 Feedback Controls in the Citric Acid Cycle. As a major phase of aerobic cellular respiration, the citric acid cycle can be accelerated or inhibited by the end products; also, the excess of a product in the citric acid cycle can inhibit the synthesizing process in the previous step – glycolysis.



Considering that metabolism made of thousands of biochemical reactions has a circular and autopoietic organization (Letelier, Cárdenas, & Cornish-Bowden, 2011), the reactions are inevitably related one to another and the pathways must share "essential parameters" between them. In the example presented above (Figure 4.17), glycolysis, pyruvate oxidation, citric acid cycle, and respiratory chain are integrated subsystems with their individual abilities of self-regulation increased by outsourcing the responsibility to others. De Beule (2012a) suggested that the establishment of joint control depends on code-based communications between the subsystems, which are not, originally, the intrinsic properties of individual systems. From the example, an act of communication is made between citric acid cycle and glycolysis: the former can not only inhibit its own catalysis but also communicate to the latter to fulfill the same goal. The code of such communication, then, can be seen as a cause-effect relation unknown to the original subsystems which is specified to connect them – in this case, it is the inhibition of glycolysis by citrate.



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5.1 INTRODUCTION

5.1.1 Review of Chapter 4

There are two major topics in Chapter 4: (1) the modeling of a meaningcreating system comprising both code semiosis and teleological semiosis; (2) the communication of meaning between these systems.

First, the creation of meaning is studied within the frameworks of meaning generator system (Menant, 2003) and self-regulatory system (De Beule & Stadler, 2014). In both frameworks, the creation of meaning operates based on an arbitrary code connecting the received incident information and a constraint or parameters defined by the system. At the same time, the defined constraint or parameters are related to the purpose of the system, which is its self-maintenance; therefore, the system can evaluate the current condition in relation to the satisfaction of its purpose and react upon the evaluation. Such systems are referred to as code-based and goal-oriented systems in this thesis. Evidently, the creation of meaning is closely linked to a system's ability of regulation. De Beule and Stadler (2014) proposed that the regulation is self-referential (see 4.3.1.1.), meaning that the code



responsible for the connection between incident information and the system's purpose can be constantly reconditioned by its own functioning. Self-referentiality is especially remarkable when the framework of self-regulatory system is applied to the case of enzyme catalysis, where the excess of an end product of a metabolic pathway can inhibit the catalysis from the beginning (see 4.3.2.2.).

Second, discussing the communication of meaning, the focus is placed on the relations between systems. Menant (2003) proposed the concept "domain of efficiency": meaningful information is considered efficient after being transmitted to another system if it can cause regulatory actions in the new system. Therefore, if the transmitter system and the receptor system share the same constraint, they can both benefit from the transmission of meaningful information. De Beule and Stadler (2014) described the situation as the compatible interaction between two self-regulatory systems. In other situations, the interaction may be incompatible, or it is not between two self-regulatory systems, but between one self-regulatory system and a tool. The increase of self-regulatory capacity, through either tool using or establishing mutually beneficial relationships, can lead to the integration of the two systems into a larger one. Valentin Turchin (1977) named the phenomenon as metasystem transition, which is studied in detail in the first part of this chapter (see 5.2.1.), with a special attention paid to the establishment of protocols facilitating the interactions between subsystems during the process.



5.1.2 Presentation of Chapter 5

In Chapter 5, the communication of meaning is examined from the angle of inter-subsystem relations.

First, Vefa Karatay and Yagmur Denizhan (2005) examined Turchin's theory of metasystem transition and categorized five stages of the process. In metasystem transition, the integration of subsystems requires the creation of common codes. The process of metasystem transition distinguishes between a subsystem's own codes used for its self-maintenance – subjectivity, and the codes it needs to obey with other subsystems for their interactions and the maintenance of the larger system – objectivity. Therefore, the process can be considered the expansion of a semiosphere (Lotman, 2005) where more signs are created in response to the increasing interactions between subsystems.

Inspired by the economic theories (Arthur, 1990, 1999), Karatay and Denizhan (2005) distinguished two modes of operation in the process of metasystem transition – cooperation and optimization. Cooperation happens at the beginning of subsystem interactions where the overall self-regulatory capacity is increased as the regulatory tasks of each subsystem are outsourced to other systems. The benefits encourage the larger system to expand by trying to establish cooperative relations with more systems. Necessarily, protocols facilitating the interactions between subsystems should be created. For example, subsystems are organized to be specialized and complementary in their regulatory actions for the self-maintenance of the larger system. This is when optimization takes place. Metasystem transition is a process by which self-regulatory systems integrate and evolve. The modes of cooperation and optimization are studied in the example of cellular respiration.



Reviewing the process of meaning creation and considering the study of meaning in both the models of meaning generator system and self-regulatory system, the establishment of connections and the purpose of the system's selfmaintenance involve not only the aspect of syntactics but also the aspects of semantics and pragmatics. Respectively, the semantics concerns the reception of the received incident information and the reaction to it, while the pragmatics concerns the purposefulness behind.

The process of metasystem transition, in turn, can also be examined from this angle. By the theory of complementarity of syntactics, semantics, and pragmatics, Peter Cariani (1989, 2015) suggested that an effective and efficient control requires the acquisition of new protocols as well as new operational instruments for a precise measurement, successful regulatory actions, and the evolvability of the system regarding the satisfaction of its purpose. Cariani's theory can be applied to the studies of both cybernetics and biology. He considers each one of syntactics, semantics, and pragmatics as a module of control and explained the necessity to combine two or all of them in enhancing the self-regulatory capacity of the larger system (Cariani, 1989, 2015). Finally, using the example of the genetic code, Cariani (2015) showed that there are modules of syntactics, semantics, and pragmatics at the cellular level and they function in a complementary way. Also, with the example of alternative RNA splicing, it is shown that the evolution of genome requires adaptive changes in both the syntactic and the semantic parts of the system.



5.2 THE SEMIOTIC MECHANISMS IN METASYSTEM TRANSITION

5.2.1 The stages and the modes of a cycle of metasystem transition

Presented in 4.3.1.2., resulting from the interactions between self-regulatory systems, metasystem transition as the creation of "a higher level of organization" (para. 1) enables a more effective and efficient control of the larger system (De Beule & Stadler, 2014). In the end of the discussion, it is proposed that new protocols are needed for specifying the tasks of regulation of each subsystem and optimizing the regulatory capacity of the whole (De Beule & Stadler, 2014). In this section, Karatay and Danizhan (2005) suggested that these protocols are created to serve the two modes of a cycle of metasystem transition: cooperation and optimization.

According to Turchin, metasystem transition results from the multiplication and the integration of subsystems (S_1 , S_2 , S_3 , ..., S_n) as well as the formation of a control over these systems (C) through trials and errors (Figure 5.1) (Heylighen, 1995 as cited in Karatay & Danizhan, 2005, p. 48). Turchin (1977) also added that, from the functional point of view, metasystem transition means the appearance of new types of activities when the control shifts to a higher stage of the organization; the structural components are created by replication and selection.



Figure 5.1 The Metasystem Transition. The control Cof a set of subsystems S_1 , S_2 , S_3 , ..., S_n is a metasystem in relation to these systems; the joining of a new control A is called a metasystem transition. Adapted from "In search of a reconciliation between semiotics, thermodynamics and metasystem transition theory", by V. Karatay & Y. Denizhan, 2005, *Axiomathes*, 15(1), p. 48. Copyright 2005 by Springer. Adapted with permission.

Heylighen (1995) suggested that metasystem transition necessarily exists in the biological world because living organisms with a large variety of regulatory skills are more likely to survive the changing environment. In fact, the increase of the variety of an organism means the increase of the environmental variables of another organism that interacts with the former; then, the latter must increase its own variety to keep up with the environment (Heylighen, 1995). Therefore, inside a larger system, interacting subsystems reinforce the increase of variety of each other forming a positive feedback (Heylighen, 1995). The development of variety inside the larger system slows down when further increase constraints less and less effective the given metalevel; the pace of evolution accelerates, again, after a new metasystem transition occurs (Heylighen, 1995). The process of metasystem transition is characterized as cycles of rapid and slow increases of variety (Figure 5.2). The cycles of metasystem transitions, according to Umerez and Moreno (1995),



are self-organizing: "lower level components are 'directed' by the global pattern towards a kind of behavior that reverts in the maintenance of the very global pattern" (p. 147). Umerez and Moreno (1995) explained that the natural boundary conditions of lower level components give rise to a higher level of control and the latter redefines the lower levels by creating new boundary conditions. In this way, external boundaries become internal ones; the self-generated constraints substitute some of the initial conditions.



Figure 5.2 The Increase of Variety through Metasystem Transitions. The variety of regulatory actions of the whole system increases through a cascade of metasystem transitions. Inside each cycle, the beginning is characterized by a rapid increase of the variety, then, the increase slows down as the interactions between the subsystems are stabilized. Adapted from "(Meta) systems as constraints on variation – a classification and natural history of metasystem transitions", by F. Heylighen, 1995, *World Futures: Journal of General Evolution*, 45(1-4), p. 73. Copyright 1995 by Routledge. Adapted with permission.

Karatay and Danizhan (2005) agree that the larger system grows by the mutual influences between the control and the subsystems – the variation of the subsystems strengthens the control and the control enables the subsystems to vary. Karatay and Danizhan (2005) have further segmented the process into five stages to define an operational cycle of metasystem transition: The first stage is the

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"open-ended diversification of ith-level agents" (p. 49) characterized by a transition of the systemic functioning from homogeneity to individuation. Then, in the second stage, these agents are most likely to interact and establish cooperative relations if they function in a complementary way. The third stage is the "stabilization of mutually advantageous interactions" (p. 49) which should be the establishment of a selectively permeable boundary – "creating an identity for the system and protecting it against destabilizing effects" (p. 50). Thanks to this boundary, in the fourth stage, the control mechanism is strengthened so that the agents are functionally better integrated into the larger whole. A strong control of a goal-oriented system, again, promotes the increase in number and variety of agents – the emergence of the "(i+1)st level agent" (p. 50) – the fifth stage. The newly integrated agent will, again, interact and build synergetic relations with other agents, adapt to the existing context and go through the process of stabilization.

Szathmáry and Smith (1994) have concluded several major transitions in the history of life such as the birth of autocatalytic systems, the birth of the genetic code, the birth of multicellular organism, the emergence of (proto)language all characterized by the appearance of greater complexity, or more precisely, the transition from self-dependent replication to the other-dependent one, giving rise to more efficient mechanisms for communication. Studying the phenomena of metasystem transition in humans, Last (2014) suggested that the human ability to procure energy increased at three key points: the birth of spoken language required in hunting; the birth of written language needed in agriculture; and the birth of printing press required in industry. Salthe (2012) believes that the transition from lower to higher levels of organization marks an increase in "semiotic freedom" (p. 370), which is the remarkable separation of the informational constraints (i.e. the higher levels) from the dynamic physical

interactions (i.e. the lower levels), allowing regulatory actions to be created in a more specific way. Language is considered placed at the highest level of life as a complex system as it can represent almost any relations (Salthe, 2012). Karatay and Danizhan (2005) proposed to consider the interactions between subsystems (or agents) as sign-mediated communications: Separately, each agent exists in its own subjective reality, thus in a self-referential way. Therefore, for agents with different subjective realities to interact, an agreement specifying the mapping relations between one and the others needs to be reached. From this code-based agreement, each agent-participant gains knowledge of the objective reality, functioning and existing by using others as a reference. While interacting agents are integrated into a larger whole, quantitatively and qualitatively more developed code-based agreements are established, and the whole system has a stronger control mechanism. From this point of view, the process of metasystem transition necessarily involves the use of signs (or the creation of code). As Karatay and Danizhan (2005) put, "the branching growth of the penultimate level and the subsequent establishment of an internal context at the last stage can be interpreted as the emergence of the Innenwelt of the higher-level agent and an accompanying endo-semiotic complexification." (Figure 5.3) (p. 51).





Figure 5.3 A Cycle of Metasystem Transition cycle. The interactions between agents are stabilized by the establishment of conventions. Thus, the agents that are originally self-referencing can use others as references, resulting in a metasystem transition. Adapted from "In search of a reconciliation between semiotics, thermodynamics and metasystem transition theory", by V. Karatay & Y. Denizhan, 2005, *Axiomathes*, *15*(1), p. 52. Copyright 2005 by Springer. Adapted with permission.

The stages of metasystem transition describe an operational cycle made of the coupling of "branching growth of the penultimate level" (p. 51) and "stabilization of mutually advantageous interactions" (p. 49), Karatay and Denizhan (2005) referred them as the modes of cooperation and optimization. Furthermore, inspired by William Brian Arthur (1990, 1999), economist especially interested in complexity theory, they proposed an economic interpretation of the phenomenon (Karatay & Denizhan, 2005). According to Arthur (1990, 1999), the reactions of each part leads to the changes of the larger system; then, under the constraint of the larger system, the parts react anew. The accumulation of "random" event can be magnified in positive feedbacks and play a determinant role in the developmental course of the system. In the beginning of the integration



of a new metasystem level, the possibilities of forming synergetic interactions between the agents are to be explored, thus the system is the phase of exploiting a "new and unexhausted niche" which "creates surplus values" (Karatay & Denizhan, 2005, p. 54). At this moment, cooperation is encouraged - many codebased agreements specifying the interactions between agents exist; but as a stronger control mechanism takes in form, they will be selected in favor of the realization of the system's goal (Karatay & Denizhan, 2005). Indeed, when the resources of the new level reach to their limits – most interactive choices are tried and tested, the "returns" decrease and the system redistributes its energy in a more economical way: it ceases the diversification and the specialization of agents (i.e. the cooperative mode), while encouraging the organizational optimization of the already formed whole to maintain its stability (Karatay & Denizhan, 2005). Elsewhere, Karatay and Denizhan (1999) suggested that the growth of a complex system characterized by the modes of cooperation and optimization is, in fact, a trade-off between an advantage and a disadvantage – the advantage being an overall increase of control capacity regarding information processing and resource exploitation, while any growth is economically disadvantageous because more resources are required to maintain the stableness of the system.

5.2.2 Cellular respiration as a process of metasystem transition

In the biological context, the two modes of a cycle of metasystem transition are illustrated with the example of cellular respiration. At the end of 4.3.2.2, by presenting aerobic cellular respiration (Figure 4.17), we have discussed the composite nature of the regulation of metabolic pathways. Cellular respiration is the mechanism by which organisms convert biochemical energy from nutrients

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into ATP to fuel cellular activity, and then release waste products (Purves, Sadava, Orians, & Heller, 2004, p. 126). The whole process is made of a series of steps (Figure 5.4): When oxygen is available, glycolysis takes place first and is followed by pyruvate oxidation, the citric acid cycle, and the electron transport chain (Purves et al., 2004, p. 126). When oxygen is unavailable, the pyruvate produced by glycolysis is metabolized by fermentation; while pyruvate oxidation, the citric acid cycle, and the electron transport chain do not happen (Purves et al., 2004, p. 126).



Figure 5.4 The Harvest of Energy by Organisms. Glucose in food is metabolized by glycolysis and aerobic/anaerobic respiration.

Karatay and Denizhan (1999) suggested that as the result of metasystem transitions in living systems, evolution operates in an add-on manner – both material structures and organizational patterns are repeatedly used, François Jacob referred the phenomenon as tinkering (Jacob, 1977).

During the course of evolution complexity increases by successive meta-system transitions giving rise to nested hierarchical (organizational) structures. In spite



of their nestedness each of the different meta-system levels has its own dynamics and rules, which emerge with the self-organisation process. (Karatay & Denizhan, 1999, para. 2)

Aerobic cellular respiration is 18 times more efficient in harvesting energy than the anaerobic one (Purves et al., 2004, p. 126). The end products of fermentation still contain chemical potential energy that can be released by oxidation (i.e. the oxidation is incomplete) – ethanol, for example, can react with oxygen to give carbon dioxide and water (Figure 5.5) (Purves et al., 2004, p. 126). On the other hand, in the case of complete oxidation, the energy inside the nutrients is released not in one single reaction but a step-by-step manner (Figure 5.5) (Purves et al., 2004, p. 128). Pyruvate oxidation, the citric acid cycle, and the electron transport chain can be seen as metasystem levels combined to maximize the cell's capacity in harvesting energy – the mode of cooperation. For instance, yielding 24 molecules of ATP, the citric acid cycle is far more efficient at harvesting energy than any single reaction could be (Purves et al., 2004, p. 134).

PATHWAY	SUBSTRATE-LEVEL PHOSPHORYLATION	OXIDATIVE PHOSPHORYLATION	TOTAL ATP
Glycolysis	2 ATP	2 NADH = 4-6 ATP	6-8
Pyruvate oxidation		2 NADH = 6 ATP	6
Citric acid cycle	2 ATP	6 NADH = 18 ATP 2 FADH ₂ = 4 ATP	24
TOTAL	4 ATP	32 ATP	36-38

Figure 5.5 The Efficiency of Energy Release. The citric acid cycle releases much more energy than glycolysis. Adapted from *Glycolysis and Cellular Respiration*, by LibreTexts Biology, 2016. Retrieved October 4, 2017 from

https://bio.libretexts.org/Under_Construction/BioStuff/BIO_101/Reading_and_Lecture_No tes/Glycolysis_and_Cellular_Respiration.

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The composite nature of energy releasing steps favors the strengthening of the cell's self-regulatory capacity. As it is explained in 4.3.2.2, each step (pathway) is, in fact, a control point for regulating the whole process of cellular respiration (Figure 4.17): it can retroactively accelerate or inhibit its own reactions; also, it can serve as an additional feedback control to the reactions of another combined pathway (Purves et al., 2004, p. 143). Furthermore, molecules produced in the steps of cellular respiration have other roles in the cell: for example, the intermediates of the citric acid cycle are themselves catabolic products or anabolic building blocks of other molecules, such as amino acids and nucleotides (Purves et al., 2004, p. 143). The stabilization by a strong regulation of the synergetic relations between these steps for the cell's benefits characterizes the mode of optimization in the case of aerobic cellular respiration.

5.3 BIOSEMIOTIC SYSTEMS EVOLVE BY SIGN-RELATIONS

5.3.1 The theory of the complementarity of syntactics, semantics, and pragmatics

5.3.1.1 Defining syntactics, semantics, and pragmatics in a code-based and goaloriented system

In metasystem transition, while a system expands by integrating another level of organization – a new subsystem, protocols are needed to coordinate its functioning in the larger whole. These protocols are considered mediated by signs or codes as they specify the mapping relations between one subsystem and another. Therefore, in fact, they concern the syntactic organization of the system. On the other hand, what concerns the users of signs – the semantics and the pragmatics – are yet to be examined. Cariani (1989, 2015) proposed that the complementarity of syntactics, semantics, and pragmatics is required for a sign system to realize an effective and efficient control.

According to Cariani (1989, 2015), syntactics is a set of operationallydeterministic rules defining the transitions between operational states. Computer programs, for example, are purely syntactic operations, because the defined manipulation of signs depends only on the type of the sign, not its "meaning" (Cariani, 1989, 2015). The aspect of meaning, defined by Cariani, involves the connection between the systems of signs and the system of sign users which is the world beyond the sign system (Cariani, 1989, 2015). More precisely, the semantic meaning of a sign is determined by real-time sign using, while the connection between the two systems is established through their interactions: perception (measurement) and reaction (regulation) (Cariani, 1989, 2015). The process is portrayed by the models of Meaning Generator System (Menant, 2003) and Self-Regulatory System (De Beule & Stadler, 2014): the reception of incident information causes a regulatory reaction of the system. One of the most important factors that determine the semantic aspect of a system is the purpose - named "vital constraint" or "target of regulation" in these models. The aspect of pragmatics is concerned when it comes to the evaluation and the strengthening of purpose-satisfying mechanisms through perception-reaction and the use of code (Cariani, 1989, 2015). For example, in human language, the meaning of a word varies according to the context or/and the intention of the speaker.

Cariani (2015) explained the complementary relations between syntactics, semantics, and pragmatics using the example of a weather reporting device (para. 5). This device can signal the weather of a given city by sounding bursts of the

pulse. There are two types of pulse bursts: one is a set of bursts with short intervals (I1) and the other is another set with long intervals (I2). The two types of pulse bursts are separated by a long interval of silence which is the longest of all. Thus, the syntactics of this system, or more precisely, the rules for distinguishing sign types are established based on the length of an interval – an interval between the bursts of pulse can be (1) a long silence; (2) a shorter silence (I2); or (3) the shortest silence (I1). Cariani (2015) has emphasized the importance of differentiation in the creation of signs: if it is a string of pulse bursts of only the shortest intervals, the message lack of a grammatical structure can hardly signify anything. In this example, the semantics – rules that specify the relations between the system of signs and the system of sign users – is defined as follows: pulse bursts of the shortest intervals (I1) correspond to "cities" and pulse bursts of shorter intervals (I2) correspond to "weather conditions"; for example, message [(3, 4) (1, 3)] means "snow in New York and rain in London" (Figure 5.6 a. and b.) (Cariani, 2015, para. 5). The creation of semantic meaning requires measurement realized by meteorologists with specialized instruments in these cities, and influences on the receptors of the meaning - the choice of clothes, the change of travel plans, etc., thus bringing pragmatic values (Cariani, 2015).





SEMANTIC CATEGORY	SIGN	SIGN STATES
	type of intervals in burst	#intervals in burst
CITY	burst with short intervals (I1)	1: London 2: Tokyo 3: New York
WEATHER	burst with long intervals (I2)	1: clear 2: cloudy 3: rain 4: snow

a. The syntactics

b. The semantics

Figure 5.6 A System of Weather Report. The system consists of two parts: a. the syntactics that specifies the distinctions between bursts of pulses; b. the semantics that specifies the correspondences between the bursts of pulses and the reality – city and weather. Adapted from "Towards an evolutionary semiotics: the emergence of new sign-functions in organisms and devices", by P. Cariani, 1998, *Evolutionary systems*, p. 364. Copyright 1998 by Springer Science & Business Media, Dordrecht. Adapted with permission.

The syntactic structure disambiguates one message out of 12 possibilities. In order to understand the message emitted by this weather reporting device, the receivers should be able to distinguish bursts of pulses of different lengths of intervals and to count the number of bursts in a set of those of similar intervals. The semantic implement enables the empirical connections to events in the world: the receivers can know the real-time weather of a given city by listening to the pulse bursts. Indeed, the semantics of a system concerns the sensibility of measuring instrument and the effectiveness of regulation, which is discussed in



the next section (see 5.3.1.2). The purpose of the weather report, then, is related to the users of the device. They can be meteorologists, travelers, farmers, etc. and for each group of people, the weather of a given city means something pragmatically different. Therefore, changes may be required for the device to better satisfy the purpose of individual users. In 5.3.1.3, there is a discussion on the evolution of a code-based and goal-oriented system under the pressure of the pragmatics.

5.3.1.2 The complementary roles and the adaptations of syntactics, semantics, and pragmatics

In Chapter 4 by the models of Meaning Generator System (Menant, 2003) and Self-Regulatory System (De Beule & Stadler, 2014), the creation of meaning is defined as the establishment of the connection between the received incident information and the satisfaction of the system's purpose which is its selfmaintenance. In the example of weather reporting device, by looking into the aspects of syntactics and semantics, it should be noted that, in fact, there are two types of meaning: (1) the syntactic meaning, determined by the code which maps the incident information to the realization of system's self-maintenance; (2) the semantic meaning, which depends on the reception of incident information in realtime, the measurement of the distance between the system's current state and its purpose of self-maintenance, as well as the reactions to reduce this distance. Cariani (2015) suggested that a code-based and goal-oriented system, at least, should consist of two parts: (1) measuring devices, or sensors, which can interact with the world and set up the "initial conditions" for the system; (2) a symbolic convention, or a mathematical algorithm, which generates a prediction based on the initial conditions. In short, the first part is responsible for the creation of semantic meaning and the second part for the creation of syntactic meaning.



The two types of meaning ensure the system's functioning through feedback control (Figure 5.7): First, measurement is carried out to set up the initial conditions of the formal procedure, generating a prediction; then, the prediction is compared to the actual outcome known through another measurement – the perception (Cariani, 2015). If the two results agree, then the system is functioning effectively in satisfying its purpose or the purpose of the user; if not, then it means that the system is unable to predict the outcome of its functioning, thus theoretically, less capable in the satisfaction of the purpose (Cariani, 2015).



Figure 5.7 Syntactic Meaning and Semantic Meaning. In a code-based and goal-oriented system, the syntactic meaning is used to define the computational rules and the semantic meaning is used to set the initial conditions of the computation as well as to evaluate the result based on the system's goal based on the measurement of the world (t₁ for prediction and t₂ for evaluation). Adapted from "Towards an evolutionary semiotics: the emergence of new sign-functions in organisms and devices", by P. Cariani, 1998, *Evolutionary systems*, p. 365. Copyright 1998 by Springer Science & Business Media, Dordrecht. Adapted with permission.

When there is a mismatch between the prediction and the perception, Cariani (2015) suggested, there are three options of modification (Figure 5.8): (1)

the change to the algorithm (Δ syntactics); (2) the change in the measuring devices (Δ semantics); and (3) the change on the user's purpose (Δ pragmatics). Cariani (2015) explained that the alteration of a malfunctioning system usually starts from the algorithm because it is relatively easy and cheap to try another set of computations which is known to the system's builders; on the other hand, altering the sensors can be more difficult and more expensive to achieve. The evaluation of the algorithm and the measuring devices is related to the purpose of the system or/and its user, which is, in fact, a pressure of selection on the system's "mutational-constructional capabilities" (Cariani, 2015). In fact, syntactics, semantics, and pragmatics are independent and complementary operations ensuring the functioning of a code-based and goal-oriented system (Cariani, 2015). Organisms, for instance, their bodies have incorporated the three parts: the sensory organs function as measuring devices detecting changes of themselves and their living environment; the nervous systems, coordinating the sensors and the effectors, correspond to the computational properties; finally, through acting with the effecter organs which impact directly onto the world, the organisms regulate the functioning of their bodies (Cariani, 2015).





 Δ = alter structure \rightarrow alter function

Figure 5.8 The Alterations of the Three Complementary Parts. When an error appears – the prediction of the calculation does not match the actual result – each of the parts of syntactics, semantics, and pragmatics can be altered to determine the cause of the error and to correct it. Adapted from "Towards an evolutionary semiotics: the emergence of new sign-functions in organisms and devices", by P. Cariani, 1998, *Evolutionary systems*, p. 366. Copyright 1998 by Springer Science & Business Media, Dordrecht. Adapted with permission.

Cariani (1991, 2003) has specified that the basic functionalities of sensing, coordinating, and effecting – formally as measurement, computation, and control – are required in building the connection between organisms/devices and the environment; and this connection is contingent by nature – the system always perceives and responds to a particular state of change in the world. The process of coordination, furthermore, can involve not only feedback control but also the feedforward one which generates memory-based predictions about the coming events (Cariani, 2003). For instance, neural circuits that are present at many levels



in higher animals – "from two-neuron sensorimotor reflexes in the spinal cord to sets of elaborate and complex interconnections in the forebrain" (p. 13) – assume the role of the planner of operations (Cariani, 2011). Detailed explanations on feedforward control and anticipatory actions are given in 6.3.1 and 8.2.2.

5.3.1.3 The add-on evolution of syntactics, semantics, and pragmatics

In the previous section, the complementary roles of syntactics, semantics, and pragmatics in a code-based and goal-oriented system are studied. However, not all three parts are necessarily incorporated into one single device. In fact, Cariani (1989, 2015) suggested that the ability to integrate all three modules and strengthening the syntactic or/and the semantics part for better control outcomes based on the user's purpose results from a process of add-on evolution. Cariani (1989, 2015) has made the distinction of four types of device to illustrate the evolution of complexity and adaptability: formal computational, formal-robotic, adaptive, and general evolutionary.

The first device is digital computers which consist of only syntactic operations: to solve a problem in the real world, the user of a computer needs to convert the situation in the form of symbols and feed it to the program as the initial conditions; the computer runs from the initial state to other states until a terminal one is reached (Cariani, 2015). Therefore, it is the user that connects computations to the world and defines the purpose of the system.

A robotic device, then, has the parts for both computations – algorithms, and connections to the world – sensors and/or effectors; in other words, it can create both syntactic and semantic meaning (Cariani, 2015). The device alone can recognize physical signals such as images and sounds, encode them into symbols,



yield results by computations, and impact on the world through effectors – walking, picking up objects, etc.; the role of a human user/designer lies in deciding for the best parts for sensing, computing and affecting in solving given problems (Cariani, 2015). Therefore, the device itself is non-adaptive.

Trainable machines, such as "neural networks, genetic algorithms, adaptive classifiers, Boltzmann machines, and many others" are devices that are syntactically adaptive (Cariani, 2015, para. 9). Like non-adaptive computers, the symbolic encoding of input information by the user is required; special to the adaptive ones, however, the output of computation is used as feedback to adjust the programming to better satisfy the user/designer's purpose – the device can change its internal conventional structure (Δ syntactics) (Cariani, 2015). A trainable machine can be connected to sensors and effectors to solve problems in the physical world; however, without semantic adaptations, it is limited to a given extent of sensibility and effectiveness – "as good as its percept and action primitives allow" (Cariani, 2015, para. 9).

Semantic adaptation means the emergence of new sensory distinctions or/and action alternatives using feedback information (Δ semantics) (Cariani, 2015). For artificial machines, it requires the building of new measuring or/and effecting devices, usually achieved by engineers and scientists; for organisms, it appears that implements for new sensory and effecter distinctions can develop – for instance, the immune system of vertebrates can develop specific responses to new types of antigens²⁵ through the selective mutation of antigen receptors, thus

²⁵ In immunology, an antigen is an organism or a molecule recognized by and interact with the host organism to initiate an immune response (Purves et al., 2004, p. 370).
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being semantically adaptive (Cariani, 2015). In 7.3.2.2, this process is explained in detail.

Due to different types of plasticity, the four types of devices are distinguished one from another by their capabilities and limitations (Figure 5.9) (Cariani, 1989, p. 29). Cariani (1989) has emphasized that adaptive devices (syntactic adaptation) cannot give rise to absolute novelties because all syntactic possibilities are determined beforehand and the device can only discover the relatively useful ones. However, semantic possibilities are not predetermined and the exploration of them is open-ended. New functions that are not anticipated can appear when semantic properties adapt; thus, the concerned devices are referred to as the evolutionary one (Cariani, 1989).

DEVICE TYPE	PLASTICITY	CAPACITIES	LIMITATIONS
Formal- computational	Fixed syntax	Reliable execution of pre-specified rules	Limited to pre- specified rules and states
Formal-robotic	Fixed syntax Fixed semantics	Reliable execution of fixed percept- action combinations	No feedback or learning from environment
Adaptive	Adaptive syntax Fixed semantics	Performance- dependent optimization of percept-action coordination	Limited to percept & action categories fixed by the sensors & effectors
General evolutionary	Adaptive syntax Adaptive semantics	Creation of new percept & action categories; performance- dependent optimization within these categories	Time to construct & test new sensors & effectors may be very long

Figure 5.9 The Capacities and Limitations of the Devices. The devices distinguished by the adaptivity of their syntactics or/and semantics show differences on the level of functions. Adapted from "On the design of devices with emergent semantic functions", by P. Cariani, 1989, doctoral dissertation, State University of New York, p. 29. Copyright by Peter Cariani. Adapted with permission.

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Cariani (1991, 2015) has noted that humans are specially gifted in creating artificial implements for syntactic and semantic adaptations: enhanced memory to enable complex coordination (e.g. RAM of a digital computer), as well as sensory prosthetics (e.g. microscope, CT scanner, hearing aid) and tools (e.g. chainsaw, bike, chemical plant) to increase the number of distinctions that humans can make on the world. Cariani (2015) suggested that "pragmatic autonomy" is attained when a device can redefine its evaluative criteria based on the selection of semantic and syntactic categories (para. 11). However, Cariani (2015) believes that very few devices are adaptive on their own; the closest may be those that can tune the (preset) parameters to control their sensors, but they cannot achieve autonomy because of they cannot build new sensory/effective structures.

5.3.2 Syntactic and semantic adaptations in the genetic code

In 1.2.1.4., the "central dogma of molecular biology" and the genetic code (Purves et al., 2004, pp. 236, 239; Tamarin, 2001, p. 276) are presented to show the role of symbolic conventions in the construction of organic materials. In this section, we review the genetic code from the new perspective by distinguishing the syntactic, semantic and pragmatic aspects of a code-based and goal-oriented system.

Cariani (2015) considers DNA sequences as symbols. The flow of information from DNA to RNA then to protein, then, involves syntactic rules of transcription and translation, responsible for the mapping of a DNA nucleotide sequence onto an amino acid (Figure 5.10). The produced protein has a role in cellular activities thus directly influence the organism's survival. Thus, proteins act as the semantic devices connecting the genetic sequences to the physical world (i.e. the connection between genotype and phenotype). The pragmatics of the genetic code concerns the evolution of genome in realizing the goal of survival through the interactions between natural selection and the organisms' own regulatory actions. Furthermore, Cariani (2015) suggested that the genetic code is syntactically adaptive because mutations can occur in the processes where genetic information is transferred. The organisms with muted genes, then, face the pressure of selection; the survived ones can pass on these genes to future generations. Therefore, a change starts from the syntactic part of the system is connected to the reality by the semantic part, tested and evaluated by the pragmatic part which amplifies the syntactic change. The process of syntactic adaptation is characterized as a cycle made of: "symbol string \rightarrow construction process \rightarrow formation of physical parts of the device \rightarrow action of the device \rightarrow performance in the environment \rightarrow differential survival \rightarrow selection of symbol strings" (para. 11).



Figure 5.10 The Syntactics, Semantics, and Pragmatics of the Genetic Code. The synthesis of protein from DNA based on the genetic code includes not only the syntactic rules specifying the mapping relations between the sequences of DNA and amino acids but also the semantic and the pragmatic aspects specifying the functions of the protein in living organisms and the purpose of these functions. Adapted from "Towards an evolutionary semiotics: the emergence of new sign-functions in organisms and devices", by P. Cariani, 1998, *Evolutionary systems*, p. 371. Copyright 1998 by Springer Science & Business Media, Dordrecht. Adapted with permission.



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In fact, the mechanism for transferring genetic information is much more complex than what is just explained. Kjosavik (2007) pointed out the necessity to be specific when using the term "genetic code": "[...] if one is to speak of a 'genetic code', and of 'genes coding for proteins', this can only be understood within an idealization that ignores the complexities of the process that leads from genes to assembled proteins." (p. 335). More precisely, Kjosavik (2007) believes that there are two different versions of the RNA system – the primary mRNA transcript which contains non-coding genes and the mature mRNA transcript which only contains the coding ones. The removal of the non-coding regions of genes is called RNA splicing (Purves et al., 2004, p. 289). Barbieri (2003) believes that there is a real code involved in RNA splicing: like protein synthesis, there is an arbitrary correspondence created between the primary and mature RNA transcripts. It is used here as the example of cellular syntactic and semantic adaptations.

Eukaryotic genes contain non-coding base sequences called introns which are interspersed with coding regions called exons; both introns and exons appear in the primary transcript of RNA (pre-mRNA), but the transcript to be translated into proteins – the mature mRNA – does not contain any introns (Purves et al., 2004, p. 285). In a process called RNA splicing (Figure 5.11), the introns are removed from the pre-mRNA and the exons are spliced together (Purves et al., 2004, p. 289). The splicing mechanism recognizes the boundaries between exons and introns – the removal of introns needs to be done properly; otherwise, a different or non-functional protein will result (Purves et al., 2004, p. 289).



Figure 5.11 RNA Splicing. The primary transcript of a eukaryotic gene contains non-coding base sequences called introns; the introns need to be removed so that the mature transcript can be used to synthesize proteins. Adapted from *Transcription: from DNA to RNA*, by LibreTexts Biology, 2017. Retrieved October 4, 2017 from

https://bio.libretexts.org/LibreTexts/University_of_California_Davis/BIS_2A%3A_Introduct ory_Biology_(Easlon)/Readings/18.1%3A_Transcription-from_DNA_to_RNA.

Indeed, there exists a mechanism of alternative splicing responsible for generating a family of different proteins from a single gene (Figure 5.12) (Purves et al., 2004, p. 296). For example, the pre-mRNA for the protein tropomyosin can be spliced in five different ways, resulting in five different mature mRNAs, which are then translated into the five different forms of tropomyosin found in skeletal muscle, smooth muscle, fibroblast, liver, and brain (Purves et al., 2004, p. 296). In fact, there are many more human mRNAs than human genes; it is estimated that half of all human genes are alternatively spliced (Purves et al., 2004, p. 296). Through alternative splicing, the genotypes of an organism develop in variation and complexity which will result in the differentiation of phenotypes. In other words, the mechanism enables both syntactic and semantic adaptations of the genetic system.





Figure 5.12 Alternative RNA Splicing. Tropomyosin, the primary transcript of a gene can be spliced in different ways resulting in different types of protein. Adapted from *Transcription: from DNA to RNA*, by LibreTexts Biology, 2017. Retrieved October 4, 2017 from https://bio.libretexts.org/LibreTexts/University_of_California_Davis/BIS_2A%3A_Introduct ory_Biology_(Easlon)/Readings/18.1%3A_Transcription—from_DNA_to_RNA.

RNA splicing changes the syntactic rule which defines the mapping relation between a DNA sequence and amino acids in a protein – the correspondence may not exist, as the original sequence can be modified before being translated. The alternative splicing of exons, in fact, enriches the category of sign-distinctions – more sequences are created to match more types of protein.

At the same time, semantic adaptation is also achieved through alternative splicing. By the previous interpretation of the genetic code, a genetic sequence is connected to the physical world when is expressed into proteins. However, the synthesis of proteins is a much more complicated process, the conditions under which a certain protein is produced needs to be specified by a more sensible and effective instrument. Introns as the non-coding part of the genes are not semantically incapable; indeed, they cannot be translated into amino acids, but they are indispensable in the differentiation of proteins encoded by the same gene. The splicing mechanism must be able to sense the signal telling which type of protein to produce, then to react according to its own rules to have the concerned introns removed.

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Chapter 6 GOAL-DIRECTED SYNERGETIC ACTIONS BY THE USE OF SIGN

6.1 INTRODUCTION

6.1.1 Review of Chapter 5

In Chapter 5, the focus of the study is placed on intersystem relations in the process of metasystem transition.

As Karatay and Denizhan (2005) proposed, this process consists of five stages characterized by two modes – cooperation and optimization. At the beginning, a code-based and goal-oriented system controlling several subsystems expand by integrating another subsystem – the "branching growth of the penultimate level" (p. 48). Then, the subsystems interact one with another while conventions specifying their cooperative relations are created. The roles of these subsystems are furthermore optimized to strengthen the self-regulatory capacity of the larger system. A goal-oriented system with strong control, again, will accelerate its qualitative and quantitative expansion into the next level.

Karatay and Denizhan (2005) interpreted the cycle of metasystem transition, respectively, from the perspectives of (1) semiotics and (2) economy. (1) Originally, subsystems are self-maintaining agents who live in their own reality obeying

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codes that are subjectively created. Then, the interactions between these agents make the creation of a common code, which is objective, necessary. The development of this objective code favors the stabilization of the larger system consisting of integrated agents. (2) At the beginning of a metasystem transition cycle, synergetic interactions between agents create "surplus values" (Karatay & Denizhan, 2005, p. 54), thus encouraging the expansion of the larger system. However, when cooperative relations are exploited, the resources of the newly integrated level reach a limit. At this moment, the system tends to optimize its energy in the stabilization of the whole network.

Cariani (1989, 2015) addressed a shortcoming of the previous definition of intersystem relations in realizing a strong control: it requires not only the creation of new protocols (changes of the syntactics) but also the adaptation of measuring and effecting instruments (changes of the semantics), in order to better satisfy the system's purpose.

The syntactics concerns the mapping relations between states; the semantics is responsible for the creation of meaning, because, by real-time measurement, it provides initial conditions for the computation; the pragmatics reflects the desire of the system's user/designer, which is considered a driving force for the evolution of the system's syntactic and semantic structures. Cariani (1989, 2015) emphasized that, in fact, syntactics, semantics, and pragmatics play complementary roles in achieving the purpose of the system: Empirical information cannot be gained by operating computations without the input from the measuring devices. Also, new goals cannot be created by simply performing computations and measurements. By evaluations and regulations, the system can adjust its syntactic or/and semantic structure to find out better ways in realizing the goal. Syntactic adaptations are observed among trainable machines, and



semantic adaptations are achieved by the emergence of more competent sensors or/and effectors. When a system defines goals on its own and selects syntactic and semantic categories retroactively, it is considered functionally autonomic.

The studies of intersystem relations continue in Chapter 6. Comparing to Chapter 5 where the focus is placed on the mechanic composition of a code-base and goal-oriented system made of subsystems, in Chapter 6, there is a closer look at the actual instances of interactions between these subsystems.

6.1.2 Presentation of Chapter 6

According to Heylighen (2016), the communication between agents can be realized through an indirect means called stigmergy – the trace of an action left on a medium that stimulates the performance of a subsequent action. The theory of stigmergy is defined by its fundamental concepts: the rule of "condition-action" as well as trace and medium. One of the characteristics of stigmergy is the creation of a feedback loop in which an action can also serve as the condition of another action, and so on. Trace and medium, on the other hand, concern the capacities of perceiving and manipulating parts of the world of an agent or a group of agents if they are required to work together. A coordinated work is achieved using the product of the action of one another as the condition for one's own action.

Heylighen (2016) suggested as each agent is a goal-oriented system, putting several of them together in the achievement of common goals, requires, first, that their individual goals are not contradictory one to another. While working together, each agent corrects its own errors based on its individual goal. The more diverse the individual goals are, the more compatible the coordinated actions will be. The same type of idea is expressed in the theories of metasystem transition



(Karatay & Denizhan, 2005; V. F. Turchin, 1977): by integrating a new subsystem, the regulatory tasks of the larger system can be further specified. Two types of organization are proposed: sequential coordination and parallel coordination (Heylighen, 2016). In the example of intracellular signal transduction, it turns out that the combination of both aspects allows the situation to be efficiently explored and exploited.

Heylighen (2006) suggested that the quality of goal-orientation is intrinsically a matter of control. Two common types of control - feedback and feedforward are briefly presented (Heylighen, 2006). In particular, feedforward control operates under the rule of "condition-condition" – the presence of one condition makes the agent to expect the presence of another condition, which is connected to an action (Heylighen, 2006). On one hand, feedforward control can compensate a shortcoming of feedback control - it could be too late for the regulation to occur after the errors have already appeared; on the other hand, feedback control can be used to reduce the uncertainty created in feedforward control as the agent supposes the occurrence of an action based on the signs of its condition (Heylighen, 2006). Therefore, a better form of control should be the combination of the two: by repeating the cycles of anticipation and observation, the agent makes use of its cognitive capacities and comes close to knowing the reality (Heylighen, 2006). This mechanism is illustrated in the phenomenon of amplification of a signal in its transduction pathway - increasing the amplitude of the signal without compromising the specificity of the pathway.



6.2 THE COORDINATION OF ACTIONS BETWEEN SYSTEMS

6.2.1 The theory of stigmergy

6.2.1.1 Defining stigmergy

The concept of stigmergy was first introduced in 1959 by Pierre-Paul Grassé to describe a mechanism of coordination used by social insects in their collective activities: the behavior of a social animal, even an isolated one, is observed to be driven by its role inside the collective group, making it unable to survive outside of it (Theraulaz & Bonabeau, 1999). Etymologically derived from Greek, "stigma" means "mark or puncture", while "ergon" means "work, action, or the product of work" (Heylighen, 2016, p. 6). According to Grassé, combining "stigma" and "ergon", stigmergy means "the stimulation of workers by the very performances they have achieved" (Grassé, 1959 as cited in Heylighen, 2016, p. 6).

La coordination des tâches, la régulation des constructions ne dépendent pas directement des ouvriers, mais des constructions elles-mêmes. L'ouvrier ne dirige pas son travail, il est guidé par lui. C'est à cette stimulation d'un type particulier que nous donnons le nom de STIGMERGIE (stigma, piqûre; ergon, travail, œuvre = œuvre stimulante). (Grassé, 1959, p. 65)

The quotation is translated by the author of this thesis: *The coordination of tasks and the regulation of constructions are not directly dependent on the workers but on the constructions themselves. The worker does not direct his work, he is guided by it. It is to this stimulation of a particular type that we give the name STIGMERGY (stigma, sting; ergon, work = stimulating work).*

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Then, Van Dyke Parunak (2006) proposed in his study on human-human stigmergy, the mark left by an agent's action can be detected by not only the agent himself but also other agents in the same environment and used for the determination of their subsequent actions: "Our experience with a wide range of distributed systems suggests that it is the only way for members of a large distributed population, whatever their individual cognitive capabilities, to coordinate themselves with bounded computational resources." (para. 2).

In his works on self-organizing activities, Heylighen (2016) defined stigmergy as: "an indirect, mediated mechanism of coordination between actions, in which the trace of an action left on a medium stimulates the performance of a subsequent action." (p. 6). Moreover, stigmergy is considered to operate in a circular manner. Heylighen (2016) specified that (Figure 6.1): (1) The nature of stigmergy is bidirectional, there is a feedback loop between marks and actions – "an action produces a mark which in turn incites an action, which produces another mark, and so on" (p. 6). (2) As a "perceivable effect, trace of the product of an action" (p. 6), a mark is left on a medium which can be accessed by multiple agents. It is a means to coordinate actions between the agents.





Figure 6.1 The Feedback Loop of Stigmergy. The mark left on a medium by an action (of an agent) stimulates another action (of the same agent or other agents) and so on. Adapted from "Stigmergy as a universal coordination mechanism I: Definition and components", by F. Heylighen, 2016, *Cognitive Systems Research, 38*, p. 6. Copyright 2015 by Elsevier B.V. Adapted with permission.

There are two fundamental concepts in Heylighen's theory of stigmergy: action and condition; medium and trace (Heylighen, 2016).

(1) Action and condition

Using the terms in artificial intelligence, Heylighen (2016) defined action as "a causal process that produces a change in the state of the world" (p. 6); while the cause, or the condition of the action, is defined as which "specifies the state of the world in which the action occurs" (p. 6). For agents, the causal relation between condition and action is observed as: if the condition holds, then perform an action (Heylighen, 2016). In Heylighen's example, an automatic thermostat will switch on the heating when the temperature is detected to be below the goal temperature (Heylighen, 2016, pp. 6–7). However, Heylighen's definition of causal relation is not limited to artificial intelligence where agents are involved; he suggested that the same phenomenon can be observed in the physical world: for example, mixing sodium hydroxide and hydrogen chloride yields sodium chloride and water

(NaOH + HCl \rightarrow NaCl + H₂O) – the simultaneous presence of sodium hydroxide and hydrogen chloride molecules is the necessary condition for the reaction (action) to take place, from which sodium chloride and water (products of the action) result (Heylighen, 2016, p. 7).

Then, in Heylighen's feedback loop of stigmergy, the products of an action can create a new condition which leads to another action, and so on. He continued with the examples of thermostat and chemical reaction: after switching on the heating, the temperature rises, and when it reaches a certain limit, the new condition – "the temperature is high" will trigger another action of the system – "switching off the heating"; while sodium chloride is synthesized from the reaction between sodium hydroxide and hydrogen chloride, it can continue to react with other molecules in the solution and produce other compounds (Heylighen, 2016, p. 7).

Heylighen (2016) emphasized that causal relations are not fully deterministic: "the presence of the condition makes the performance of the action more probable" (p. 7). Formally, it is: "P(action | condition) > P(action), where P(A) is the general probability of A occurring, and P(A | B) the conditional probability of A occurring given that B is the case." (p. 7). He explained that a thermostat may fail to respond when damages occur to its sensors; sodium hydroxide and hydrogen chloride cannot be fully converted into sodium chloride and water without the right proportion of amounts of the reactants (Heylighen, 2016).

(2) Medium and trace

Heylighen (2016) defined medium as "the part of the world that undergoes changes through the actions, and whose states are sensed as conditions for further

actions" (p. 7). Evidently, the definition of medium concerns the semantic capacities of the agents – the capacities to make real-time measurements (with sensors) and to impact on the physical world (with effectors) (see 5.3.1) (Cariani, 1989, 2015). Furthermore, suggested by Heylighen, the capacities of perception and action may not be both present at the same time: A human being, for example, can perceive the clouds in the sky but normally cannot change their positions; while the same person can throw a rock in the sea, but not knowing where the rock will end up deep in the water (Heylighen, 2016, p. 7). The stigmergic medium, however, requires the accessibility of the environment by both perception and action; sands on a beach, compared with clouds in the sky and sea, is a medium of action coordination between human agents (Heylighen, 2016, p. 7).

Whether a part of the world or an environment, can be regarded as a stigmergic medium, depends on the agent's (agents') limits of perception and action capacities (Heylighen, 2016). In 5.3.1.3, it is suggested that these limits can be overcome by the emergence of new sensory distinctions or/and action alternatives (Δ semantics) (Cariani, 1989, 2015). For example, human beings build devices to perceive phenomena which cannot be detected directly by their biological sensory organs. Also, in the context of stigmergy where the feedback loop of condition-action is not limited to the effort of a single agent, necessarily, a defined medium is a threshold for an agent's potential participation.

Heylighen (2016) defined a trace as "the perceivable change made in the medium by an action, which may trigger a subsequent action" (p. 8), which is the key to the coordination of actions between agents. Heylighen (2016) suggested that, (1) As the consequence of an action, a trace carries information about the very action; (2) A trace may not be intentionally left by an agent. Therefore, the trace can be considered as signs through which agents gain knowledge on the

perceivable and controllable part of the world. As more traces are left on the medium, perceived and made use of by an agent or agents, a "continuously updated memory" (p. 8) of that part is created. Heylighen (1999) compared the communications between agents through traces as sharing an object – a ball in a soccer game, for instance – the activities of the players are coordinated as their attentions are all directed to the position and the movement of the ball; although direct communications are rare, each player knows when to execute a particular action according to the state of the ball (p. 254). Then, he added that the action of each player is also influenced by the positions and the movements of other players; therefore, by perceiving shared signals, agents can adjust their reactions in real-time to achieve a common goal (Heylighen, 1999, p. 254).

6.2.1.2 The coordination of actions

Agents are goal-oriented. Their interactions with the trace are nevertheless purposeful. Heylighen (2016) characterized them as challenges: "a situation that incites action, in order to remedy a perceived problem or shortcoming, or to exploit an opportunity for advancement" (p. 8). The agents' nature of goal-orientation is also considered as "a minimal form of intentionality" (p. 8) – agents whose actions are appropriate to the conditions that trigger them, in the sense that they help the agent to move toward its (implicit or explicit) goals (Heylighen, 2016). It is important not to confuse "minimal form of intentionality" with the psychological term of intentionality which requires the presence of mind. Here, being "intentional" means the actions of an agent is not random but can be evaluated and selected based on certain criteria regarding the satisfaction of its purpose.



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Living organisms, for example, have a general type of purpose as survival and reproduction; thus, their behaviors, as well as the physiological and psychological properties that enable these behaviors, are shaped by and evolve from the purposeful interactions between the organisms and the environment. The fitness of an organism, especially, is addressed by Heylighen as the ability to maintain or grow given the specific configuration of its environment; the process of adaptation, then, is considered as the selection of different configurations based on their degree of fitness (Heylighen, 2001). The same logic can be applied to the interactions between agents – the actions of different agents are coordinated in a certain way to achieve a common goal.

In 4.3.1.1, we have addressed the issue of error-controlled regulation in a goal-oriented system (Figure 4.8): when a response is considered deviating from the system's goal, it is more likely to be corrected, ensuring the successful realization of the goal (De Beule & Stadler, 2014). Heylighen (2016) believes that a retroactive mechanism can also be used in the context of stigmergy when many agents are working together to achieve a common goal: First, an error is detected when there is a distance between the current state and the satisfaction of the preset goal; it should be noted that the stigmergic regulation does not distinguish the type or the cause of the error. Second, the error is corrected by an appropriate "compensatory action" (p. 10), which is, "an influence in the opposite direction of any deviation" (p. 10), regardless of the nature of the deviation. Finally, when multiple agents are engaged in the realization of a common goal, their individual goals do not need to be identical, but not contradictory one to another.

Heylighen (2016) explained the mechanism using the example of pushing an obstacle (p. 10). A group of agents is pushing a large obstacle out of the way. Each individual agent corrects its course based on the perceived movement of the



obstacle – if it is shifting too much to the side, or if it stops moving, and it does not question the nature of any deviations – if there is a hole in the ground, or if another agent is working against it. The overall movement of the obstacle is determined by the sum of individual efforts. As long as the agents are pushing towards generally the same direction, the obstacle gets to be moved. In this case, a coordinated work is achieved using the product of the action of one another as the condition for one's own action.

Furthermore, Heylighen (2016) suggested that if the individual goals of the agents are neither identical nor contradictory, a compromise occurs. For example, one group of agents push the obstacle to the east, while another group to the north, the result will be a movement toward the northeast, satisfying the goals of both groups (Heylighen, 2016, p. 11). Heylighen (2016) explained, for the involved agents, the more various their individual goals are, the less possibility of them getting in the way of each other. The advantage brought by the variety of agents' action potentials is discussed by presenting the theory of metasystem transition in 5.2.1: the creation of "a higher level of organization" leads to the creation of new protocols for specifying tasks of each subsystem and optimizing the regulatory capacity of the whole (Karatay & Denizhan, 2005, para. 1). An agent's operational protocols, or the "condition-action" rules by which it acts, go through evaluations and selections to be appropriate to the interactions with the environment and other agents in their joint efforts; the inappropriate ones are most likely to be eliminated sooner or later (Heylighen, 2016).

Heylighen (2013) proposed to define organization as a structure with function, that is, "the components (agents) of the system are arranged in an orderly way (structure) so as to achieve a certain goal (function)" (p. 5). The coordination of work is important because it is about minimizing frictions and



maximizing synergies to achieve what cannot be achieved individually. The specification of tasks in the theories of metasystem transition (Karatay & Denizhan, 2005; V. F. Turchin, 1977), or as Heylighen (2016) called the division of labor in the theory of stigmergy, concerns the issue of planning and project management. Each agent is specialized in realizing its own goal; the question is how to make use of its goal-realizing actions in the achievement of another goal – a common one while working with other agents. Two general types of organization are proposed: sequential coordination and parallel coordination (Heylighen, 2016).

(1) Sequential coordination: the product of an action of one agent is the necessary condition for the action of another agent – a "workflow".

In the case when one action is a prerequisite for the next, the overall output can be controlled from the source; and one common type of control is by negative feedback (Heylighen, 2016). For example, in 4.3.2.2, it is explained that metabolic reactions happen in sequence – the product of one reaction is the substrate for the next, and the excess of the end product can inhibit the reaction at an earlier step (Figure 4.17) (Purves, Sadava, Orians, & Heller, 2004, p. 143). At the same time, positive feedback – the amplification of movements toward the goal – can also be used to control a sequential framework. For example, the excess of citrate produced in the citric acid cycle inhibits its own production from the earlier steps; while on the other hand, it accelerates the production of fatty acids in a different pathway (Purves et al., 2004, p. 143). Heylighen (2006, 2016) believes that the combination of negative feedback and positive feedback allows the agent to be flexible: through error-control, a stable and robust configuration can be maintained facing disturbances; through amplification, chance fluctuations which



may eventually benefit the agent's self-maintenance can be anchored in the category of protocols.

(2) Parallel coordination: the actions of one agent do not affect the actions of another agent as they work simultaneously; the overall output may be different from the sum of individual efforts.

A parallel organization is non-linear and the influence of one agent's actions on the actions of another agent is less predictable than in a sequential organization (Heylighen, 2016). This influence can be inhibiting, amplifying, or neutral; therefore, the overall output will be smaller, greater than, or equal to the sum of their individual efforts (Heylighen, 2016). Two types of parallel coordination of actions are distinguished: First, the actions concern the same part of the medium; second, the actions concern separate and independent parts of the medium (Heylighen, 2016). The second case is a typical example of the specification of tasks which enables the maximum exploitation of an agent's expertise (Heylighen, 2016). It is, in fact, an essential reason for which goal-oriented systems keep growing in diversity by integrating more subsystems (metasystem transition, see 4.3.1.2 and 5.2.1). Heylighen (2013) addressed the division of labor as what depends on the diversity of the agents' expertise: the more diverse they are, the more adapted the agents are facing different tasks. On the other hand, in the first case, when different agents work on the same task, the aggregation of their efforts is usually better than the effort of a single agent – the phenomenon is known as "wisdom of crowds" or "collective intelligence" (Heylighen, 2007, 2013, 2016). Collective intelligence is characterized by the generation of more effective solutions to problems when agents distinguished by their expertise communicate by a set of symbolic rules and work together (Heylighen, 2013).



6.2.2 The coordination of actions: signal transduction I

The example that we use to study stigmergy in the biological context is the transduction of signals between cells. The chemotactic behavior of E. coli (Hansen, Endres, & Wingreen, 2008)²⁶, for example, can be described by the rule of condition-action: Chemical gradients are sensed through E. coli's transmembrane receptors which then interact with the responder proteins in the periplasmatic space. The signals are transmitted across the plasma membrane into the cytosol, where the effector proteins are activated. The effector proteins alter the tumbling frequency of the E. coli's motors. Therefore, the change in the concentration of a surrounding substance is the condition for E. coli's action as a series of cellular responses, leading to its movements toward or away from the substance (depending on the type of the substance).

While a bacterium's movement is determined by the changes in its environment – an external medium, the cellular responses of human beings as multicellular organisms, have an internal medium, which consists of other cells and extracellular fluids (Purves et al., 2004, p. 302). The extent of an internal medium can range from local areas to the whole organism: autocrine signals affect the cells that make them; paracrine signals diffuse to and affect nearby cells; signals to distant cells, such as hormones, usually travel through the circulatory system (Purves et al., 2004, p. 302). Cells as agents can react to the traces – chemical signals – left on the medium by the actions of other agents. Most of these chemical signals come from other cells; others come from the environment via the digestive and respiratory systems (Purves et al., 2004, p. 302). The change of

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²⁶ Chemotaxis: the process that allows the bacterium E. coli to react to small relative changes of the ambient concentrations of attractants and repellents (Hansen et al., 2008, p. 14).

concentrations of certain chemicals can also incite responses from the cell; for example, CO_2 and H^+ in the extracellular fluids resulting from the metabolic activities of other cells (Purves et al., 2004, p. 302).

The entire signaling process, from signal detection to final response, is called a signal transduction pathway; it involves a signal, a receptor, transduction, and effects (Purves et al., 2004, p. 302). In many cases, a cell must be able to receive the chemical signal and respond to it. By this way, cells work together stigmergically to communicate an incident event, regulate the conditions, and realize the selfmaintenance of the organism.

Intracellular signal transduction results from a joint effort of several parties. It can be categorized into direct transduction and indirection transduction: the former concerns only the receptor itself and occurs at the plasma membrane; while the latter, which happens more commonly, requires a second messenger to mediate the interaction between receptor binding and cellular response(Purves et al., 2004, p. 307). In both cases, signal transduction involves a cascade of events – proteins interact with other proteins until the final effects are achieved (Purves et al., 2004, p. 307). In other words, it usually takes several agents functioning under the rules of "condition-action" for a specific response to be caused by an incident signal.

In his studies on the integrating role of signal transduction, Luis Emilio Bruni (2003, 2008a) suggested that the intermediate steps between the reception of the signal and the final effects may include interconnected modular components. Modularity is considered a central feature of signal transduction: on one hand, a particular cellular response is resulted from combining different signaling networks; on the other hand, two different pathways may share a common component (Bruni, 2008a). Bruni (2008a) concluded that: "The same result can be



achieved through different 'infrastructure' by combining common components and principles, or, conversely, different arrangements of the same, or very similar, components can result in very different responses." (p. 381). In other words, the code for a specific response may not be created out of the blue; it can result from a meta-structure made of several intermediate steps each with its own "conditionaction" rule and responsible for generating other codes which are like the first one in some parts but different regarding the final response. Briefly, specificity is created in an add-on manner.

Take the example of the response to epinephrine by liver cells: Epinephrine molecules can bind to the G-protein linked receptors on liver cells; the binding triggers two processes leading to two different types of response – one is the inhibition of the synthesis of energy-storing molecules glycogen, and the other is the activation of glycogen phosphorylase in order to liberate glucose molecules from glycogen to fuel the energy-requiring response of fight-or-flight (Purves et al., 2004, p. 309). As the two processes are triggered by the same chemical signal and share some intermediate steps in their pathways of signal transduction, the code for the inhibition and the one for the activation are in fact resulted from the same meta-structure of rules. Formally, it is the binding of epinephrine molecules to the cellular receptors \rightarrow the activation of *G* proteins \rightarrow the activation of the synthesis of cAMP (the second messenger) \rightarrow a protein kinase cascade which both inhibits the conversion of glucose to glycogen and stimulates the release of previously stored glucose (Figure 6.2).

For an individual transduction pathway, the coordination of actions has a sequential nature – a workflow from the reception of a signal to the response. For an organism, usually, the organization of cellular responses is both sequential and parallel. In the example above, having two transduction pathways activated by the

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same chemical signal provides the organism with an immediate energy supply, which is evidently advantageous for it to survive in life-endangering situations. Indeed, the key to parallel coordination – second messengers – allow a cell to respond to a single event at the plasma membrane with many events inside the cell, thus amplifying the signal. For example, a single epinephrine molecule can stimulate the synthesis of dozens of cAMP (the second messenger) for the activation of multiple enzyme targets (Purves et al., 2004, p. 309). As Heylighen (2016) suggested, the combination of parallel and sequential aspects gives rise to an efficient exploration and exploitation of the situation.







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The phenomenon when signals from different pathways are mixed together is referred to as crosstalk (Decraene, Mitchell, & McMullin, 2007). It is believed that there is a potential for any molecular component to contribute to multiple pathways of different hierarchical levels because all of them share the same physical reaction space, which is the cell (Decraene et al., 2007). Although the occurrence of (unintended) crosstalk is considered an error in the engineering of communications, in the case of cellular signaling networks, it can bring positive and constructive effects to the process (Decraene et al., 2007), because: (1) The overall regulatory capabilities of the system may be improved by the interfering signal – the "noise". (2) The networks of signaling pathways can grow and evolve in complexity by the mechanisms of crosstalk. Bruni (2008a) emphasized that the occurrence of crosstalk does not compromise the specificity of a given signaling pathway: the cell can identify meaningful patterns out of a background full of ubiquitous signals, which concerns, obviously, the ability of sign usage.

6.3 GOAL-DIRECTEDNESS AND ANTICIPATION

6.3.1 Feedforward control and the reduction of uncertainty

6.3.1.1 Feedforward control

In 1.3, it is proposed and discussed that the actions of living organisms are directed by the goal of survival and reproduction (Alexander, 2009, 2013). By the theory of deterministic and stochastic causation (see 3.2.1), it is suggested that the better an organism is at achieving this goal, the more offspring it will produce, thus more of its genotype will spread in the population; also, on one hand, there is



natural selection; on the other hand, the evolution of fitness depends as well on the organism's active role of regulation (van Hateren, 2015d). In 4.2.1.1 and 4.3.1.1 shown by the models of Meaning Generator System (Menant, 2003) and Self-Regulatory System (De Beule & Stadler, 2014), control and regulation are considered the indispensable capacities of a goal-oriented system. In these models, regulation works in a retroactive way (i.e. using negative feedback): once an incident is considered deviating from the realization of the system's goal, it will be corrected.

Heylighen (2006) agrees with this point of view by saying that goaldirectedness is intrinsically a problem of control. In his theory of stigmergy, it is explained that as an agent acts according to the trace of an action, there is a feedback loop in which perturbations can be compensated (Heylighen, 2016). Furthermore, Heylighen (2006) brought up an interesting point of view: in the mechanism of error-control, the agent must "know" beforehand which action to perform to compensate which perturbation. This knowledge is understood as the already existing codes or rules of "condition-action" in Heylighen's theory. Then, Heylighen (2006) proposed to consider the existence of a "rudimentary form of cognition" in goal-directed systems (para. 7). In other words, feedback control exists as a means to anticipate incident events, thus itself being a part of a mechanism of feedforward control.

Hooker (2009) defined anticipation as the ability to achieve future selfregulatory closures, based on the present ones, to maintain the autonomy of the system. Furthermore, Hooker (2009) suggested that one of the major aspects of anticipation is the width of the interactive time window: on one hand, there is what he called "the root form of anticipation" (p. 526) – distal perception represented by vision, which expands the time window of organism-environment interactions to the near future; on the other hand, the functions of memory extend the time window to the opposite direction – the past so that the histories of interactions have an impact on the present ones. Comparing to anticipation, errorcontrolled regulation has a shortcoming: the perturbation or error needs to have already occurred then detected by the agent to be taken care of²⁷. Heylighen (2006) explained the problem with the example of a person risking of falling off a cliff – it is usually too late to correct the error when the person is already falling; the better type of control, in this case, should be a feedforward one – the person looks out for the cliff and keeps himself away from its borders (para. 7). In other words, anticipation means an action is initiated when there are only signs but not the actual occurrence of the condition.

Heylighen (2006) formalized the mechanism of feedforward control as a rule of "condition-condition": If condition A occurs, then expect condition B: $A \rightarrow B$. The relation between A and B, does not necessarily have to be a causal one; it means that A and B are logically associated. For example, "banana" can be associated with "fruit", "sweet", "yellow", or "monkey", that is, the recognition of banana is associated with the expectation of it being a fruit, sweet, yellow, or eaten by a monkey (Heylighen, 2006, para. 8). In the case of feedforward control, one condition leads to another, eventually, to an action that can address the anticipated problem. As a key to survival for living organisms, Kull (1998) also believes that anticipation derives from a self-referential use of signs: "[...] a sign is translated into interpretation, which will work as an interpreter in some further act of semiosis (i.e. it corresponds to something which will be recognized afterwards)." (p. 102).



²⁷ The advantages and disadvantages of feedback control and feedforward control are discussed in detail in 8.2.2.1.

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Indeed, the ability to associate conditions varies from agent to agent. It is, in fact, a problem related to both syntactic and semantic adaptations of a given system (see 5.3.1.3). On the level of the syntactics, more mapping relations (i.e. rules of "condition-condition" and "condition-action") need to be included in the system's computational category in order to have a large knowledge of the events to anticipate; on the level of the semantics which concerns real-time measurement and regulatory reactions, the sensibility of the properties for detection is especially important – for anticipatory actions, due to the uncertainty on the occurrence of an action-connected condition, the system needs to adjust closely to the slightest change in the situation.

6.3.1.2 The reduction of uncertainty

As feedforward control happens before an action-connected condition occurs, it is possible for an agent to react wrongly to the situation. Furthermore, Heylighen (2006) suggested that, a small error at the beginning can multiply and grow, leading to a very deviated prediction which no longer has any value in guiding the agent's actions – "That is why tomorrow's weather forecast is generally reliable, but a forecast for next month or next year is basically useless." (para. 8).

According to Heylighen (2006), the uncertain association between two conditions in feedforward control can be expressed in the mathematical form of conditional probability, which is the probability of an event given that another

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event has occurred (Gut, 2005, p. 17)²⁸. The measurement of conditional probability relies on the agent's perception and knowledge (i.e. syntactic and semantic capacities), thus varying among individuals. Conditional probability measures the reliability of an agent's prediction based on the current situation: for example, the probabilities of the associations between "banana" and other items – "fruit", "yellow", and "monkey" are: "P₁ (banana \rightarrow fruit) = 1, P₂ (banana \rightarrow yellow) = 0.7, P₃ (banana \rightarrow monkey) = 0.05"; then, it means that for the agent who perceives a banana, it is understood as a fruit, which is very likely to be yellow, but very unlikely yet possible to be accompanied by a monkey (Heylighen, 2006, para. 9). As the conditional probability of "banana-monkey" is greater than 0, seeing a monkey based on the presence of a banana is still more likely to happen than seeing a monkey alone without any associations.

Although in some cases, responding wrongly to an incident in the goal of self-maintenance can accidentally turn out to be beneficial (misinterpretations, see 3.3.1.2); in some other cases (which is especially true for anticipation), a wrong action not only fails to realize the goal but also leads to a waste of time and energy. Heylighen (2006) believes that high uncertainty implies poor control, thus low fitness; and during biological evolution, there is a strong selective pressure upon organisms for them to minimize uncertainty. On one hand, uncertainty can also be reduced by enhancing the sensibility of the agent's perception; on the other hand, the reduction of uncertainty can also be achieved with better coordination between the received information and the regulatory actions. In 5.3.1.3, it is explained that the functions of information-reaction coordination, that is, the computation based on the rules of "condition-condition" and/or "condition-

²⁸ The definition of conditional probability: "Let A and B be two events, and suppose that P(A) > 0. The conditional probability of B given A is defined as $P(B | A) = P(A \cap B)/P(A)$." (Gut, 2005, p. 17).

action", are carried out the brain and the nervous systems observed in organisms near the higher end of the evolution hierarchy (Cariani, 1989, 2015).

Heylighen (2006) proposed a means that combines feedback and feedforward control, allowing the agent to solve problems with a minimum of trial-and-error: As an agent anticipates (feedforward control), the uncertainty of its action rises; then, by observation, the agent knows whether the prediction matches the reality or not, and it adjusts its actions accordingly (feedback control), reducing the uncertainty. If the uncertainty is not completely eliminated after one observation, the agent must anticipate again and another observation will continue reducing the remaining ambiguity. The cycle of anticipation and observation keeps unfolding until the reality is known to the agent. Although the process may repeat for several times, the efficiency of this mechanism is remarkable as the results are pre-selected in each cycle.

Heylighen (2006) suggested that any reduction of uncertainty can significantly increase the agent's chance of successfully tackling the situation. He gave the example that a stimulus as the lights and shadows produced by moving leaves of a large bush can lead to many interpretations in the viewer's mind: The viewer's knowledge of his location – the backyard of his home or the Indian jungle – plays a determining role in reducing the uncertainty in the presence of a tiger; if it is in the second case, the Indian jungle, then it is obviously better to be mentally prepared for the attack from a dangerous animal (Heylighen, 2006, para. 10–11). Heylighen (2006) further developed this point of view by proposing that the essence of cognition is to produce such a mechanism that can complement or fill in incomplete data using both anticipation and observation to achieve an optimal control. In fact, the reduction of uncertainty does not exist only on the macro-scale of organisms – motor reactions to sensory stimulus; there are numerous examples



on the scales of cellular functions, in this thesis, there are: the amplification of a signal in its transduction pathway (see 6.3.2), the responses of immune cells to unknown antigens (see 7.3.2), and the homeostasis of blood sugar (see 8.2.2).

6.3.2 The anticipatory control: signal transduction II

In 6.2.2, it is explained that the system of intracellular signal transduction is built in an added-on matter – common steps are shared between different pathways – modularity (Bruni, 2003, 2008a). Thus, the question is: how the specificity of a given pathway is ensured? First, the reception of the chemical signal by the cell's receptors requires specificity. The signal molecule must fit into the site of its receptor the way that a substrate fits into the active site of an enzyme; the binding of the ligand causes the conformational change of the receptor protein, which initiates a chain of cellular responses (see 4.3.2.1) (Purves et al., 2004, p. 304). Then, the pathway from signal to effects is also specific in the sense that it is selected from a "repertoire of responses" as the correct one based on the given context (Bruni, 2003, p. 140).

For example, calcium ions act as a second messenger in many transduction pathways including fertilization, cell proliferation and development, learning and memory, muscle contraction, and secretion (Berridge, Lipp, & Bootman, 2000). The remarkable versatility of calcium ions emerges from the use of an extensive molecular repertoire of signaling components, which comprise a Ca²⁺ signaling toolkit ma de of four functional unites (Figure 6.3): (1) The generation of Ca²⁺mobilizing signals by a stimulus, which activates (2) the ON mechanisms that feed Ca²⁺ into the cytoplasm; (3) Ca²⁺ functions as a second messenger to stimulate numerous Ca²⁺-sensitive processes; and at last, (4) the OFF mechanisms remove Ca²⁺ from the cytoplasm to restore the resting state (Berridge et al., 2000). These components can be assembled in combinations to create signals with widely different spatial and temporal profiles (Berridge, Bootman, & Roderick, 2003). In other words, specificity in signal transduction does not result from a single event but a process with many mediators; a process is specific as it is made of a selection of components arranged in a specific order.





A signal transduction pathway is made of several steps. Using the words of Bruni (2003), each step is, in fact, a "checkpoint", which itself is controlled and regulated by other steps in the larger network (p. 141). Bruni (2003) considers regulation as a continuous process, in which a hormone or a neurotransmitter is rather a cooperator (with an inhibiting or an activating effect) than a regulator – "all the pathways involved in such 'control' or 'regulation' processes are themselves opportunities for further regulation and control." (p. 141). Then, with



the example of receptor tyrosine kinases (RTKs), cell surface receptors responsible for the regulation of cell proliferation and differentiation, promotion of cell survival, as well as modulation of cellular metabolism, which "regulate nothing less than life" (p. 142), Bruni (2003) showed that regulation is not physically localized, it has no dimensions or units. In 4.3.1.1, the target of regulation in the model of Self-Regulatory System (Figure 4.10 b) is defined by the regulatory action itself – the system regulates to exist and it exists to regulate (De Beule & Stadler, 2014). In this sense, life or being alive is a process of regulation.

It is previously explained in the example of the response of liver cells to epinephrine (Figure 6.2), once bound to the receptor, the signal from a single stimulus is amplified, because each newly activated protein kinase can catalyze the phosphorylation of many target proteins and eventually, two different types of responses are caused (Purves et al., 2004, p. 312). The phenomenon of amplification in signal transduction is characterized by an increase of numbers and types of molecules - the message carried by a small number of molecules is transmitted to a large number of molecules of different types (Bruni, 2003). Bruni (2003) suggested that there is a "meta-kind of sensibility" that allows a message deemed to be more drastic or urgent to benefit from a different arrangement of ratios, thus being useful for stopping immediately the unrolling of a cascade or yielding more end products under special conditions (p. 164). The "sensibility" of cellular response is vital to the whole process because it allows a problem to be solved efficiently – the second it appears, before it is too late; also, it allows the system to stay vigilant when certain stimulation is expected (Bruni, 2003). For example, Ca²⁺ which is widely used as a second messenger in many signal transduction pathways is quite remarkable on the speed and the amplitude of its release: the opening of Ca²⁺ channels drastically increases the cytoplasmic concentration of the ion - "up to a hundredfold within a fraction of a second"

(Purves et al., 2004, p. 310); Also, Ca²⁺ can stimulate its own release from intracellular stores, thus triggering cell responses in situations that the original signal is not strong enough (i.e. below the threshold) (Berridge et al., 2003).

The ability to amplify signals is used by cells to anticipate incident events; at the same time, as it has just been explained, signal transduction pathways are highly specific. In other words, the uncertainty raised by the cell's anticipations must be compensated by observations to ensure the accuracy of the response. Bruni (2003) argued that the phenomenon of amplification may appear to be a quantitative event as the concentration levels of subsequent enzymes are increased, but cellular response results from specific combinations of threshold concentrations of successive and/or simultaneous adjacent steps. Therefore, it is more accurate to say that the signal leads the right responses, not more responses (Bruni, 2003). We propose to consider signal transduction as a process of uncertainty reduction made of cycles of "anticipation-observation" (Heylighen, 2006). On one hand, the signal is quantitatively amplified as a means of anticipation; on the other hand, each step in the pathway of transduction guides the direction of the unrolling cascade of reactions to the accurate target. In liver cells' responses to epinephrine (Figure 6.2) (Purves et al., 2004, p. 312), for example, when the signal reaches to the second messenger cAMPs, it is amplified but unspecified; the response as an inhibiting one or an activating one is distinguished only in the following cascade of protein kinase. In signal transduction, the combination of feedforward control and feedback control is used to achieve an efficient and effective control. Bruni (2008b) addressed the phenomenon as an evidence of the semiotic feature of life-related events: "These combinations provide enormous potential for complex interplay of consensual factors to provide a more global interpretation of the context." (p. 398); and "[The contextual response] gives the



system remarkable semiotic plasticity for very sensible and complex fine-tuning and calibration functions." (p. 400).

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PART III

THE SPHERE OF MEANING FOR LIFE

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7.1 INTRODUCTION

7.1.1 Review of Part II

The center of discussion in the first part of this thesis is the creation of meaning which is defined in two ways: (1) Meaning is created when being connected to Sign by a codemaker (Barbieri, 2008a, 2008b, 2013b); (2) Meaning is created when a system responds to a stimulus in the achievement of a goal (Alexander, 2009, 2013). Combining the two aspects, the creation of meaning requires infrastructures that address the syntactic or/and semantic, as well as pragmatic organizations of the system. Such examples can be found at the beginning of Part II – Meaning Generator System (Menant, 2003) and Self-Regulatory System (De Beule & Stadler, 2014). The main topic of the second part is the transmission of meaning. When meaning is communicated between individuals, they form a system that is more capable of achieving goals than any of its component. This is where the coordination of teamwork and communication become necessary.



In Chapter 4, by proposing the concept of "domain of efficiency", Menant (2003) argued that for the transmitted information continuing to be meaningful, there should be a type of compatibility of the vital constraints between the transmitter system and the receiver system. Sharing the same idea, De Beule and Stadler (2014) who suggested that compatible interactions are favored by natural selection, which then gives rise to the integration of subsystems into a larger whole – the phenomenon is known as metasystem transition. In Chapter 5, we study the five stages and two modes of metasystem transition (Karatay & Denizhan, 2005). The dynamic process is characterized by the creation of rules which encourages and stabilizes the mutually beneficial interactions between subsystems. Also in Chapter 5, Cariani (1989, 2015) proposed an efficient control mechanism relies not only on syntactic protocols but also measuring and effecting devices which connect computations to the reality. In this manner, subsystems can be combined based on their operational roles. Chapter 6 is about the actual instances of agents (subsystems) working together. The communication between them, as Heylighen (2016) proposed, is achieved in an indirect way by a mechanism named stigmergy. The mechanism defines a part of the world as a medium that can be perceived and manipulated by a group of agents; then, the traces left on the medium by the action of an agent provides the condition of the subsequent action of another agent. Heylighen (2016) defined the compatibility between agents as the absence of contradictions between their individual goals. Under this condition, the joint effort of agents can be coordinated in a sequential or a parallel organization, even the two combined together. The goal-oriented nature of an agent is seen as a problem of control; Heylighen (2006) then suggested that the existence of a "rudimentary form of cognition" (para. 7) by which the agent already "knows" the exact regulatory action to perform in response to perturbations. Two general types of control - feedback and feedforward – are briefly presented. As each of them addresses the shortcomings of another, combing feedback and feedforward control helps the agent to react efficiently for its own benefits when the information on the current situation is incomplete.

In Part II, the examples used to explain the transmission of meaning in the biological context can be related to most multicellular organisms regardless of the complexity of a cognitive system on the macro scale – the scale of the brain and nervous systems. The macro scale along with the much more complex human cognition, on the other hand, is discussed in Part III.

7.1.2 Presentation of Chapter 7

In Part I and Part II, a code-based and goal-oriented system is characterized as cognitive without giving a conclusive definition on the phenomenon of cognition in the realm of life. In the first part of Chapter 7, the definition of cognition is addressed with Pamela Lyon's theory proposing that cognition is a part of biological evolution (Lyon, 2004, 2006). Lyon (2004, 2006) has categorized the studies on human cognition into two groups – the anthropogenic approach and the biogenic approach – one is distinguished from the other mainly on the issue of the origin. The first approach assumes human cognition as the paradigm of all cognitive systems and uses it to construct models of artificial intelligence. The second suggests the necessity of a continuum of development, that is, the process of biological evolution, to establish what is known as human cognition today. In other words, cognitive functions cannot be separated from their physiological basis.



Criticizing the anthropogenic approach with the biogenic one, Lyon (2004, 2006) emphasized the characteristics of living organisms as being both open and closed to the environment. Living organisms are open to their environment in order to import energy that is essential for their self-maintenance; the process of self-maintenance, then, is made of functional closures that define the homeostatic self as well as the domain of interactions with the environment. The domain of organism-environment interactions gives rise to the organism's cognitive reality, in which its biological structure and cognitive functions intermingle, yielding a strong control of the organism.

In the second part of this chapter, we present and study the theory of Organism-Environment System, proposed by Timo Järvilehto and postulates the inseparability between the organism and the environment: together, they form one system which determines the cognition of a given individual (Järvilehto, 1998, 1999, 2000, 2009). Järvilehto (1998, 1999, 2000, 2009) emphasized that there is no asymmetry between the organism and the environment; both are active in the achievement of action results.

Cognition of higher level which necessarily involves the brain and the nervous system is considered to result from biological revolution (Järvilehto, 2000). From single-celled to multicellular organisms, the regulatory capacities of the organisms have strengthened while individual systems each with a specialty are connected to work together (Järvilehto, 2000). For example, neurons which coordinate the actions of the receptor and motor organs and keep records of the previous experience can largely facilitate the exploration of positive action results of the organism (Järvilehto, 2000).

In order to explain the role of the environment in the building of an organism's cognitive reality, Järvilehto (1999) has invented a thought experiment

in which, originally, an imaginary organism without any sensory organs "knows" about the environment and "behaves" accordingly (pp. 94-96). Then, modifying the parameters of the experiment twice, he showed that perception is not a linear process but depends on the organization between the organism's biological structure and the environment's conditions (Järvilehto, 1999).

Furthermore, Järvilehto (2000, 2001) suggested that consciousness does not reside in the brain or the body of an individual; it results from the cooperation between organism-environment systems in the achievement of common goals. Järvilehto (2000) has categorized the concept into three levels – general consciousness, personal consciousness, and subject consciousness – and argued that self-consciousness means the ability to see oneself from the perspective of the others; the body of the individual sets the reference point of its participation in the teamwork and benefits from the common results.

The theory of Organism-Environment System is illustrated in the biological context with the human immunity which can be further divided into an innate system and an adaptive system. The adaptive immune system is especially remarkable in the building of cognitive patterns: The system can keep memories of the encountered pathogens in order to eliminate them more rapidly and effectively in the future; also, it can adapt to the binding specificity required by a particular pathogen, thus evolving a better response to the same pathogen (Purves, Sadava, Orians, & Heller, 2004, pp. 370–371). Järvilehto's definition of consciousness, then, can be related to the interplay between two mechanisms of responses in the adaptive immune system – the humoral and the cellular immune responses – in which an immune cell is conscious of its own role only when being defined in relation to the roles of other molecules. As well, it is shown that the immune identity of an individual human being is dynamically distinguished from



the non-self-antigens; the reference point of selfhood or the distinction of selfothers is constantly defined and subject to modifications even failures (Purves et al., 2004, pp. 379–384).

7.2 COGNITION AND THE EVOLUTION OF LIFE

7.2.1 The anthropogenic approach to cognition: the characteristics and the critiques

By developing the anthropogenic/biogenic distinction, Lyon (2006) has discovered that most approaches to cognition throughout history have been anthropogenic. The reasons are obvious: "We have access to our own minds and can communicate our experience of mentality to others, so human cognition is the logical place to start." (Lyon, 2006, p. 12). The anthropogenic approach may show advantages in explaining language-mediated behaviors, however, the principles developed on this basis - the anthropogenic "family traits" - cause difficulties in theorizing cognition (Lyon, 2006). According to Lyon (2006), the most popular assumption of the anthropogenic approach is that cognition is implemented in the brain and the nervous systems. The mechanism can be understood as information processing in which inputs received from the inner and/or the outer environments are transformed according to computational rules into outputs behaviors. The mechanic analogies, for example, are computers which are incorporated with central processing units allowing the machines to perform complex calculations (Lyon, 2006, p. 14). Lyon (2006) criticized this point of view in two aspects: (1) With numerous interdependent units, the brain controls almost the entirety of the organism's functioning; it is very unlikely to be able to tease out the purely cognitive parts from the non-cognitive ones. (2) In many cases, the presence of brain or nervous systems is not the necessary condition for generating situation-adaptive behaviors. Lyon has shown with the example of a type of jellyfish off the northeastern coast of Australia endowed with the simplest metazoan visual system which does not rely on neurons or axonal connections (Nordstrom et al., 2003 as cited in Lyon, 2006, p. 13).

Secondly, using human cognition as the paradigm, anthropogenic theories search for explanations for complex behavioral traits such as "language, abstract thinking, beliefs, desires, phenomenal consciousness, and culture" (Lyon, 2006, p. 14). Language, especially, is given great significance. For example, in Turing test, the machine's level of intelligence is determined by its ability to generate humanlike responses during the conversations with a human (Saygin, Cicekli, & Akman, 2000). Lyon (2006) argued that the cybernetic analogies of human cognition with implements for positive and negative feedback control can be biologically inspired, but never concern "the most biologically salient aspect of human communication" - meaning (p. 14). In the Shannon-Weaver model of communication, for example, it is the syntactic structure of the transmitted message being concerned, not the meaning of it to a particular group of users (Shannon & Weaver, 1949 as cited in Lyon, 2006, p. 14). We have learned from the theory of the complementarity of syntactics, semantics, and pragmatics (see 5.3.1) (Cariani, 2015) that it is possible to combine measuring and effecting devices to computers, thus connecting the results of computations to the reality as well as the users. However, Cariani (2015) believes that the capacity of constraining one's selection of syntactic and semantic categories – pragmatic autonomy – is hardly observed in artificial intelligence.

Finally, the pragmatic aspect of information processing – "beliefs, desires, and other content-bearing 'propositional attitudes'" – is addressed by

anthropogenic theories as a problem of intentionality, or "the mind's directedness on the world" (Lyon, 2006, p. 14). In other words, intentionality connects a state of computations with a representational content in the reality. The role of intentionality, therefore, resembles the role of codemaker in the theory of code semiosis (see 1.2.1.2 and 1.2.1.3) (Barbieri, 2008a, 2008b, 2013b). According to Lyon, the major weakness of this assumption lies in the negligence on the problem of symbol-grounding: "[...] how cognitive states come to be 'about' anything at all (the symbol-grounding problem) and how myriad representations are continually and coherently updated as circumstances change in real-time (the frame problem)." (Harnad, 1993 as cited in Lyon, 2006, p. 15). The mechanism of chemotaxis, for example, allows organisms to respond to minute changes in their environment (see 6.2.2) (Hansen, Endres, & Wingreen, 2008) by establishing the connection between the incident event and the satisfaction of the purpose of self-maintenance. Based on Barbieri's interpretations, the problem of symbol-grounding is related to the nature of the codemaker (see 1.2.1.3): the code for linguistic signs is made by human mind, while the code for protein synthesis concerns the functions of RNA (Barbieri, 2008b). In other words, the type of intentionality determines the type of representations it produces. This point of view necessarily implies a rupture between the natural world and the cultural one. Barbieri (2013a) has indeed distinguished between two types of semiosis - the code semiosis and the interpretative semiosis.



7.2.2 The biogenic approach of cognition: self-organizing complex systems and autopoiesis

Focusing on brain and the nervous systems, the anthropogenic approach to cognition sets human beings apart from the rest of living organisms; on the contrary, the biogenic approach is founded on the essential principle of contemporary biology – evolution by natural selection, postulating that complex cognitive capacities have evolved from their simpler forms (Lyon, 2004, 2006).

[...] a researcher who takes a biogenic approach assumes that the nature of cognition is best understood in the general context of biological organization and functioning, not in the specific context of the human instantiations of these functions. Cognition may prove to be a complex, multifaceted global function, like respiration, without which no organism can survive, or it may be a complex but more circumscribed trait, like avian song learning, that provides an adaptive advantage only for those lineages that possess it. (Lyon & Keijzer, 2007, pp. 142–143)

Lyon (2006) has proposed to explore the biological approach by two categories of theories: (1) self-organizing complex systems focusing on the thermodynamic features of living organisms; (2) autopoiesis focusing on the phenomena of self-production in functional closures.

7.2.2.1 The theory of self-organizing complex systems

Self-organization, the appearance of structure or pattern without an external agent imposing it, can be observed both in the laboratory and in daily lives (Heylighen, 2001). Crystallization, for example, molecules that randomly move are

fixed within an ordered structure because the decrease in entropy of the crystal is compensated by a greater increase in the entropy of the liquid that these molecules are dissolved (Heylighen, 2001, para. 2). Prigogine and Nicolis (1985) named systems exhibiting features of dynamic self-organization as dissipative structures (see Introduction): The system is open to its environment as exchanges of energy and/or matter occur between them. Although entropy is generated within the system, it is actively dissipated out of the system; in this way, the system increases its own orderliness by exporting more disorder to the environment. Living organisms, obviously, are dissipative systems that realize self-organization, thus reducing the internal entropy, by importing order from the environment. The thermodynamic phenomenon was, then, studied in the framework of cybernetics. William Ross Ashby (1991) suggested that self-organization is a process that uncertainty of a dynamic system reduces and the different parts of the system adapt better to each other.

Lyon (2006) argued, the self-maintenance of an organism depends on the responses to many shifting parameters of its interacting environment: temperature, weather, the availability of food, water, shelter, the chemical profile of the atmosphere, the presence or absence of predators and parasites, the presence or absence of toxic substances, etc.; therefore, cognition, which directly or indirectly modulates the physical-chemical-electrical processes of life, should be considered as a means of homeostatic regulation. As it has been explained, energy is required in the organism's continuous self-maintenance against the tendency of approaching disorderliness – the thermodynamic equilibrium (Prigogine & Nicolis, 1985), Lyon (2006) suggested that behaviors aiming in securing the energy supply of an organism – "foraging, food storage and retrieval, patch usage, stealing and concealing food" (p. 18) – must have been strengthened in the biological evolution; the cognitive system, meanwhile, is needed to make continuous assessments on



the current situation and the potential for interactions, relating to the organism's energy needs. For instance, the function of memory – the capacity to retain information – is intrinsically required in this case²⁹: the response of an E. coli as swimming towards a food source or away from toxin results from the comparison between (at least) two sampling actions on the environment – the direction of its movements is decided based on the concentration gradient of the sensed substance (Lyon, 2006, p. 20). In other words, memory is essential in building the connection between perception and action.

Furthermore, Lyon (2006, 2015) suggested that cognition is also responsible for prioritizing the received information according to the immediateness of the organism's needs. It is, in fact, an adaptive advantage for an organism to tackle the most critical problems at a time, thus avoiding life-threatening dangers. On this account, pain should be dealt with before thirst and hunger because "body trauma is more immediately critical for survival than either fluid or energy requirements" (Goodson, 2003 as cited in Lyon, 2006, p. 21). The underlying condition for the prioritization of information is a mechanism capable of attributing different values to different input signals. According to Lyon (2015), valence, which is referred to as the attractiveness, acceptability or tolerability of a stimulus (i.e. generally categorized as positive, negative, and neutral), are assigned to information that concern the current circumstances, internal and external, of an organism; previous experiences, receiving and reacting to the very type of information also influences its valence. The valence of signals may appear to be implicit in the example of E. coli's chemotactic behaviors, although the responses do show an evident distinction between attractants and repellents (see 6.2.2) (Hansen et al., 2008). In

 $^{^{29}}$ see 6.2.2, the chemotactic behaviors of E. coli.

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humans, specialized brain-based systems take care of the evaluation and the prioritization of received information (Spruijt, Van den Bos, & Pijlman, 2001). A more detailed presentation can be found in 8.3.

7.2.2.2 The theory of autopoiesis

The term autopoiesis was introduced in 1972 by Humberto Maturana and Francisco Varela to define the self-maintaining chemistry of living cells; then, it has been applied to the studies of systems theory and sociology (Di Paolo, 2005). While the theory of self-organizing complex systems suggests that living organisms organize their orderly structures, the theory of autopoiesis suggests that living organisms are self-producing – "the continual production by a network of the very components that comprise and sustain the network and its processes of production" (Lyon, 2004, p. 9). A typical example of an autopoietic system is the biological cell: end product inhibition in metabolic pathways (see 4.3.2.2); the transcription and the translation of genes to produce proteins that induce changes which lead to further gene expressions (signal transduction, see 6.2.2 and 6.2.3).

The self-maintaining actions of a living organism are considered by the theory of autopoiesis as made of circular causal flows which, in turn, keep the system of control inside a functional closure ("Self-Regulatory System", see 4.3.1.1). Maturana and Varela (1980) argued that no organism can exist without functional closure for the following reasons: (1) The capacity of sustaining the processes relevant to the organism's self-maintenance despite changes in the environment requires the living system to be autonomous. (2) On the account of "sustaining self-identity" (i.e. homeostasis), cognition is used to distinguish "self"



from "non-self". However, the reference point for the definition of an organism's selfhood is not necessarily fixed.³⁰ (3) With the establishment of a boundary, the organism's domain of interactions is defined. The cognitive system of an organism should be able to select from numerous environmental signals those that can potentially lead to the interactions which are adequate to the organism's survival and reproduction. In this manner, for a given species of organisms, their domain of interactions is also their domain of cognition, which has already been incorporated with certain interactive patterns.

Lyon (2006) suggested that "cognition is intrinsically future-oriented" (p. 23). In 6.3.1.2, it is explained that reality is known from the combination of anticipation and observation - the latter is used to reduce the uncertainty caused by the former (Heylighen, 2006). Lyon (2006) referred to the process as randomness reduction and suggested that the role of cognition also lies in reducing and modulating the influence of random perturbations. She argued that the very physiological properties that an organism is endowed with have already determined, for more or less, the parts of environment that the organism can interact with (Lyon, 2006). For example, without the help from other devices, human beings can only sense as much as their sensory organs allow. In the meanwhile, structural determinism does not imply the predictability of the system's actions: The structure of the system, on one hand, determines the system's functioning; one the other hand, the structure is influenced by the functioning in the continuous feedback loop (Lyon, 2006). As the intermingling between biological structure and cognitive functions grows stronger and stronger in practice, it will be eventually impossible to separate physiological processes from pure cognitive moments (Lyon, 2006).

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 $^{^{30}}$ The ability of self-other distinction is presented in this chapter by the process of immune responses (7.3.2), as well as in 9.2 along with the concerned neuropsychological mechanisms in humans.

Studying the role of genes in behaviors, Järvilehto and Lickliter (2009) believe that humans are born with inherited structures into an environment, but these structures are not "ready" – the behavioral possibilities that these structures entail are yet to be discovered.

From both of models presented in the biogenic approach to cognition – selforganizing complex systems and autopoiesis, we learn that the environment for a certain organism is not neutral but a part of its cognitive reality, depending on the organism capabilities of interactions. In other words, the perceived environment and the organism form one system. In the next section, the point of view postulating the interdependence between organism and environment is studied by the Organism-Environment Theory (Järvilehto, 1998, 1999, 2000, 2009).

7.3 COGNITION EMERGES IN THE CONTINUUM OF ORGANISM AND ENVIRONMENT

7.3.1 The theory of organism-environment system

7.3.1.1 The inseparability of organism and environment

The theory of Organism-Environment System was first proposed by Järvilehto in 1994 in his work on systemic psychology. The fundamental concept is the inseparability of an organism and its environment: The two are not independent, although usually being distinguished for practical purposes; in fact, together they form one single system of cognitive reality – "The organism cannot exist without the environment and the environment has descriptive properties only if it is connected to the organism." (Järvilehto, 1998, p. 321). Järvilehto (1998) defined that living organisms are systems consisting of integrated cells and tissues, as well as specified parts of the environment, with which they form a unitary system.

According to Järvilehto (1998), behaviors – all organismic processes inside and outside the body – should not be considered as the interactions between two systems, but the reorganization of one system. The results of behaviors, based on their influence on the realization of the goal of self-maintenance, can be categorized as positive and negative ones (Järvilehto, 1998). The structure and the functioning of an organism-environment system exist and evolve to create conditions for behaviors that can achieve positive results (Järvilehto, 1998).

Järvilehto (1998) strongly argued that all parts of the organism-environment system are active in the achievement of results – there is no asymmetry between the organism and the environment and the role of the environment is not passive at all. In this framework, sensory experiences do not depend solely on the environment, while motor effects require more than the efferent signals of the organism; learning is seen as the process of differentiation and widening of the organism-environment system as more action results can be achieved (Järvilehto, 2006). As it is explained in the following section, cognitive (even psychological) capabilities are not located inside the body of the organism but extend into the environment.

7.3.1.2 The evolution of cognition

Järvilehto's approach on cognition is a biogenic one as it takes into consideration the evolution of cognitive systems from single-celled organisms to multicellular organisms with neurons.



Järvilehto (2000) started from the first living things on earth – single-celled organisms with limiting borders – the cellular membranes. Although the self-maintenance of single-celled organisms is achieved inside a functional closure, the cells are not limited to their membranes; on the contrary, the membranes act as organs of connections to the environment, which is consisted of substances required in the organisms' life process (Järvilehto, 2000). In order to survive and reproduce, single-celled organisms must continuously use their environment by identifying those substances and transporting them through the membranes (Järvilehto, 2000).

By aggregating together, single-celled organisms gained better chance in surviving sudden changes in the environment (Järvilehto, 2000). The aggregation of individual organism-environment systems is, in fact, a process of metasystem transition (see 5.2.1) (Karatay & Denizhan, 2005; V. F. Turchin, 1977). By sharing some parts of the environment, single-celled organisms collect together and produce formation in which they secured the survival of each other under changing circumstances; the joining of the individual organism-environment systems led to a more complex and differentiated structure of a larger organism-environment system (Järvilehto, 2000). The benefits of metasystem transition are related to stronger capacities of control. Indeed, as each single-celled system adhered one to another, it also brought its specialized regulatory skills (Järvilehto, 2000). In this way, the environment of a multi-cellular organism is made of highly differentiated parts; and new protocols are created to coordinate their exploitation for potential benefits.

Järvilehto (2000) considers the appearance of neurons as an especially decisive phase of the development of multi-cellular organisms for their ability of directly influencing the activity and the metabolic conditions of other cells. The



influence on other cells exerted by neurons is made possible by a group of substances known as neurotransmitters (Purves et al., 2004, p. 846). The individual environments of different cells are thus connected and they can be coordinated to work together. Moreover, the association and the coordination of sensor and motor cells, thanks to neurons, made higher cognitive activities possible – in this way, sensors and effectors can be tuned to correspond to specific situations in the environment (Järvilehto, 2000). For example, the function of memory is indispensable in the process of perception-action (see 6.3.1.1; 7.2.2.1). With neuronal circuits connecting the receptor and motor organs, experiences in achieving results are kept and can be extracted during the exploration of the environment, so that the organism knows what to look for and what to avoid (Järvilehto, 2000). Therefore, for an organism, its potential actions are no longer undifferentiated with the possible results completely unknown.

7.3.1.3 A thought experiment: knowledge without senses

In a thought experiment proposed by Järvilehto (1999), an imaginary organism without any sensory organs but only motors can "acquire" information on the environment to which it has no direct access and acts appropriately in it³¹. By this example, Järvilehto (1999) aimed to show how environment determines the behaviors of an organism (pp. 94-95):

(a) The imaginary organism is swimming inside a cube filled with a homogenous energy field (like water) using two pairs of fins which move the organism in

³¹ The process of the thought experiment (Järvilehto, 1999, pp. 94-95) is rephrased from the original text and presented in three paragraphs in block format, marked in this section as: (a), (b), and (c).

two dimensions: forward-backward or right-left. The pairs of fins are connected by a set of interneurons ensuring that only one pair is active at a time. The motor mechanism is powered by the energy obtained from the environment while the organism is moving inside. When the energy for one pair of fins is used up, the movement in a particular direction stops and the other pair of fins is activated, as their energy is being stored during the movement of the first pair of fins. If the movement of the organism stops completely, it cannot restore energy and dies.

(b) The organism starts to move in one direction (forward or backward; left or right) inside the cube using one pair of fins. As the other pair of fins is inhibited from moving but charging energy at the same time, the organism can more indefinitely if the walls do not exist. When it hits the wall, the active pair of fins still moves until its energy store is depleted. The stop of the first pair of fins activates the movement of the second; so, the organism starts to swim in a different direction until it hits another wall. As the organism repeats the cycle of wall-hitting, using and charging energy in the meanwhile (thus the charging time depends on the distance of the organism to the wall), after a number of rounds, it can be observed that the movement of the organism within the cube starts to optimize – it already turns before hitting the wall, and develops continuous movement within the walled space.

As the organism with no sensors still can anticipate the situations in the environment, Järvilehto (1999) argued that both the organism and the environment have active roles in forming the cognitive reality for the organism. Järvilehto (1999) then modifies the setting of the experiment: (1) The walls no longer exist; (2) the environment is no longer a homogenous energy filed, but consists of energy gradients; (3) the organism is endowed with a receptor which can sense and acquire energy from specific spots in the environment; (4) the

energy spots can be restored after being used; (5) the organism has many pairs of fins that allow it to move in any direction. Järvilehto (1999) described the following scenario (p. 95):

(c) In order to survive, the organism has to move around in the heterogeneous environment to look for energy spots; and the movement itself requires energy. If by chance, the organism has found an energy spot by moving to one direction, then it can continue moving in the same direction until the stored energy is depleted. In this case, another pair of fins starts to work, moving the organism in another direction. If with luck, another energy spot is found in the new direction, the organism can, then, move further in this direction until the direction of movement has to be changed again. As the organism moves from one energy spot to another and the used energy spot can be restored, eventually, the itinerary of movements is optimized based on the locations of the spots and the organism's consumption of energy.

Furthermore, Järvilehto (1999) proposed a final modification on the settings of the experiment: the receptor of the organism can change to fit all types of energy spots (pp. 95-96). In this case, the organism can investigate the environment by locating energy spots of different qualities and fitting into the functional whole with the environment based on its energy needs (Järvilehto, 1999).

In the three versions of the experiment, Järvilehto (1999) has shown that perception is not a linear process proceeding from the stimulus to the percept, but a structure which involves both the organism's sensory and motor organs as well as the particular conditions of the environment. Järvilehto (2009) has suggested elsewhere that the reaction to a stimulus depends on an anticipatory organization rather than information processing.

A perceptual process does not start with the stimulus; rather the stimulus is the end of this process. The stimulus is like the last piece in a jigsaw puzzle. The last piece of the puzzle fits in its place only because all other pieces of the puzzle have been placed in a particular way. (Järvilehto, 1999, p. 97)

As it is also shown in the scenarios, eventually, the organism "knows" how to act in each environment. Järvilehto (1999) suggested that this type of knowledge should not be confused with the knowledge understood in common sense, which is the description of something created by a self-conscious agent. It is better to understand knowledge as the results of actions as traces left on a medium according to the theory of stigmergy (see 6.2.1.1) (Heylighen, 2016): the traces themselves can act as a condition for the subsequent actions. In other words, this type of knowledge does not presuppose the organism's awareness of anything; it simply exists as a functional structure of an organism-environment system.

7.3.1.4 Consciousness emerges in the achievement of common results

As a familiar phenomenon of human mental lives, consciousness is usually the question of how conscious mental states including sensations, perceptual experiences, and occurrent thoughts can be the product of physical processes in the brain (Davies, 1999). Developing the theory of organism-environment system, Järvilehto (2000) holds a different point of view on the origin of consciousness. Järvilehto (2000) believes that although consciousness cannot exist without the brain or the body, it does not physically reside in any of them; consciousness results from the cooperation between organism-environment systems in the achievement of common goals. Järvilehto (2000) has defined three levels of consciousness: (1) General consciousness – the common knowledge shared between individuals in a society, used for the organization of teamwork. (2) Personal consciousness – the knowledge on the role of an individual in the whole cooperative organization, including the relations to other individuals and to the common result. The reference of perspective in determining these relations is the body of the individual. (3) Subjective consciousness – the knowledge on one's own emotional responses such as feelings and desires, which can be seen as the production of the cognitive (psychological) system.

Järvilehto's main argument on the origin of consciousnesses lies in the necessity of working together: organisms join their efforts together to achieve a goal that cannot be achieved by an individual alone (Järvilehto, 2000). Järvilehto (2000) argued that from fungi associating with each other during difficult life conditions to social insects as bees and ants, common results are different from individual ones in the sense that they are not only quantitatively greater but qualitatively better. The achievement of common results requires each participant to change its own organization to fit in the larger one; meanwhile, protocols are created to ensure the stabilization of their specialized roles (Karatay & Denizhan, 2005). Moreover, one participant needs to communicate the knowledge of its own situations to the others – where it is at, what it can do, when it can do it, for example – via the traces of its actions (see 6.2.1.1) (Heylighen, 2016; Järvilehto, 2000). Järvilehto (2000) considers the communication of one's potential participation in the achievement of common results to be the beginning of general consciousness.

Then, Järvilehto (2000) explained, in the larger organization, for one participant, the existence of another is understood as a part of the environment where the opportunities for positive results can be found. In other words, a participant is seen as a tool one by another. On this account, in order to communicate the knowledge of oneself to the others, a participant needs to take



the perspective of the others, seeing itself as the tool in the eyes of the others (Järvilehto, 2000). According to Merleau-Ponty (2002), the body of an organism is perceived by itself as an object to understand its own functions. Inspired by this point of view, Järvilehto (2000) proposed that the body of an individual sets the point of reference in relation to the rest of the world; this marked the beginning of personal consciousness.

Järvilehto (2000) defined personal consciousness as the understanding of the personal participation and exploitation of an individual in the achievement of common results. Järvilehto (2000, 2001) argued that: (1) Personal consciousness can only exist when there are communications between individuals – "I" can only be meaningful when there is "you" because it requires the ability to reflect one's own action results from the point of view of the others. (2) Personal consciousness is not located inside the body, brain or neurons, but in the continuum of oneself and the environment – the body of an individual is seen as an object which can bear its actions, as well as the spatial location of the point of intersection inside a social system. (3) Personal consciousness is made of relations in the cooperative organization – a conscious subject is not the flesh, but a unique set of social relations. Therefore, a robot may never become a person.

As it is explained that the knowledge of oneself is located outside the body rather than contained inside the brain (Järvilehto, 1999). Subjective consciousness, as Järvilehto (2000) suggested, does lead to the awareness of a subject but as an object: Being conscious of oneself means being able to make a description of one's actions and their emotional influences, thus seeing oneself as an object. Järvilehto (2000) considers the common idea that presupposes pure subject moments as a linguistic misunderstanding. For example, in the sentence "I am painting the house", "I" can only be seen as a subject in the grammatical sense; logically, it is an



object referring to the body which is described as the initiator of the action "painting" (Järvilehto, 2000, p. 49).

By the descriptive quality of language, Järvilehto (2000) believes that words are used as means of communication, or more precisely, proposals for actions to achieve certain results. Elsewhere, Järvilehto (2001) noted that "[...] the participation in the common results widens the action possibilities and the personal consciousness of the individual. The development of personal consciousness is therefore in direct relation to the possibility of using the common results in one's own action." (para. 6).

Järvilehto (2000) has noted that a word cannot describe an (ongoing) action but only the result of it. For example, for a person to describe the action of taking a pencil from the table, the describer needs to divide it into action results: "my hand is now here, I move it, at the next moment it is there, I take a grip on the pencil, etc."; If the person is asked to further explain the meaning of "move" or "take", he needs, again, to rely on the results by saying that moving means – "the hand is now here but at the next moment there" (Järvilehto, 2000, p. 49). In fact, each verb in the human language is an abbreviation of a sequence of action results. In 9.3.2, the relation between the early-age development of language and action results is presented and discussed (Zlatev, 2008, 2014).



7.3.2 The establishment of cognitive patterns and the achievement of common results: immunity

7.3.2.1 The theory of Organism-Environment System and the immune system

Järvilehto's theories on the inseparability of organism and environment, the evolution of cognition, and the emergence of consciousness in a social organization are explained in the biological context with the examples of the immune system. The immune system is capable of detecting, eliminating and anticipating harmful antigens.

In 7.2.2.2, explaining the models of self-organization and autopoiesis, it is argued that an organism is both open and closed to the environment, thus, it is capable of distinguishing environmental substances as beneficial or harmful to the maintenance of its self-identity. The immune system, in fact, can be seen as platforms of interactions between the organism and the environment. There are mechanic barriers such as skin; chemical and biological barriers such as respiratory, gastrointestinal and genitourinary tracts; also, all over the body, blood and lymph tissue forming a circular network (Purves et al., 2004, p. 368).

Järvilehto (1999, 2009) argued that the environment is not passive but active in the establishment of an organism's cognitive reality: for any signal to be considered meaningful by the organism thus inducing regulatory responses, it must fit in the pattern of signal transduction which is already formed between the organism and the environment. As it is explained below, the fitting problem is very important in the functioning of the immune system.

All organisms have an innate immune system as a "rapid first line of defense" (Hofmeyr, 2001, para. 2) responding to invading pathogens³² that limits the initial infections through generalized and fixed mechanisms including inherited pattern recognition receptors (Brinkworth & Thorn, 2013). The innate immune system is "inherited, germline encoded, nonspecific, and typified by barriers (e.g., mucosa, skin), antimicrobial peptides, phagocytosis (initiated by cells such as macrophages and neutrophils), and inflammation" (Janeway & Medzhitov 2002; Kumar et al. 2009 as cited in Brinkworth & Thorn, 2013, p. 19). Vertebrates also have an adaptive immune system that can initiate specific responses to the invasions of "non-self" entities and damaged cells as well as remember the successful ones for their future uses (Purves et al., 2004, pp. 370–371). The adaptive immune system is made of lymphocytes - a class of white blood cells that can detect and eliminate pathogens (Purves et al., 2004, p. 366). The recognition of pathogens by lymphocytes occurs as a fitting process: The surface of a lymphocyte is covered with many identical receptors, while the surfaces of pathogens contain antigenic determinants (i.e. epitopes); the binding between a receptor and an antigenic determinant depends on the complementarity of their structures (Hofmeyr, 2001; Purves et al., 2004, p. 370). An immune response is initiated when the number of bound receptors on a lymphocyte's surface exceeds a certain threshold (Hofmeyr, 2001).

In conclusion, the immune system can detect and eliminate invasions with inbuilt cognitive patterns – some are non-specific thus fixed, others are specific and evolvable upon learning. In both cases, it is the organization of one organism-



³² A pathogen is a harmful agent such as virus that can cause diseases in the host organism (Purves et al., 2004, p. 365). An antigen is the part on the pathogen that is recognized by the host organism and causes an immune response (Purves et al., 2004, p. 370).

environment system that determines the infrastructures for the immune responses, thus shaping an organism's unique immune identity. In the next section, the adaptive immune system is studied to see how cognition is involved in the building of effective and up-to-date defenses.

7.3.2.2 Cognition pattern building in the human adaptive immune system: perception, memory, and learning

Järvilehto (1999, 2009) has defined perception as a preexisting cognitive pattern inside which stimulus is the last element to fit in – an organism can perceive as much and as good as its sensory organs allow. However, this pattern which can be inherited in the first place does not necessarily remain unchanged. Cognitive patterns are created and selected while the organism-environment system is constantly reorganized. For example, the adaptive immune system can memorize the encountered pathogens, thus preparing for responding more effectively and efficiently when these pathogens invade again; also, when encountering pathogens new to the organism, the system can adapt the receptors on the lymphocytes to the specificity required for the binding of the concerned pathogens (Hofmeyr, 2001; Purves et al., 2004, pp. 372, 382).

The adaptive immune system consists of two major types of lymphocytes – B cells and T cells (Purves et al., 2004, p. 366). The immune identity is unique for every human being as it is made of a great variety of different B cells and T cells; the diversity is primarily created by chromosomal rearrangements and mutations right after the cells being formed in the bone marrow (Purves et al., 2004, pp. 371–372). Both types of cells can recognize specific "non-self" entities and generate specific responses to eliminate them; however, each type of them has its own

mechanism encountering an invasion – the one for B cells is called humoral (relating to antibodies) immunity and the one for T cells is called cellular (or cellmediated) immunity (Purves et al., 2004, p. 371). The two mechanisms function at the same time and cooperate with each other by sharing some of the steps (Purves et al., 2004, p. 371). In this section, we focus on the abilities of memory-keeping and evolving binding specificity of B cells. In the next section, we examine the mutually dependent functioning of the two immune mechanisms represented by B cells and T cells.

(1) Memory cells

For an organism, there are millions of different B cells, and each one of them produces a particular antibody which is then displayed on the surface of the B cell to neutralize specific types of pathogens (Purves et al., 2004, p. 372). When an antigen binds to an antibody, the related B cell is stimulated to divide, forming clones of the cell (Purves et al., 2004, p. 372). Among the produced cells, some develop into plasma cells (or effector cells) that secrete the same type of antibodies as the parent cell which can eliminate the specific antigens; a few develop into memory cells that divide at a low rate, preserving the clone, thus retaining the ability to quickly respond to the same type of antigens in the future by producing more plasma cells and memory cells (Purves et al., 2004, p. 372). The process is known as clonal selection in the sense that it is the antigen that selects the type of B cells to proliferate, determining the unique immune identity of a given organism (Purves et al., 2004, p. 372).

In 6.3.1.2, Heylighen (2006) proposed to combine feedback control (observation) and feedforward control (anticipation) for a goal-oriented system to be effectively prepared in solving problems. It is exactly the method by which

immunological memory builds and updates the cognitive pattern of an organism's immune responses. When a person is exposed to a particular antigen for the first time, it usually takes several days before the number of antibodies increases; however, encountering the same antigen for the second time, a much more rapid and effective response can be triggered – it takes a shorter time to produce a great number of antibodies (Purves et al., 2004, p. 372). In other words, the immune system "remembers" this antigen and anticipates the next encounter for years afterward or even for a lifetime (Purves et al., 2004, p. 372).

The history-based immune identity of an individual organism distinguishes it from the others. More precisely, the very environment of the organism determines how its cognitive pattern of immune responses is built to prepare for specific invasions; geographically restricted patterns of selection in humans, for example. It is reported that several MHC alleles³³ common in West Africans but rare in other ethnic groups are associated with protection from severe malaria (Danilova, 2008).

(2) The evolution of binding specificity between lymphocyte receptors and antigens

Thanks to the immunological memory, the immune system is prepared for a rapid and effective elimination encountering an invasion for the second time. On the other hand, for the first time that the immune system encounters an invasion, the mechanism of protection concerns the specificity of the binding between the

³³ MHC, short for major histocompatibility complex, are surface proteins of most mammalian cells essential for self-tolerance and coordinating immune responses (Purves et al., 2004, p. 367). A more detailed presentation can be found in 7.3.2.3. MHC alleles are genes that code for MHC proteins.

lymphocyte receptors and the antigenic determinants (Hofmeyr, 2001). The binding may not be perfect at the beginning, but the lymphocyte receptors can evolve to adapt to the required specificity (Hofmeyr, 2001). In other words, the cognitive pattern of immune responses is constantly updated in order to successfully neutralize any invasions.

Lymphocyte receptors are created in a pseudo-random process of DNA recombination, meaning that once a B cell is selected for massive replication, the offspring and the parent cell are not exactly the same (Hofmeyr, 2001). Segments of the genes on the parent cell's chromosome are rearranged; therefore, the produced B cells are new to the original pool of responsive options (Hofmeyr, 2001). When the same antigen is encountered again, some of the produced B cells can secrete antibodies that bind better to the antigen; they will be selected and continue to proliferate (Hofmeyr, 2001). On the other hand, the produced B cells that express low affinity in antibody-antigen binding are less able to stimulate their own proliferation; they will die after a short time (Hofmeyr, 2001). In other words, a B cell becomes specified in responding to a given antigen as the binding specificity between its antibody and the antigen evolves.

The newly encountered antigen can be seen as a template or a preformed pattern, and the bond antibody as the last element to fit in the pattern. Random changes occur to the B cell which produces the bond antibody to look for an even better fit while keeping what already matches. Therefore, the evolvable immune mechanism combines feedforward control anticipating potential invasions and feedback control for specifying the recognition of a given antigen. The antibodyantigen fitting problem is not determined by the organism or the environment alone. Although the role of the environment – the nature of a particular antigen – seems to be crucial, the evolvability of the organism – the random changes



responsible for creating different types of B cells – enables active adaptations to the preformed pattern. In 8.2.1, by presenting the theory of cognitive niche construction (Magnani & Bardone, 2008), an organism's ability to create opportunities to fit in a goal-satisfying (or problem-solving) pattern is discussed in detail. In fact, the interactive plan between antigen and the immune system is changing all the time. Tools can be developed by pathogens to inhibit immune responses; then, the immune system can evolve to strengthen its protection against them (Danilova, 2008).

7.3.2.3 Consciousness in the human adaptive immune system

Presented in 7.3.1.4, the emergence of consciousness is believed to be related to the cooperation of several organism-environment systems in the achievement of common goals – each system should be able to see itself from the perspective of the others in order to define its role in the whole teamwork as well as its benefits from the achieved results (Järvilehto, 2000, 2001). In other words, the awareness of oneself depends on the presence of the interacting others. In adaptive immune system, involving respectively B cells and T cells, the humoral mechanism and the cellular mechanism cooperate with each other as common steps are shared during the processes (Purves et al., 2004, p. 371). The two types of cells are coordinated in a larger framework with the goal of protecting the organism from harmful antigens. Eventually, it is shown that the general awareness of the immune identity results from the interactions between several parties including B cells, T cells, MHC proteins, other molecules required in the immune responses and the antigens.



In a humoral immune response, as presented in 7.3.2.2, a B cell is stimulated to divide by the specific binding between antigenic determinants and antibodies on a B cell's surface (Purves et al., 2004, p. 372). In fact, for an antibody-secreting cell – a plasma cell – to develop, a helper T cell (written as T_H) is needed to be bound to the antigen-presenting cell (Purves et al., 2004, pp. 378–379). Like a B cell, a T cell also has membrane receptors which can bind to a specific type of antigens; after the binding, the T cell produces clones (Purves et al., 2004, p. 378). Among the differentiated offspring of the parent T cell, there are two types of effector cells: (1) Cytotoxic T cells (or T_C cells) which can recognize and eliminate infected cells; (2) Helper T cells (or T_H cells) which are involved in both the cellular and the humoral immune responses (Purves et al., 2004, p. 378). In cellular immune responses, a T_H cell binds to an antigen presented on a B cell, activating the B cell; at the same time, the T_H cell sends signals to activate the T_C cells (Purves et al., 2004, p. 378).

The interplay of the humoral and the cellular immune responses enhances the system's capacities in the elimination and the anticipation of antigens. In fact, it is suggested that the genes that code for T cell receptors and those for the receptors of antibodies (secreted by B cells) may share a common ancestor (Purves et al., 2004, p. 378). The interdependence between the two mechanisms provides the necessary conditions for the functioning of each party in the realization of the common result – the defense against antigens. For a plasma cell (an effector B cell), the elimination of an antigen can only be realized when it binds to not only the antigen but also a helper T cell. In other words, a plasma cell is conscious of its role in the "orchestra" of immune responses only when it is defined in relation to the roles of other participants.



The distinction between oneself and the others concerns the problem of setting the reference point in an organism's participation in achieving the common results. For the adaptive immune system, distinguishing self and non-self is highly important because if the system fails to do so, it may attack its own cells and cause autoimmune diseases (Purves et al., 2004, p. 384). The human immune system recognizes its own cells by their surface proteins, including a very important group known as the MHC proteins with a major role of presenting antigens on the cell surface to a T cell receptor (both T_C cells and T_H cells) (Purves et al., 2004, pp. 378–379)³⁴. Two of the three classes of MHC proteins are mainly involved in the humoral and the cellular immune responses: (1) Class I MHC proteins that combine with abnormal cells or fragments and present them to T_H cells (Purves et al., 2004, pp. 378–379).

MHC proteins are crucial in setting the reference point of selfhood in the adaptive immune system. It should be noted that self-tolerance is established in the interactions of lymphocytes with other molecules involved in the immune responses, meaning that the process is dynamic and subject to failures. During the development of T cells, they are tested in the thymus in two key aspects: (1) The cell must be able to recognize the body's own MHC proteins; if it is not, it cannot participate in any immune responses and will die within about three days (Purves et al., 2004, p. 381). (2) The cell must not recognize MHC molecule presenting self-antigens; if it does, it is considered harmful and will be programmed to die (Purves et al., 2004, p. 381). Therefore, the test establishes the distinction between self and non-self, enhancing the specificity of the binding between an antigen and

³⁴ The MHC proteins in humans are called human leukocyte antigens, or in short, HLA (Purves et al., 2004, p. 378).

a T cell receptor. However, the self-other distinction can be altered: As the MHC genes are different among individual humans, a transplanted organ is usually treated as a "non-self" by the host's immune system; the problem, then, can be solved with drugs that suppress the immune system, thus redefining the reference point of selfhood (Purves et al., 2004, p. 381).

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Chapter 8 ANTICIPATION AND LEARNING

8.1 INTRODUCTION

8.1.1 Review of Chapter 7

Throughout this thesis, the cognitive functions of a code-based and goaloriented system interacting with its environment are discussed within several theoretical frameworks.

In Chapter 4, by the models of Meaning Generator System (Menant, 2003) and Self-Regulatory System (De Beule & Stadler, 2014), the way that an agent receives information about an incident and reacts accordingly in the goal of self-maintenance is described within the framework of a causal process from stimulus to response.

The causal relationship is further developed by the theory of stigmergy (Heylighen, 2016) in Chapter 6 – the ability of receiving and acting upon some incident information varies among individual organisms; the presence of a stimulus does not necessarily lead to a regulatory response, instead, the stimulus and the organism's regulatory abilities are the conditions that make the occurrence of a responding action more probable.



The theory of Organism-Environment System (Järvilehto, 1998, 1999, 2000, 2009) in Chapter 7 recognizes both the environment and the organism as the determinant factors in the responding action of an agent to incident information. Perception is considered not as a linear process from stimulus to percept but a piece of the puzzle that can fit into the organization consisting of the agent's receptors and effectors, as well as the particular conditions of the environment (Järvilehto, 1999).

In Chapter 7, cognition is defined as resulted from the biological evolution in the sense that the infrastructures of cognitive functions are by nature anticipatory and capable of adapting to changing situations. The issues of anticipation and learning are addressed by Lyon as the problem of symbol-grounding – the establishment of correspondences between representations and real-life events which are continuously changing; and she suggested that symbol-grounding is made possible by living organisms by the cognitive functions such memory, task prioritization, the selection of beneficial opportunities (Lyon, 2004, 2006). On the other hand, Järvilehto (1999, 2000) has emphasized the active role of environment in the determination of an organism's cognitive reality – in his thought experiment, an organism can anticipate and learn about the environment through even the least informational interactions; furthermore, interacting with other organismenvironment systems, an individual system can develop the awareness of its own role in the teamwork targeting a common goal.

The cognitive functions – anticipation and learning – observed among living organisms, especially human beings are studied in Chapter 8. The environment is constantly changing, and humans change too. As a result, humans anticipate events that may happen in their lives and learn to adapt to different situations. Interacting with the environment, humans explore chances for actions that can be



beneficial to their self-maintenance; when these chances are not available, they can even create conditions to increase the possibility of achieving the goal (Magnani & Bardone, 2008, 2010).

8.1.2 Presentation of Chapter 8

In 6.2.1.1, it is suggested by the theory of stigmergy that a mark left on a medium by the action of an agent can stimulate subsequent actions from the same agent or other agents (Heylighen, 2016). In the theory of cognitive niche construction, elaborated by Lorenzo Magnani and Emanuele Bardone, it is proposed that organisms look for signs for actions in their environment to achieve self-maintenance; and when these signs are not available, they can also manipulate the environment to create them (Magnani & Bardone, 2008, 2010). Signs for actions and actions themselves are distinguished. Using the term "affordance", Magnani and Bardone (2008) proposed that objects from the environment "afford" different organisms differently. In other words, affordance does not belong to either the environment or the organism; in fact, it results from specific instances of interactions between the two parties (Magnani & Bardone, 2008). Therefore, affordances are not permanently fixed for an organism facing its living surroundings. Magnani and Bardone (2008) suggested that the processes of exploring and even creating affordance during organism-environment interactions are suggested to rely on the method of logical inference - abduction, defined by Charles Sanders Peirce. Abduction is characterized by the ability to bring something new to the inquiry of a given issue (Burch, 2017); Magnani and Bardone (2008) further developed the concept by proposing a method called "manipulative abduction" which is referred to as "discovering through doing" in the acquirement of knowledge (p. 10).



Tests and verifications which are used in the validation of hypotheses are governed by two major mechanisms - the feedback control and the feedforward control. The general advantages and disadvantages of these mechanisms are first presented and discussed based on the studies of Del Giudice (2015) on selfregulation. Then, Del Giudice (2015) proposed that: (1) The efficacy of feedback control can be improved by interconnecting several feedback loops using each one of them as a checkpoint to deliver an accurate final output step-by-step. (2) The efficacy of feedforward control can be improved by pairing it with feedback control in sequence so that the latter can reduce the uncertainty produced by the former. Furthermore, it appears that feedback control is especially important in the initial phases of inquiry with explorations and model building involved – it is used to provide the basis for rapid responses achieved by feedforward control (Del Giudice, 2015). The functioning of these control mechanisms is exemplified in the homeostasis of blood glucose. It is shown that, during intensive physical exercise, the need of glucose supply is anticipated by the human body (Suh, Paik, & Jacobs, 2007).

In the second part of this chapter, the efficiency of organisms (humans especially) in building their cognitive reality which eventually contributes to the self-maintenance is studied with the theory proposed by Berry M. Spruijt, Ruud van den Bos, and Femke T. A. Pijlman based on the economic concept of costbenefit ratio (Spruijt, Van den Bos, & Pijlman, 2001). They suggested that environmental stimuli, signs or information for self-maintaining actions, are perceived in a way that values are given to them at the same time (Spruijt et al., 2001). In humans, these values are emotional states which are used to manage goal-achieving behaviors by a motivational system – those associated with positive emotions are rewarding, thus are more likely to be repeated in the future; those associated with negative emotions are aversive and should be avoided



(Spruijt et al., 2001). When percepts are evaluated by the same standard, it is possible to prioritize regulatory actions beforehand (Spruijt et al., 2001). The value assigned to a specific type of information varies from time to time; the determination of value is an individual event which is influenced by the current state of the organism-environment interaction (Spruijt et al., 2001).

The central nervous system is believed to be the physiological basis of the human motivational system (Spruijt et al., 2001). By parallel information processing, units responsible for the perception of different types of information, their evaluation, and the selection of the most optimal response operate simultaneously and the results are integrated into one output (Spruijt et al., 2001). The rewarding values associated with the received information are represented by two substances essential in the reward pathway in the brain – dopamine and opioids – dopamine controls the "wanting" of a reward while opioids control its "liking"; the systems for "liking" activate the ones for "wanting" so that specific behavioral patterns for getting rewards can be established (Spruijt et al., 2001).

The motivational system is adaptive. When rewards are abundant, animals become tolerant to stimulus; but in the opposite situation, animals are sensitized in the reaction to rewarding values (Spruijt et al., 2001). Another adaptive feature of the system is the compensation between different types of motivated behaviors. When rewards cannot be obtained from one type of behavior, the emotionally positive state of the organism can still be maintained by those obtained from another type of behavior (Spruijt et al., 2001). Finally, the motivational system is adaptively anticipatory because not only the successful results of self-maintaining actions can bring rewards, their preparatory phase is also rewarding (Spruijt et al., 2001). In this way, animals are constantly driven to the active search for the Signs of rewards, maximizing the chances of actually obtaining them.



8.2 SEARCHING AND CREATING CHANCES FOR ACTIONS IN THE SPHERE OF MEANING

8.2.1 The theory of cognitive niche construction

Järvilehto (1998, 1999, 2000, 2009) considers the interactions between organisms and their environment as organization and reorganization of a single organism-environment system (see 7.3.1). For Magnani and Bardone (2008, 2010), their position is compatible with the theory of organism-environment system on the determinant role of the environment in the establishment of cognitive reality. Magnani and Bardone (2008, 2010) believe that organisms, humans especially, can delegate and distribute their cognitive functions to the environment to lessen the limits; sign-mediated models or representations, for example, are considered externalizations of thoughts and ideas. Bardone and Secchi (2010) suggested that humans overcome their internal limitations by "disembodying" of thoughts and ideas: for example, using external support to store information – writing text on a piece of paper – gives rise to the possibility of "re-projecting" of these thoughts and ideas, since the paper is used as a "cognitive and epistemic mediator" to uncover hidden information and concepts which cannot be achieved only with the mind (pp. 192-193).

All living organisms have the goal of self-maintenance to achieve. According to Magnani and Bardone (2008, 2010), organisms do not simply live their environment, but actively shape and change it in order to look for suitable chances. These chances are considered as information, which is not internally stored as memory or already available in an external reserve but needs to be extracted and picked up upon occasions through the organism-environment interactions; while organisms are interacting with their environment, the process of exploring and even creating chances to enhance their fitness is called the construction of cognitive niches (Magnani & Bardone, 2008, 2010). As what Bardone (2011) suggested with the term "ambient intelligence", humans' ability of outsourcing cognitive resources to the environment marks a new stage of history of cognitive niche construction (p. 64). Especially, the invention and the use of computing devices that can mimic the functions of human mind fit right in the eco-cognitive aspect of human life as an effective and efficient assistance in tackling daily problems (Bardone, 2011).

In 3.2.1, according to the theory of modulated stochastic causation, the fitness of an organism is determined by both the selective pressure imposed by the environment and the regulatory actions of the organism facing non-adapting situations (van Hateren, 2015d). Magnani and Bardone (2008) suggested studying the active role of an organism in controlling and regulating their self-maintaining activities in the framework of cognitive niche construction. Magnani and Bardone (2010) proposed that organisms are equipped with ontogenetic mechanisms for adaptive actions - the vertebrate immune system (see 7.3.2.3), for example - to cope with various changes in the environment which cannot be specified at the genetic level. Seen from the perspective of an organism, the environment offers possibilities for actions - "water to swim, air to fly in, flat surface to walk on, and so on" (p. 6); however, not all the possibilities but only some of them can be exploited by the organism based on the limits of its physical structure and the explicit ways to satisfy the goal of self-maintenance (Magnani & Bardone, 2008). A cognitive niche is not equal to a habitat; in fact, the construction of cognitive niche requires modifications of the organism's habitat in order to make it suitable for its survival and reproduction, including the elimination of negative effects (Magnani & Bardone, 2008).



Comparing to "information", Magnani and Bardone (2008, 2010) prefer to use the term "affordance", originally proposed by Gibson, to define the chances for actions provided by the environment. According to Gibson (1979), the affordance is a property belonging to the environment - it does not change according to the need of an observer, and it may not be perceived by certain individuals. Other scholars, however, argued that affordance is observerdependent: a cardboard box is perceived as a seat by a child but may not be by an adult due to the difference in weight (Heft, 1989). Magnani and Bardone (2008, 2010) agree that the same object found in the environment may "afford" different organisms in different ways; thus, the term should be appropriately used considering the specific role of an organism facing various chances. Magnani and Bardone (2008, 2010) further suggested that besides the differences in the method, there are also differences in the degree when it comes to the ability of "affording": When the chances for actions are not evidently available, some organisms can extract them from limited information, or even create them. Therefore, affordance should not be understood as proprieties of the environment; it only exists when a specific organism interacts with its environment.

Moreover, Magnani and Bardone (2008, 2010) argued that value is involved in the perception of affordance – for a perceiving organism, an object is recognized not only as its physical self, but also the chances for actions which can be exploited to serve the goal of self-maintenance. In 2.3, it is shown that value defined in a semiotic system can establish a common standard for signs to be compared one with another, that is, value makes the differentiation of signs possible (Neuman & Nave, 2008). In the same way, as an organism attributes different values to different objects, the prioritization of tasks is possible based on their importance and immediacy. For instance, in 7.2.2.1, it is proposed that prioritizing the reaction to body trauma than to thirst or hunger is an adaptive advantage (Goodson, 2003



as cited in Lyon, 2006). In the next section, the neurocognitive mechanism which uses emotions as the common value for task prioritization (Spruijt et al., 2001) is studied.

Magnani and Bardone (2008, 2010) distinguished the possibilities for actions from the actions themselves. The affordance of an object for an organism reflects the affinity between the constraints of both parties. Or to put it this way, affordance results from the instances of interactions between the object and the organism; it is not determined beforehand but requires a process of finding out what can be done with the object by the organism (Magnani & Bardone, 2008, 2010). During this process, the uncertainty of action is reduced while the affordance is determined. In 6.3.1.2, the reduction of uncertainty is formalized as cycles of anticipation and perception: An organism presumes the coming event based on limited information, initiates an action, and evaluates the presumption based on the results of the action (Heylighen, 2006). The pairing of anticipation and deduction as methods of logical reasoning. Indeed, Magnani and Bardone (2008) believe that abduction which is necessary for the creation of new knowledge captures the essence of affordance.

According to Peirce, abduction is the process of inferring hypotheses which are plausible but still fallible to explain an observed phenomenon; then, these hypotheses are assessed with deduction and induction – tests and verifications – to validate the discovery of something new (Burch, 2017). Peirce suggested that abduction is the only logical operation that introduces new ideas (Burch, 2017). Unlike deduction – the logical inference that starts with reasons and looks for consequences, abduction works in the very opposite order – from consequences to reasons, resulting in the fallibility of the conclusion; the mistakes, however, keep



bringing originality into the pool of knowledge (Burch, 2017). Explained in 3.3.1.2, responding errors (misinterpretations) can be beneficial to organisms in the long run: they occur during the organism's exploitation of chances for actions and the enhanced fitness can be amplified by natural selection (Robinson & Southgate, 2010). Noted by Peirce, picking is commonly observed in newborn chickens regardless of the availability of food, thus abduction should be an innate capacity of making inferences (Peirce, 1901 as cited in Magnani & Bardone, 2008). Magnani (2009) also believes that abduction can be instinctual and non-linguistic: for example, activities performed with bodily skills, are ways by which living organisms adjust themselves to the environment in a way that is highly circumstantiated, without forming any strategies beforehand. In 9.3, this argument is addressed by the theory of embodied cognition (Gallagher, 2001; Zlatev, 2008) which explains the humans' innate cognitive capacities of understanding each other.

The concept of manipulative abduction is developed to describe the ability to create affordances with an object which presents little or no meaningful features to an organism – when the chances for actions are not evidently available (Magnani, 2007; Magnani & Bardone, 2008). Simply put, it is a method of "discovering through doing" in the process of inquiry (Magnani & Bardone, 2008, p. 10). The idea is inspired by the work of Kirsh and Maglio in which two types of abductive actions are distinguished: (1) pragmatic actions – performed by an agent to be physically closer to a goal; and (2) epistemic actions – performed by an agent as changes of internal computations to tackle problems more effectively (Kirsh & Maglio, 1994 as cited in Magnani & Bardone, 2008). Magnani (2001) argued that manipulation is necessary because it (1) simplifies and redistributes efforts when information is "redundant and unmanageable" (p. 61); (2) gives access to more data when the information at hand is incomplete; (3) promotes the invention of

objects that can be used for acquiring data that is otherwise unavailable. In fact, the two types of actions can be related to, respectively, as the semantic adaptations and the syntactic adaptation of a code-based and goal-oriented system presented in 5.3.1 (Cariani, 1989, 2015). On one hand, being physically closer to a goal relies on an enhanced sensibility and effectiveness of the semantic parts for the agent to better measure and influence the physical world. On the other hand, the syntactic parts can be altered to find the computational structure yielding the best results. In this sense, the mechanism for an organism to reason abductively takes the form of (at least) an adaptive robotic device specialized in solving real-life problems.

Magnani and Bardone (2008) gave an example to show the process of manipulative abduction - the demonstration of the fact that the interior angles of a triangle always add to 180° (p. 29). As it is shown in Figure 8.1, the process is marked by the agent's manipulation that modifies the original configuration and uncovers new affordances; the reasoning looking for explanatory hypotheses is by nature abductive (Magnani & Bardone, 2008). Evidently, the abductive approach smartly differs from the inductive one which implies the impossible in this case: measuring all the triangles that could exist in the world. Both pragmatic and epistemic actions are involved in the demonstration: A line parallel to one side of the triangle is drawn to create correspondence angles (Angles "2") and alternative interior angles (Angles "1"). Based on the theorems of geometry, the correspondence angles are equal and the alternative interior angles are also equal. They are, in fact, "meaningful features" extracted from the object - the original triangle; and as the environment is thus restructured and the conclusion on the sum of the angles is easily reached (Magnani & Bardone, 2008, p. 12). At the same time, Magnani and Bardone (2008) noted that the creation of affordances is agentdependent - in the example above, the affordances can only be created when the agent is familiar with the geometric theorems.





Figure 8.1 Manipulative Abduction. To prove that the interior angles of a triangle always add to 180°, affordances – the correspondence angles (Angles "2") and the alternative interior angles (Angles "1") – are created by restructuring the original triangle. Adapted from "Sharing representations and creating chances through cognitive niche construction. The role of affordances and abduction.", by L. Magnani & E. Bardone, 2008, *Communications and discoveries from multidisciplinary data*, 123, p. 29. Copyright 2008 by Springer-Verlag Berlin Heidelberg. Adapted with permission.

Manipulative abduction in the process of inquiry necessarily requires the method of trial and error, namely, the sequential combination of feedforward control and feedback control. In the next section, a detailed explanation of the two types of control in living organisms and the comparison between them are given.

8.2.2 Feedback and feedforward control in the homeostasis of blood glucose

8.2.2.1 Advantages and disadvantages of feedback control and feedforward control

Despite that the environment may change rapidly and unpredictably, the internal condition of an organism is maintained relatively stable; to achieve homeostasis, information is indispensable (Purves, Sadava, Orians, & Heller, 2004, pp. 781–782). In feedback control, for example, the reception of incident information or measurement of the current situation is used to determine the agent's regulatory reaction. Feedback control can be categorized into negative and



positive ones. Negative feedback control is characterized by the counteraction of the influence which is considered as an error signal. For example, end product inhibition in metabolic reactions (see 4.3.2.1) – the excess of the end product of one reaction inhibits another reaction taking place earlier than the first one in the pathway (Purves et al., 2004, p. 122). Positive feedback control, on the contrary, means the amplification of the influence. For example, the emptying of body cavities such as urination, defecation, sneezing, and vomiting (Purves et al., 2004, p. 785).

As it is explained in 5.3.1 with the theory of the complementarity of syntactics, semantics, and pragmatics (Cariani, 2015), in order to solve real-life problems, measurement is required to set the initial parameters for the logical procedure. In the case of organisms, their sensory organs and the related neural pathways play the role of measuring devices. Measurement, however, is not immune to errors. Del Giudice (2015) suggested that in feedback control, a trade-off exists between tracking speed and the ability to reject noises: When the output is measured more frequently, more noises will enter the channel, getting mixed up with the useful information. At the same time, effective filtering of the noises will slow down the speed of making measurements. Sih and Del Giudice (2012) suggested that for living organisms, the trade-off between speed and accuracy leads to the trade-off between risk and reward: bolder animals act more actively and quickly without having a full evaluation of the risks; unaggressive and less exploratory animals collect fewer rewards in short terms, but they take time in making accurate assessments of the situation to ensure their survival.

This problem is proposed to be dealt with by interconnecting multiple loops of feedback control in a hierarchical arrangement – as one upstream loop regulates the variables of another loop downstream, the tasks of control is modularized, yielding a more flexible and precise performance (Del Giudice, 2015). It should be noted that, in cascade control, (1) as a goal at a given level can be achieved by various means at lower levels, the flexibility of goal-achieving actions increases with the level of the hierarchy (Carver & Scheier, 2000); (2) as the control loops are successively connected one to another – the output of the first loop becomes the input of the second, the efficiency of the whole system depends on the specific order of their combination (Albertos & Mareels, 2010). In 6.3.2, it is shown that cell signaling is not a single event but a cascade of responses (Bruni, 2003). A signal transduction pathway is made of many intermediate steps and each of them acts as a "checkpoint" for an effective feedback control (Bruni, 2003, p. 375). As a specific selection of responses takes place in a specific order, the final output of the pathway is highly accurate.

Besides the noise caused by measurement, feedback control has another natural limitation: it can only operate when errors have already occurred and detected by the agent (Del Giudice, 2015). In other words, there is always a delay for initiating regulatory actions while the event unfolds. The delay may be life-endangering for a living organism. As it is explained in 6.3.1.1, it is usually too late to correct the error when a person is falling off a cliff (Heylighen, 2006, para. 7). In this case, feedforward control – looking out for the cliff and keeping away from its borders – is evidently more advantageous than feedback control.

Feedforward control is characterized by the pre-emptive actions that counteract future disturbances (Albertos & Mareels, 2010; Del Giudice, 2015). An effective and safe performance of car driving, for example, cannot be achieved without feedforward control (Purves et al., 2004, p. 785). Beside the rapidity for regulatory responses, other advantages included the insensitivity to noises – because the mechanism does not rely on the complete and accurate measurement



of the situation in real-time (Del Giudice, 2015). Logically, feedforward control can be equalized to the abductive inference which generates hypotheses on an observation with a certain degree of fallibility. Despite that feedforward control operates on incomplete information, it cannot work if there is no information at all; in fact, the better the agent knows the situation, the more credible the predictions will be (Del Giudice, 2015). As it is shown in 6.3.1.2, when paired together, feedback control counteracts the uncertainty raised in feedforward control; feedforward control alone, however, faces most likely a decreasing accuracy in the agent's ability to predict (Heylighen, 2006). Miller, Galanter, and Pribram (1960) proposed a similar method called "reinforcing feedback" using a formal unit "Test-Operate-Test-Exit (TOTE)": Feedback control is repeatedly used as a stimulus that drives the reduction of uncertainty; the result can either affirm or deny the assumption. After every reflex, the agent can attain a more desirable state of overall control (p. 30).

The advantages of combining feedback control and feedforward control in the sequence are specified as increasing behavioral flexibility and optimizing learning (Del Giudice, 2015). While providing accurate information on the situation in every operation cycle, the feedback mechanism trains the feedforward one to yield better performances in the future. Feedback control is valuable in the initial phase of model building through systematic explorations of the environment; then, based on the built model, feedforward control can generate rapid and effective regulatory actions (Del Giudice, 2015).

8.2.2.2 An example: regulating the homeostasis of blood glucose during physical exercise

In this section, an example of a homeostatic regulation is presented to show that both mechanisms of control – feedforward and feedback – are essentially involved in the process.

Under normal circumstances, for humans, there is a match between the uptake of glucose by tissues and the appearance of glucose in the bloodstream, resulting in a relatively constant blood glucose concentration (Suh et al., 2007). During physical exercise, for example, the increasing need for glucose is taken care of in order to maintain the balance. As the uptake of glucose by skeletal muscles is stimulated by exercise, the intensity and duration of which influence the magnitude of glucose uptake, forming a positive feedback control loop (Suh et al., 2007). It has been shown that in healthy, post-absorptive humans, the uptake of glucose from the blood by the working muscle during moderate exercise can supply 15-30% of the required energy; while in highly intensive exercise, the supply can increase to 40% (Wahren et al., 1971; Cooper et al., 1989 as cited in Suh, Paik, & Jacobs, 2007).

The liver plays an important role in maintaining the quantitative match between the uptake and the production of glucose by two processes: (1) glycogenolysis and (2) gluconeogenesis (Suh et al., 2007). Glycogenolysis happens at the beginning of physical exercise: glycogen stored in the liver is converted into glucose; the latter is released into the blood (Suh et al., 2007). As the exercise continues and the store of hepatic glycogen decreases, gluconeogenesis takes place: carbon-based compounds such as lactate, glycerol, and certain amino acids are converted into glucose (Suh et al., 2007). The two processes are stimulated by the same hormone – glucagon (Suh et al., 2007). In other words, glycogenolysis and gluconeogenesis are successive steps of one chain of reactions which can be regulated retroactively; together, they form a cascade feedback control. It is shown that glycogenolysis occurs within 2-6 hours after a meal, while gluconeogenesis is significant in prolonged fasting – in subjects who fasted for 60 hours that gluconeogenesis accounts for almost all the increase in splanchnic glucose production during mild exercise (Bjorkman et al., 1981 as cited in Suh, Paik, & Jacobs, 2007). Therefore, the feedback control in blood glucose homeostasis is strengthened by combining the two processes with each one of them targeting a specific condition of energy supply.

In the meanwhile, blood glucose homeostasis during physical exercise is also proved to be regulated by feedforward control. In several experiments on (Kjaer et al., 1986; 1991 as cited in Suh, Paik, & Jacobs, 2007), it is shown that there is a mismatch between the production and the uptake of glucose, which is an increase, instead of a decrease of glucose concentration in blood during intense exercise. This mismatch is proved to be remarkably anticipatory: it is more distinct when the work intensity increases and in early moments rather than late ones during exercise (Kjaer et al., 1986, 1987, 1991; Sonne & Galbo, 1985 as cited in Suh, Paik, & Jacobs, 2007). In other words, the production of a certain amount of glucose has already occurred before this amount of glucose is actually needed by the organism.

As it is suggested above, the homeostasis of blood glucose operates with both anticipation and perception: an intensive physical activity is prepared for in its early stages with an exceeding level of fuel supply; then, it is supervised by a combinatory mechanism which can either inhibit or amplify the supply effectively, depending on the organism's needs in real-time.

Furthermore, discussing anticipation, an interesting question comes along: Why are organisms specially prepared for some types of information, rather not others, while all of them can potentially be beneficial to their self-maintenance? Or, to put it simply: How do organisms prioritize the things to recognize then to react accordingly? In the next section, we present a neurobiological value-assigning system which enables the anticipation of behavioral outcomes and the learning of making the most profitable choice.

8.3 THE EVALUATION AND THE PRIORITIZATION OF CHANCES FOR ACTIONS

8.3.1 The motivational system: the behavioral and the neurobiological mechanisms

Del Giudice, Ellis, and Shirtcliff (2011) suggested that time and energy are limited resources in the lifetime of an organism, therefore, they should be optimally allocated. The process involves weighing benefits and costs and the result can be amplified by natural selection; for example, there is a trade-off between bodily growth and reproduction because both require an investment of energy (Del Giudice et al., 2011). However, a behavioral strategy is only optimal in theory; in reality, the outcome is influenced by the dynamic conditions of the organism and the environment, where fine tuning of the action is needed to maximize the organism's fitness (Del Giudice et al., 2011). As it is shown throughout the third part of the thesis, vertebrates evolve to be more and more efficient in exploiting resources and avoiding potential harms in their environment. Spruijt, Van den Bos, and Pijlman (2001) suggested to examine this efficiency from the angle of economy – it is, in fact, the weighing between investment and consequences before any action taking place. For example, it is observed in the wild and under laboratory conditions that food items are collected in a way which minimizes the spent energy while maximizing the benefit (Krebs & Davies, 1993; McFarland, 1993 as cited in Spruijt, Van den Bos, & Pijlman, 2001).

For all the received information to be compared one to another, the evaluation should be based on a common value. Spruijt, Van den Bos, and Pijlman (2001) believe that the central nervous system ³⁵, which is genetically preprogrammed, serves as the physiological basis of a motivational system that reacts to and coordinates various types of received information. Then, they suggested that the value assigned to a certain type of information is a "subsequent internal state" that has an organizing effect on the brain; in humans, more precisely, it is an emotional state (Spruijt et al., 2001, p. 147). Carver (2006) has noted that valanced feelings act as a second layer of a negative feedback system that monitors and manages the performance of goal-achieving actions of living organisms. Different from the first feedback control which is the mechanical measurement of the current situation, the second one concerns the rate of the process and tells whether an action moves the organism toward the goal or away from the anti-goal (Carver, 2006).

An emotion is defined as a psychological state that functions in the management of goals (Oatley, 1999). It is given either a positive nature or a negative one whenever an event relevant to the achievement of a goal is evaluated; both positive and negative emotions are used to control and regulate the motivational system retroactively (Oatley, 1999). After studying abundant evidence, it is suggested by Spruijt, Van den Bos, and Pijlman that relevant

³⁵ In vertebrates, the brain and the spinal cord as the sites of most information processing, storage and retrieval are called the central nervous system, or short as, CNS (Purves et al., 2004, p. 845).

information for a specific event is stored and retrieved in association with an emotion (Jensen, 1996; Fraser & Duncan, 1998; Wiepkema, 1985 as cited in Spruijt, Van den Bos, & Pijlman, 2001). Therefore, alongside the inherited mechanism, humans have a trainable one to adapt their behaviors to different situations by recognizing the associated emotions. Associated with different events, emotions as "discriminative stimuli" make it possible to prioritize goals and plans (Spruijt et al., 2001, p. 148). Spruijt, Van den Bos, and Pijlman (2001) proposed that responses are evaluated and compared with each other based on their abilities to diminish the difference between the actual and the expected state of an event. The responses that yield outcomes closer to the expectation are considered to be emotionally positive thus having rewarding properties – they are most likely to be reinforced in the future; in the same way, responses that are comparatively weak in reaching the expectations are most likely to be terminated and replaced (Spruijt et al., 2001).

Spruijt, Van den Bos, and Pijlman (2001) suggested that the value assigned to a specific type of information depends on the current state of the subject interacting with an object as well as the previous experience of similar interactions. Using the example of food items, they explained that the value of a food item for a human being is determined by many factors such as the subject's current degree of hunger, the degree of difficulty in procuring the food item, its nutritious value, and taste (Spruijt et al., 2001, p. 148). Dealing with conflicts in motivational states, different types of information are compared by their rewarding values; this obviously facilitates the selection of the best response at a moment, which is, the one that yields the greatest reduction of differences between the actual and the expected state, leading to the highest reward (Spruijt et al., 2001). Thus, the outcomes of potential actions are weighed based on a "common currency" (Spruijt et al., 2001, p. 150). It is noted that the reduction of differences between the actual and the expected state can also be achieved indirectly by lessening the effects of



aversive stimuli (Spruijt et al., 2001). In other words, reward and aversion – moving toward a goal and away from the anti-goal – can be compared one to another by the same mechanism that measures the differences between states.

Examining the literature on task prioritization, Spruijt, Van den Bos, and Pijlman argued that the vertebrate central nervous system assumes the responsibility of measuring, comparing and selecting rewarding values associated with different types of information thanks to its hierarchical sets of parallel feedback systems and functional units with self-organizing properties (Lammers et al., 1987, 1988; Willner & Scheel-Kruger, 1991; LeDoux, 1996 as cited in Spruijt, Van den Bos, & Pijlman, 2001). Information is processed in a parallel way: simultaneously, an input can induce autonomic reactions, activate motivational responses and retrieve relevant information that is integrated into a final output (Spruijt et al., 2001).

As it is shown in Figure 8.2, at every layer of information processing, each unit (represented as a square) has its own reference signal and the regulatory mechanism of feedback control; then, an entire layer has the reference signal which can provide feedback to the previous layer (Spruijt et al., 2001). There are also cross-connections between the layers of information processing (Spruijt et al., 2001). Eventually, parallel streams are integrated into one coherent response (Spruijt et al., 2001).





Figure 8.2 Parallel Information Processing. In a three-layered representation of parallel information processing, the input is controlled by forming feedback loops between hierarchical layers of information processing units. Adapted from "A concept of welfare based on reward evaluating mechanisms in the brain: anticipatory behaviour as an indicator for the state of reward systems", by B. M. Spruijt, R. van den Bos, & F. T. Pijlman, 2001, *Applied Animal Behaviour Science*, 72(2), p. 149. Copyright 2001 by Elsevier Science B.V. Adapted with permission.

Ventral tegmental area (VTA) is the site of dopaminergic neurons, which determines whether an environmental stimulus is rewarding or aversive; nucleus accumbens (NAc), also called ventral striatum, is a principal target of VTA dopamine neurons for mediating the rewarding effects (F. G. Ashby, Isen, & Turken, 1999; Russo & Nestler, 2013). VTA-NAc circuits are considered the most important pathway for reward in the brain: Once activated, the subjects are incited to repeat what they have just done to get the reward; the memory centers in the brain are also incited to pay attention to all features of a particularly rewarding

experience, ensuring its future occurrence (F. G. Ashby et al., 1999; Russo & Nestler, 2013). Based on experimental evidence, Spruijt, Van den Bos, and Pijlman (2001) suggested that mesolimbic dopamine and endorphins, respectively, have specific roles in creating and reinforcing behaviors, including causing addictions – dopamine is associated with "wanting" while endorphins (opioids) with "liking".

It is believed that dopamine is involved in allocating the most optimal response to a variety of information all carrying rewarding values, rather than mediating the rewarding effects (Salamone, 1997; Berridge & Robinson, 1998; Van Ree et al., 1999 as cited in Spruijt, Van den Bos, & Pijlman, 2001). Therefore, Spruijt, Van den Bos, and Pijlman (2001) suggested that the dopamine systems concern the incentives of "wanting", but not the ones of "liking", "disliking", or the learning of new "likes" and "dislikes". Information from the amygdala and the hippocampus (in the ventral striatum) – representing properties of context and stimuli, and input from the ventral tegmental area – representing the rewarding values of a given type stimulus, are integrated into one final response; the intensity of the response is dopamine-dependent (Spruijt et al., 2001). It is shown that dopaminergic systems can be sensitized (pharmacologically, for example), contributing to long-lasting changes in reactions to rewards or aversions (Cabib & Puglisi-Allegra, 1996; Berridge, 1996 as cited in Spruijt, Van den Bos, & Pijlman, 2001).

On the other hand, opioids are reported to be largely involved in motivating affections toward certain behaviors: it is shown in experiments that opioids alter liking for food (as a reward) (Berridge & Robinson, 1998 as cited in Spruijt, Van den Bos, & Pijlman, 2001). Based on experimental results, Spruijt, Van den Bos, and Pijlman (2001) also pointed out that opioid systems can be activated before the consumption of a reward (Sweep et al., 1989; Shippenberg et al., 1996 as cited in

Spruijt, Van den Bos, & Pijlman, 2001). In other words, the subject is feeling emotionally positive by the thought of having the reward, before actually having it. The release of opioids can be conditioned. It is shown in several studies on analgesia that opioid systems become sensitized under stressful conditions to the point that the subjects experienced a decrease in pain reactivity (Williams et al., 1990; Przewlocka et al., 1990 as cited in Spruijt, Van den Bos, & Pijlman, 2001).

Finally, "liking" proceeds "wanting" in time not only logically but also physiologically – opioids can determine the release of dopamine (Spruijt et al., 2001). Closely associated with the reward, the opioid systems activate the dopaminergic systems to create and maintain a specific behavioral strategy for the acquiring of the reward (Spruijt et al., 2001). Regarding the temporal difference, it is also suggested based on the experimental findings that the opioid systems may focus on the present situation while the dopaminergic systems may influence on the organization of future behaviors: the highest efficacy of opioid drugs to change addictive behavior is in the initial phase of their development; on the other hand, dopamine is more effective in changing stereotypes that have already been established (Berridge & Robinson, 1998 as cited in Spruijt, Van den Bos, & Pijlman, 2001).



8.3.2 The adaptivity of the motivational system

In 8.3.1, it is explained that the rewarding value of a specific type of information depends on the current state of the subject with respect to its expectation (Spruijt et al., 2001). As the value varies from time to time, it is suggested that the sensitivity to rewards or aversions should also be changing continuously: on one hand, a certain degree of tolerance to rewards is developed when rewards are abundant; on the other hand, sensitization is essential when the acquiring of rewards becomes difficult (Spruijt et al., 2001). It is shown in experiments that the sensitivity to rewards or aversions increases during stressful circumstances, while repeated exposures to rewarding drugs such as morphine induce tolerance (Piazza et al., 1990; Van den Berg, 1999; Van den Berg et al., 2000; Van Ree et al., 1999 as cited in Spruijt, Van den Bos, & Pijlman, 2001). For instance, Frankenhuis and Del Giudice (2012) argued that as it is favored by natural selection to take risks when the benefits outweigh the costs, animals have developed a dynamic sensitivity to risks: well-fed animals may forage on low-risk items or give up foraging entirely because the additional gain does not impact on its fitness in a significant way; also, for animals which are doing well in achieving self-maintenance, it can be advantageous for them to take some risks because they can afford the potential loss.

Tolerance and sensitization of rewarding values make motivated behaviors adaptive in changing situations. However, Spruijt, Van den Bos, and Pijlman (2001) pointed out that using one single system to evaluate and allocate responses has a drawback: when one specific reward cannot be acquired, the subject may look for other rewards as compensation in order to remain emotionally positive. In other words, the responsiveness of any type of information is interdependent with the responsiveness of the others, making maladaptive behaviors possible. Spruijt, Van

den Bos, and Pijlman (2001) used the example of animals deprived of play to show that the value related to a specific reward can be compensated with values created by other types of rewards: an enhanced preference for sucrose and food is shown among these animals; once treated with morphine, the enhancement disappears (Van den Berg, 1999; Van den Berg et al., 2000 as cited in Spruijt, Van den Bos, & Pijlman, 2001, p. 158).

Spruijt, Van den Bos, and Pijlman (2001) suggested that under stressful circumstances, compensatory rewarding behaviors increase in frequency and duration: for example, due to excessive grooming, damages to skin, fur or plumage are usually observed among stressed animals (p. 158). However, Spruijt, Van den Bos, and Pijlman (2001) also argued that these maladaptive behaviors can be eventually beneficial. They explained that there are two types of motivated behaviors - (1) behaviors that lead to immediate physiological consequences, such as acquiring food and shelters, and (2) behaviors that lead to long-term consequences, such as grooming and explorations (Spruijt et al., 2001). Obviously, the second type of behaviors satisfies seldom the animals' most urgent needs thus usually fail to be prioritized in the motivational plan; nevertheless, this type of behavior is important for the overall fitness of individuals and their offspring (Spruijt et al., 2001). Therefore, by using the same motivational channel with the first type of behaviors, the regular display of the second type is guaranteed as it is directly rewarding as well (Spruijt et al., 2001).

As opioids are released before the consumption of the reward, motivated appetitive behaviors³⁶ can be seen as a type of feedforward control – a regulation

³⁶ Appetitive behaviors are defined as "The active, goal-seeking and exploratory phase of behaviour that precedes the more stereotyped consummatory behaviour that the animal exhibits when it reaches its

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that is initiated by recognizing the sign of an event, before the actual occurrence of the event. In 8.2.2.1, the major advantages of feedforward control are concluded as the rapidity for responses and the insensitivity to noises (Del Giudice, 2015). These are, in fact, essential to the coordination of behaviors. Spruijt, Van den Bos, and Pijlman (2001) believe that appetitive behaviors which are rewarding in themselves can be seen as a "built-in safety measure" to maintain the animal's readiness to continue achieving the goal (p. 157). For example, rooting, the foodseeking behavior of pigs, does not stop when food is provided because the rewarding values of rooting are independently given regardless of the availability of food (Spruijt et al., 2001, p. 157).

Furthermore, as the coordination of behaviors operates by the display rather than the consequences of actions, thus by the representations of things (i.e. signs) rather than these actual things, animals are given the "semiotic freedom" (see 2.2.1) to create strategic patterns of actions beforehand by manipulating causal relations in the physiological structure. In this sense, semiotic systems which nurture creativity are used to anticipate changes. Of course, due to the relative independence of semiotic relations to the reality, it is possible that the estimation and the real outcome of an event do not match, as an example is given in 3.3.1.2: the odor of rabbit (Sign) does not necessarily guarantee the presence of a rabbit (Object) (Alexander, 2013, para. 6). Misinterpretations, however, can facilitate learning while increasing the chances of self-maintenance of individuals and their species in the long term (Robinson & Southgate, 2010). The semiotics behind the motivational system includes all the aspects of syntactics, semantics, and pragmatics (see 5.3.1). By associating real-life events with (internal)

goal. Upon reaching the goal, appetitive behaviour normally ceases." ("Appetitive behavior," 2008).

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neurobiological states – emotions of different natures or rewarding values represented by dopamine and opioids, the experiences of animals interacting with the world become meaningful to them. While rewarding responses are evaluated and allocated by one supervising mechanism, it is possible to be more efficient in exploring alternative strategies for goal achievement and selecting strategies that yield the best cost-benefit balance. Most importantly, responses that can eventually contribute to the increase of the animals' fitness is reinforced by feedback control, continuously, in the actual instances of actions.

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Chapter 9 HUMAN CONSCIOUSNESS

9.1 INTRODUCTION

9.1.1 Review of Chapter 8

In Chapter 2, by presenting the theory of matter-symbol complementarity (2.2.1), Pattee (2008) suggested that using signs subsequently requires making the distinction between the physical world and the semiotic world – between things and their descriptions – named as the "epistemic cut" (p. 118). In other words, life is not only the sum of chemical and physical changes but also the descriptions of these changes rendering a sign-based reality. The description of life is exploited by living organisms in achieving the goal of self-maintenance. During the process, meaning plays an important role: the perceived information is connected to the satisfaction of the system's purpose and becomes meaningful; then, regulatory responses can be initiated according to the specific meaning (Meaning Generator System, see 4.2.1.1; Self-Regulatory System, see 4.3.1.1).

The key issue of Chapter 8 consists of studying how living organisms (vertebrates, humans especially) manipulate signs to impact on the physical world. The emphasis is placed on the ability to actively create cognitive patterns in order to increase one's fitness facing the pressure of natural selection (Magnani & Bardone, 2008, 2010). In 8.2.2, two fundamental methods of meaning exploitation are discussed: feedback control and feedforward control. The former depends on

the perception of errors, and the latter requires anticipation. These two mechanisms are "manipulated" – they are used as basic components and reorganized to create a more complicated pattern on the semiotic level, which can tackle problems more effectively. For example, as Del Giudice (2015) that: (1) Interconnecting feedback control loops increases the flexibility of the accuracy in regulating the whole system. (2) Pairing feedforward control with feedback control reduces the degree of uncertainty raised by the former. (3) In the initial phase of exploiting an unknown environment (which is relatively stable), feedback control is especially valuable in model building, which provides the basis for an effective feedforward control.

The manipulation of signs is creative. Magnani and Bardone (2008, 2010) defined the term of affordance as a fitting process between an organism and its environment - how the environment "affords" the potential actions of an organism depends on the physical conditions of the organism and the actual instances of the interaction. In other words, what an organism can do in the environment is never fixed; originality occurs from time to time. With the theory of the motivational system, Spruijt, Van den Bos, and Pijlman (2001) suggested that the central nervous system assigns values to received information based on their potential impacts on the satisfaction of the organism's needs and prioritizes regulatory responses accordingly. In this way, the actions associated with high values are considered to be rewarding and are more likely to occur at the time as well as in the future. This mechanism is characterized by a high-degree independence of the sign-based calculations from the actions in the physical world; also, the recognition of a sign has its own impact on the physical world apart from the impact caused by the actions as responses to the recognition of the sign (Spruijt et al., 2001).



9.1.2 Presentation of Chapter 9

Generally, the environment that an organism interacts with includes other organisms of the same specifies. In 7.3.1.4, on the emergence of consciousness, Järvilehto (2000) suggested that in order to work together in the achievement of a common goal and to benefit from the common results for its individual gain, an organism needs to be aware of itself from the perspective of others. That is, a subject can only exist when it is recognized as an object from the point of view of another subject. More precisely, the body of a subject sets the point of reference in distinguishing oneself from the others. Two issues crucial in the interactions between humans are addressed in Chapter 9: (1) How do people distinguish themselves from the others? (2) How do people understand each other?

In social lives, it is necessary for people to constantly perceive actions and emotions of each other. While it appears to be effortless for healthy people to understand and distinguish the behaviors of others from those of their own, van der Weiden, Prikken, and van Haren (2015) pointed out that, people suffering from schizophrenia usually have difficulties in self-other integration and distinction. In their work (van der Weiden et al., 2015), first, the neurophysiological groundwork is presented - mirror neurons and motor prediction: (1) Mirror neurons are a class of neurons that are active during both the execution of a motor act and the observation of a similar act performed by others. Mirror neurons' role in self-other integration is shown to be goal-directed, anticipatory, and can be affected by not only movements but also emotions; in self-other distinction, mirror neurons show different patterns of activation that distinguish self-produced actions from other-produced ones. (2) Motor prediction is an innate system based on feedback control to evaluate body movements regarding the purpose of the actions. It can also be used for self-other distinction



because, usually, a person can predict his own actions more accurately than the actions of others.

Then, van der Weiden, Prikken, and van Haren (2015) suggested that side by side with the neuronal basis, cognitive expectations also impact self-other integration and distinction. In an experiment called "Wheel of Fortune Task", it is shown that when there is a match between the expectation and the outcome of the subject's behavior, an increase of felt self-agency is resulted (van der Weiden, Aarts, & Ruys, 2013; van der Weiden et al., 2015; van der Weiden, Ruys, & Aarts, 2013). Furthermore, explicit and implicit expectations are differentiated one from the other by the way they guide the agent's actions – in the first case, the actions are strictly goal-oriented, and the agent is highly sensitive to errors; in the second case, there is no reference to error-control the actions, and the agent is sensitive to not one, but many targets logically associated one with another (van der Weiden et al., 2013; van der Weiden et al., 2013).

In the second part of Chapter 9, the phenomenon of intersubjectivity is studied from two theoretical stances – theory of mind and embodied cognition. In the first stance, theory of mind, there are two prominent approaches: theory theory and simulation theory. The first postulate the existence of an internal model that can be used to understand other people's mind, while the second, supported by the discovery of mirror neurons, suggest that people can simulate the sensations and the intention behind the perceived actions of others with their own mind (Gopnik, 1999). Shaun Gallagher (2000, 2001, 2008) has criticized both approaches and suggested that the understanding of mind is established in an embodied way – thanks to a cross-modal mapping between the perceived actions of others and one's own motor sensations.



The discussion on the embodied interpretation of intersubjectivity is further developed by the theory of bodily mimesis, elaborated by Jordan Zlatev, suggesting that the cross-modal mapping between the perception and the production of actions only accounts for the beginning of intersubjective skills (Zlatev, 2007, 2008, 2009a). Zlatev (2007, 2008, 2009a) formulated an evolutionary and developmental model³⁷ made of five progressive stages of bodily mimesis to study intersubjectivity is proposed; these five stages are also mapped onto a list of cognitive/communicative skills developed step-by-step during the human infancy. In this model, the cross-modal mapping is considered the beginning phase of bodily mimesis, while more advanced phases indicating the mapping between more entities – bodily movements, intentions, and recipients are included (Zlatev, 2007, 2008, 2009a). In the developed phases, especially, the understanding of symbolic relations is achieved with the acquisition of conventions and the agent can access to the grammatical relations between the symbols (Zlatev, 2007, 2008, 2009a).

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³⁷ Zlatev's model is "evolutionary" because it is formulated based on the results of the experiements on intersubjective skills that compare between human and non-human primates (Donald 1991; Tomasello 1999, 2008; Zlatev et al. 2006; Persson 2008; Paukner et al. 2009 as cited in Zlatev, 2009a). However, this angle is not addressed in this thesis; here, we focus on the developmental traits of humans.

9.2 DISTINGUISHING ONESELF FROM THE OTHERS

9.2.1 The neurophysiological basis of self-other distinction

Schizophrenia is defined as "a chronic and severe disorder that affects how a person thinks, feels, and acts" ("Schizophrenia," 2016). It is characterized by positive symptoms such as hallucinations, delusions, thought disorders, and movement disorders; as well as negative symptoms such as reduced expression of emotions, reduced feelings of pleasure, difficulty beginning and sustaining activities, and reduced speaking; as well as cognitive symptoms such as poor executive functioning, trouble of focusing or paying attention, and problems with working memory³⁸ ("Schizophrenia," 2016). Van der Weiden, Prikken, and van Haren (2015) noted in recent literature that schizophrenia patients often experience difficulties in distinguishing the feelings, intentions, and actions of their own from those of others, which may explain some of the symptoms of the disease (Amminger et al., 2012; An et al., 2010; Parnas et al., 2011, 2014; Thompson et al., 2013, 2012; Nelson et al., 2012 as cited in van der Weiden, Prikken, & van Haren, 2015).

For healthy people, it seems to be instinctive for them to understand the thoughts, feelings, and intentions of others while distinguishing those from the ones of their own (van der Weiden et al., 2015). More than 20 years ago, the discovery of mirror neurons offers an explanation for this phenomenon (Kilner &

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³⁸ "Positive' symptoms are psychotic behaviors not generally seen in healthy people"; " 'negative' symptoms are are associated with disruptions to normal emotions and behaviors"; executive functioning is "the ability to understand information and use it to make decisions"; working memory is "the ability to use information immediately after learning it" ("Schizophrenia," 2016).

Lemon, 2013). First reported in the macaque monkeys' ventral premotor area F5, they are a class of neurons that fire both when an individual executes a specific motor act and when the individual observes the same or similar act performed by another individual (Kilner & Lemon, 2013). Based on research findings (Bonini et al., 2013; Ocampo and Kritikos, 2011; Urgesi et al., 2010; Carr et al., 2003; Iacoboni, 2009; Rizzolatti & Craighero, 2005 as cited in van der Weiden, Prikken, & van Haren, 2015), van der Weiden, Prikken, and van Haren have highlighted some characteristics of the mechanism: (1) The responsiveness of mirror neurons is goaloriented: they are equally activated for different actions sharing the same goal, but differently activated for identical actions with different goals. (2) The activation of mirror neurons is more pronounced when an individual is observing incomplete actions rather than when the actions are already completed. More precisely, the observation of on-going actions allows the individual to predict the outcome of the actions. (3) Mirror neurons are activated not only by actions that are physically evident but also by facial expressions that are subtle during social interactions. In conclusion, mirror neurons enable people to simulate and understand the emotions of others, as well as anticipate their consequences.

On one hand, mirror neurons allow an individual to integrate the behaviors (both actions and emotions) of others; on the other hand, they are also responsible for distinguishing the behaviors initiated by others from those of one's own. It is shown that mirror neurons display patterns of inhibition during the observation of actions, while they display patterns of excitation during the execution of actions (Mukamelet al., 2010 as cited in van der Weiden, Prikken, & van Haren, 2015). The functioning of mirror neurons is shown to be weakened for both the observation and the execution of actions in schizophrenic patients (Mehta et al., 2014 as cited in van der Weiden, Prikken, & van Haren, 2015); also, the differentiation of the activity of mirror neurons is impaired (Jardri et al., 2011; McCormick et al., 2012;
Thakkar et al., 2014 as cited in van der Weiden, Prikken, & van Haren, 2015). Thus, patients have more difficulties in distinguishing self-initiated actions from the other-initiated ones.

The brain can predict the sensory consequences of well-practiced actions: when the motor system sends its command, an internal copy of the signal is made (i.e. an efference copy) to be compared with the sensory consequences the actual movement; as the internal predictions are constantly updated by feedbacks, humans can accurately control and regulate their actions (Wolpert & Flanagan, 2001). Van der Weiden, Prikken, and van Haren (2015) believe that motor prediction is involved in self-other distinction while studying two mechanisms in detail: (1) sensory attenuation and (2) temporal binding.

Usually, healthy people can accurately predict the sensory consequences of their actions – they have already lived the experience before the initiation of the actions, therefore, the feeling of the actual experience is attenuated (van der Weiden et al., 2015). Comparatively, as people are more able to give an accurate prediction to the actions of themselves than to the action of others, the sensory consequences of self-produced actions feel less intense than those of other-produced actions (van der Weiden et al., 2015). The mechanism of sensory attenuation explains why people cannot tickle themselves (Blakemore, Wolpert, & Frith, 2000). For schizophrenic patients, it is shown in recent research that their motor systems generate damaged efference copies which lead to less motor activation before self-produced actions and increased sensory activation of their outcomes (Bender et al., 2012; Ford et al., 2014, 2008 as cited in van der Weiden, Prikken, & van Haren, 2015). In other words, the sensory consequences of self-produced actions are less anticipated and less attenuated, making it difficult to distinguish them from those of other-produced actions.



The feedback on the outcomes of people's actions are multisensory signals – visual, auditory, tactile, and olfactory - and they are all processed by the brain; it takes longer for some signals to reach the brain compared to others: for example, feeling a toe being touched takes longer than seeing the touching (van der Weiden et al., 2015, p. 227). It is suggested that although signals arrive at different times, the brain waits for the arrival of the slowest one before integrating all of them, so that actions happening at the same time are perceived in a coherent way; the waiting time is called "temporal binding window" (Colonius & Diederich, 2004 as cited in van der Weiden, Prikken, & van Haren, 2015, p. 227). For humans, as they grow up, their brains are trained to correlate perceived signals to actions and learn the intervals between the perceptions; in this way, the temporal binding window narrows and the prediction of their action outcomes becomes more and more accurate (Lewkowicz & Flom, 2014; Hillock-Dunn & Wallace, 2012 as cited in van der Weiden, Prikken, & van Haren, 2015). It is explained that when actions are simultaneously initiated by a person and others, in a social situation, for instance, the perception of the action outcomes of his own is more likely to fit in the trained temporal binding window, compared to the perception of action outcomes of the others (van der Weiden et al., 2015). Hence, the person becomes aware of his own actions as they are accurately predicted. It is shown by experimental results that the temporal binding window of schizophrenic patients is greater than the one of the healthy people; thus, more noises - the outcomes of events that are beyond the patients' control - are let in and integrated with the outcomes of their own actions, resulting in an over-attribution of agency (Haggard et al., 2003; Voss et al., 2010 as cited in van der Weiden, Prikken, & van Haren, 2015). It is also indicated in one study that the temporal binding window of schizophrenic patients does not narrow as the likelihood of action outcomes increases (Voss et al., 2010 as cited in van der Weiden, Prikken, & van Haren, 2015). This separation between



anticipation and perception could be responsible for the experiences of delusions and hallucinations.

9.2.2 The role of cognitive expectations in the attribution of agency

Van der Weiden, Prikken, and van Haren (2015) suggested that besides the mechanisms of motor prediction, cognitive expectations also play an important role in attributing the outcomes of actions. When the actual outcome of an action matches people's expectations they had in mind, they tend to believe that they are the initiator of the action (van der Weiden et al., 2015). Cognitive expectations are, in fact, especially valuable in complicated social situations when motor predictions are less reliable – when self-produced actions lead to many outcomes in the form of multisensory signals or when there are other people producing all types of action outcomes (van der Weiden et al., 2015). For schizophrenic patients, as their mechanisms for motor predictions are impaired, it is presumed that they may be more dependent on cognitive inferences in attributing action outcomes, which also means that they are more likely to be misled by biases (van der Weiden et al., 2015).

Van der Weiden, Prikken, and van Haren (2015) further suggested that cognitive expectations which are influential in agency attribution can be classified into explicit and implicit ones. Explicit expectations can be understood as goals to reach, while implicit ones are characterized as "subtle environmental cues that carry information about the outcomes of our actions outside of conscious awareness)" (van der Weiden et al., 2015, p. 230). Usually, in experimental settings, implicit expectations are presented as masked stimuli that are effective on



behaviors but "unseen" by conscious awareness – subliminal primes (Jaśkowski & Verleger, 2007). In an experiment called "Wheel of Fortune Task" (van der Weiden et al., 2013; van der Weiden et al., 2013)³⁹, the roles of explicit and implicit expectations in agency attribution are shown:

In the experiment (Figure 9.1), the participants are asked to visually follow a gray square that is moving along a rectangular path consisting of eight white squares. At the same time, another gray square, controlled by the computer, is moving in the opposite direction at the same speed. When a stop cue appears, the participants are asked to press a stop button which will stop the movement of both squares. It appears that the moment that they press the stop button determines on which locations the gray squares would stop. But in fact, they are decided by the computer, meaning that the motor predictions of the participants are always inaccurate. Also, the participants only get to see the stop location of one of the squares (marked in black), so that the outcome becomes even less informative on the action that causes it. After each test, the participants are asked to rate the extent to which they feel that they caused the stopping of the square at the presented location.

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³⁹ The process of the experiment (van der Weiden et al., 2013, para. 6-7; van der Weiden et al., 2013, p. 895) is rephrased and presented in the paragraph in block format below.



Figure 9.1 The "Wheel of fortune" Task. The squares move in opposite directions and the participant is asked to press the Stop button when a cue appears. Adapted from "On the inference of personal authorship: Enhancing experienced agency by priming effect information", by H. Aarts, R. Custers, & D. M. Wegner, 2005, *Consciousness and cognition*, 14(3), p. 444. Copyright 2004 by Elsevier Inc. Adapted with permission.⁴⁰

In order to distinguish the experiences of self-agency influenced by explicit and implicit expectations, the experiment has a special design: half of the participants are given the explicit goal to stop their square at a specific location beforehand, whereas the other half are primed with that location very briefly before they stop the movement (van der Weiden et al., 2013; van der Weiden et al., 2013). Although the presented stop location of the square may or may not match the goal or the prime, it is shown in the experiment that, generally, the experience of self-agency increases when there is a match between the actual outcome and the explicit goal or the implicit prime, and vice versa (van der Weiden et al., 2013; van der Weiden et al., 2013).

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⁴⁰ The figure is cited and adapted in van der Weiden, Aarts, & Ruys (2013), p. 895.

In a version of the experiment, participants are asked to rate the experiences of self-agency not only over matching results but also over mismatching ones (van der Weiden et al., 2013). The mismatches are controlled as the distance between the outcomes and the goals/primes are set to be, systematically, from 1 to 4 square(s). It is shown that the experience of self-agency drastically decreases when there is a mismatch between the outcome and the preset goal, regardless of the variation of the distance between them (van der Weiden et al., 2013). However, when mismatches between the outcome and the prime occur, the experience of self-agency decreases gradually as the distance to the primed location increases (van der Weiden et al., 2013).

Despite that both goals and primes can enhance the experience of self-agency, van der Weiden, Ruys, and Aarts (2013) believe that differences do exist between them. With goals bore in mind, people's attention is focused on the specific outcomes represented by the goals and this attention is resilient to interference; in this manner, the experience of self-agency increases with the explicitness of a goal (van der Weiden et al., 2013). At the same time, goals are used as references for the detection of errors in the process of goal achievement; in other words, not only matches but also mismatches between the action outcomes and the expectations can impact on the experience of self-agency – consequently, it is strengthened in the feedback control (van der Weiden et al., 2013). On the other hand, having primes does not require monitoring or control in the achievement of a specific type of outcome (van der Weiden et al., 2013). Mismatches, if detected, are therefore "less informative or diagnostic to rely on" in the attribution of agency (van der Weiden, Ruys, & Aarts, 2013, para. 9).

Nevertheless, van der Weiden, Ruys, and Aarts (2013) noted that primes on action outcomes can play a significant role in solving problems in real life thanks to their flexibility. Priming an outcome can activate the representations of other outcomes associated with the first one. For example, when the concept of "apple" is primed, associated concepts such as "pear", "orange", "banana", etc. are also subliminally advised (van der Weiden, Ruys, & Aarts, 2013, para. 9). In 1.3.1.2, the adaptive advantage of this flexibility has been discussed where self-maintenance is defined as "a general type of objective" which can be achieved via different methods (Alexander, 2013, para. 8). Also in 3.3.1.2, misinterpretations are believed to be beneficial to the organism's self-maintenance in long terms (Robinson & Southgate, 2010). Indeed, when an apple is not available, a pear is as good as the apple in providing the energy needed for an organism's survival.

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9.3 EMBODIED COGNITION AND LANGUAGE DEVELOPMENT

9.3.1 Understanding intersubjectivity: theory theory, simulation theory and theory of embodied cognition

Self-other integration and distinction are parts of the capacities of intersubjectivity⁴¹, which is generally defined by Zlatev as "the sharing and/or understanding of others' experiences" (Zlatev, 2007, para. 2). Zlatev (2007) specified that intersubjectivity includes not only "propositional attitudes" such as beliefs, but also many rather spontaneous reactions such as emotions, attentional states, and intentions (para. 2). In this section, we present two approaches on "How is intersubjectivity achieved?" – theory of mind⁴² and embodied cognition.

It appears that the most widely held view in theory of mind is the one that is called "theory theory" which is used to explain children's cognitive development by the analogy of forming scientific theories (Gordon, 1999). According to the theory theory, since an early age, theories are intuitively developed for children to explain, interpret and predict the experiences and the behaviors of themselves and others (Gordon, 1999). These theories are like scientific theories that consist of

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⁴¹ "Human intersubectivity manifests itself as an immediate sympathetic awareness of feelings and conscious, purposeful intelligence in others. It is transmitted by body movements (especially of face, vocal tract, and hands) that are adapted to give instantaneous visual, auditory, or tactile information about purposes, interests, and emotions and symbolic ideas active in subjects' minds. On it depends cultural learning, and the creation of a 'social reality,' of conventional beliefs, languages, rituals, and technologies." (Trevarthen, 1999, pp. 415–416).

⁴² "Theory of mind" is referred to as the branch of cognitive science that concerns people's understanding of the minds of themselves and others (Gopnik, 1999). Several underlying mechanisms have been proposed over the past 30 years and many of the researches have been about the development of children's understanding of the mind (Gopnik, 1999).

abstract entities and laws specifying their relationships; also, they are continuously updated as children gather new information and learn new facts (Gordon, 1999). It is shown in experiments that children develop an understanding of the mind around the age of four ((Baron-Cohen, 1995; Leslie, 1991 as cited in Gallagher, 2001).

Another theory – "simulation theory" has also been largely endorsed, arguing that humans can use their own minds to simulate and to understand the experiences and the behaviors of others (Gordon, 1999). The term "simulation" is interpreted differently – it is referred to as the method of "putting oneself in the other's place"; or on the contrary, the approach that postulates a "shared world of facts and emotive and motivational charges" where role-taking is not necessary (i.e. "the default mode of simulation"); and sometimes, the mechanism behind automatic responses such as mimicry of facial expressions and bodily movements (Gordon, 1999, p. 765). Indeed, supporting the basic tenet of the simulation theory, the discovery of mirror neurons has provided an especially significant explanation on people's understandings of other-produced actions and emotions (see 9.1).

However, Gallagher (2000, 2001, 2008) suggested that neither theories nor simulations are enough for people to understand each other. His arguments are consistent with the findings (van der Weiden et al., 2015) on the characteristics of the motor system: First, a well-functioning simulation mechanism should be the result of training. The temporal binding window, for example, narrows when the experience of action-perception accumulates over the years, yielding a more accurate prediction of self-produced action outcomes. In complicated social situations, then, motor simulation alone is not enough to elicit solid explanations on people's behaviors; the observer needs to rely on cognitive expectations or beliefs – the theories that he has on people's mind, including social rules. Van der



Weiden, Prikken, and van Haren (2015) gave some examples: (1) Someone is laughing with other people, but it is questionable if the people are laughing with him or at him; (2) Someone who just won the lottery is crying, but of course, not out of sadness; (3) Lies, sarcasm that lead to facial expressions and body movements do not match the usual content of the message. Furthermore, Gallagher (2001) brought up an interesting question: Is it possible for people to understand others before the formation of theories and the attuning of simulation systems? In other words, what is the primary way in which newborn humans relate to, interact with and understand others?

Gallagher (2001)suggested that "pre-theoretical capabilities for understanding others" already exist in newborns because they can access to practices of an embodied cognition 43 which is "emotional, sensory-motor, perceptual and non-conceptual" (p. 85). Based on experiment findings, children before the age of three can already experience the environment as a subject - they are able to distinguish self from non-self, and at the same time, they understand the similarities shared between themselves and other people (Bermúdez, 1996; Gallagher, 1996; Gallagher & Meltzoff, 1996 as cited in Gallagher, 2001). Also, even infants can respond to human faces in a way that is distinguished from how they respond to inanimate objects, indicating an ability of subject-object distinction (Legerstee, 1991; Johnson, 2000; Johnson et al., 1998 as cited in Gallagher, 2001).

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⁴³ According to the embodiment thesis (the general characterization of embodied cognition): "Many features of cognition are embodied in that they are deeply dependent upon characteristics of the physical body of an agent, such that the agent's beyond-the-brain body plays a significant causal role, or a physically constitutive role, in that agent's cognitive processing." (Wilson & Foglia, 2017).

Gallagher (2001) defined the embodied way of understanding the mind from two perspectives which respectively address its relationships to simulation theory and theory theory.

First, it is believed that human infants are born with the ability to establish a cross-modal connection between the visually perceived motions of others and their own kinesthetic sensations (Meltzoff & Moore, 1977; 1994 as cited in Gallagher, 2001). In other words, there is an innate mechanism for infants to bodily simulate the behaviors of others. Because all humans generally share the same anatomy, their actions are "coded in the same 'language'" (Gallagher, 2001, p. 87). Gallagher (2000) has argued that proprioception and vision are intermodally connected, making neonate imitation possible: for example, vestibular structures that can respond to somatosensory and optokinetic stimuli, integrate information of head motion and orientation, as well as contribute to self-awareness are mature at birth (Guldin, Akbarian, & Grüsser, 1992; Jouen & Gapenne, 1995 as cited in Gallagher, 2000); therefore, what infant sees can be translated into a proprioceptive awareness of his own body parts which allow him to move accordingly.

Then, it appears that there is no need for infants to consult an internal representation, a theory, to understand the actions of others because they already have a direct and pragmatic visual model – the perceived embodied actions, which are mapped onto their own sensory experiences (Gallagher, 2001). Although the "intermodal and intersubjective mapping" cannot be counted as a theory, it may represent the initial phase in the development of cognitive expectations and beliefs (Gallagher, 2001, p. 87). It is shown in experiments that with the help of mirror neurons, infants form a plan of their actions and recognize the relationship between their plan and the actions of others (Gopnik & Meltzoff,



1997 as cited in Gallagher, 2001). Earlier, Gallagher and Meltzoff (1996) have made the distinction between body schema and body image: the first is a system of motor capacities, abilities and habits that can function without perceptual monitoring (thus consciousness), while the second is a system made of the perceptions, attitudes, and beliefs of one's own body. Gallagher and Meltzoff (1996) suggested that both systems are usually involved in the coordination of bodily movements – for example, in a basketball game, a person jumps up and catches the ball, the movements of his body are coordinated by the functioning of the body schema; at the same time, the body image focuses the person's attention on the relative position between himself and the ball.

Furthermore, by examining two mechanisms proposed by Baron-Cohen – the intentionality detector and the eye-direction detector, Gallagher argued that while a mapping relation between the actions of others and the sensory experiences generated by one's own motor system is established, the intentions behind are also understood in an embodied manner (Baron-Cohen, 1995 as cited in Gallagher, 2001).

Named by Baron-Cohen, the intentionality detector is referred to as an innate ability that allows infants to understand other people's intentions by their bodily movements (Baron-Cohen, 1995 as cited in Gallagher, 2001). For example, it has been shown that eighteen-month-old infants can complete the goal-oriented actions that other people have not completed (Meltzoff, 1995 as cited in Gallagher, 2001). Gallagher (2001) emphasized that this ability of interpreting intentions is non-mentalistic because the intentions are naturally incorporated in the bodily movements – "another's intentional state is simply the other's action or the state of a perceived body" (p. 88); that is, people usually understand their own actions in the most pragmatic way regarding the goal that they want to achieve with.



Gallagher (2001) explained that, for example, the underlying intention for someone reaching for a cup, normally, should be to take a drink, not simply to get the cup - this intention is bodily evident when people watch the person's whole series of actions – getting the cup, filling water in it, and drinking water with it (p. 88). In fact, taking a drink can be distinguished as an explicit goal, from getting the cup as an implicit one; the main difference between explicit and implicit goals is that the former cannot be replaced by something else while the latter can (Gallagher, 2001). For example, drinking cannot be replaced by eating, but a cup can be replaced by a bowl. Similar conclusions are drawn when analyzing explicit and implicit expectations in a "Wheel of Fortune" task (see 9.2.2): an explicit expectation functions as a reference that demands focus and does not tolerate deviations; an implicit expectation, on the other hand, can activate associated concepts and make goal achieving behaviors more flexible (van der Weiden, Ruys, & Aarts, 2013, para. 9). In this sense, a goal is explicit because it is bodily responsive to humans; comparatively, to realize an implicit goal, it may require theoretical learnings.

The second mechanism proposed by Baron-Cohen is called "eye-direction detector" which specifically enables infants to track another person's movements of eyes and face (Baron-Cohen as cited in Gallagher, 2001, p. 89). Necessarily, for the infants to understand the bodily intention of the other person – what the observed person wants to do something, they must be able to see the person's action of looking and the target of the looking – thus to establish relationships between two subjects, as well as between a subject and an object (Gallagher, 2001). The phenomenon is termed as "shared attention" (p. 89) and shown to be present among infants around nine to fourteen months-old: an infant can switch between monitoring the gaze of the other person and the target of the same thing; moreover,



around the same age, infants can point with their fingers, interacting with, instead of observing others, in order to be more productive in understanding others' intentions (Baron-Cohen, 1995 as cited in Gallagher, 2001). In 7.3.1.4, it is suggested that an individual agent gains the experience to be a subject by seeing himself – his body – as an object from the perspective of other agents (Järvilehto, 2000). Based on the learning of the embodied mechanisms in understanding the mind, it appears that the bodily explorations while interacting with others can be a major source of the awareness of oneself and the rest of the world.

9.3.2 Bodily mimesis, a developmental model of intersubjectivity, and the acquisition of language

According to the embodied approach to the theory of mind, from the very beginning of life, humans can interact with others and understand their intentions based on an innate "language" coded in facial expressions and bodily movements (Gallagher, 2000, 2001, 2008). In other words, without the help of an internal model, the actions of another person can be interpreted by infants into a meaningful message consisting of subjects (You and I), objects, and goals. Evidently, this message is different from the messages produced by a symbolic language, the one that is usually used by older children and adults in a society for communication and representation. A question, then, arises: What is the relation between the two types of language? Focusing on the skills of bodily mimesis in an evolutionary and developmental model of intersubjectivity, Zlatev (2007, 2008, 2009a, 2014) suggested that humans' acquisition of language – a symbol-based and conventional system – may have an embodied basis.



In 5.2.1, by presenting the stages in a cycle of metasystem transition, a transition from self-referential reality to other-referential reality is portrayed as the necessary condition for individual agents to interact with each other inside one single system (Karatay & Denizhan, 2005). It is suggested, more precisely, that by mapping one's own subjective cognitive activities to those of other agents, an agent gains a more "objective" view of itself and the whole system (Karatay & Denizhan, 2005). Eventually, fluent interactions between the agents are ensured by a conventional code that is used to specify the intersubjective mapping relations. Zlatev (2008) defined intersubjectivity as "the sharing of affective, perceptual and reflective experiences between two or more subjects" (para. 1) and emphasized that this "sharing" can exist in different forms – "Intersubjectivity is not a unitary capacity." (para. 2). Some of the forms are immediate and intuitive, such as emotions and body movements; some others require the access to a more complicated system of code which is responsible for beliefs and other propositionlike entities, such as human languages (Zlatev, 2008). More importantly, Zlatev's theories provide explanations on the connections between these different forms of intersubjective activities. Zlatev (2007, 2008) suggested that no matter it is for an individual organism or a species of organisms, the development of intersubjectivity takes place in a stage-by-stage way; that is, complex forms of intersubjective activities should be built based on the simpler ones.

Referred to as mimetic skills, Merlin Donald (1991) suggested human beings can produce "conscious, self-initiated, representational acts that are intentional but not linguistic" (p. 168). Donald (1991) emphasized that mimesis is different from imitation and mimicry which are observed in monkeys and apes because the former requires the ability to create intentional representations. This ability, which



depends on the use of bodily movements⁴⁴, in fact, plays an important role in the human society as it is involved in learning, rehearsal, imagination, and planning, as well as gestural communication (Donald, 1991). Zlatev (2007, 2008) used the term of bodily mimesis to illustrate intersubjective activities more concretely. Nevertheless, Zlatev's interpretation of bodily mimesis is different, mainly because his point of view is a developmental one. He believes that the initial phase of bodily mimesis reflects an innate ability to imitate which is not fully controlled by the consciousness and does not require the comprehension of representations; the advanced phase of bodily mimesis, however, should include the ability of using symbolic languages (Zlatev, 2007, 2008, 2009a, 2014).

It has been shown that infants can successfully imitate the facial gestures of adults (Figure 9.2) (Meltzoff, 1999)⁴⁵. As previously presented, the findings on infant imitative behaviors suggest an intermodal mapping between the perception and the production of actions, which is also physiologically supported by the discovery of related brain structures (Gallagher, 2000, 2001). Through the imitations of bodily movements, vocalizations, and other goal-oriented behaviors, infants enter isomorphic relations with other humans; by these relations, they can experience and learn the associations between certain actions and the "concomitant internal states" – proprioception, emotion, intention, etc. (Meltzoff, 1999, p. 390). Therefore, it is suggested that infant imitation may lay the groundwork for their development of theories on other people's mind (Meltzoff, 1999). Imitation plays an important role in many cognitive and socio-cultural

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⁴⁴ According to Donald (1991), bodily movements include "tones of voice, facial expressions, eye movements, manual signs and gestures, postural attitudes, patterned whole-body movements of various sorts, and long sequences of these elements can express many aspects of the perceived world" (p. 169).
⁴⁵ In an experiment, it is shown that neonate imitation is performed by infant as young as forty-two minutes old (Meltzoff & Moore, 1983 as cited in Meltzoff, 1999, p. 389).

functions. For example, it is believed that infants imitate other people's behaviors to distinguish them one from another and to recognize them in the future (Meltzoff & Moore, 1998 as cited in Meltzoff, 1999, p. 390). Also, infants' vocal imitation is considered to be the key to learning phonetics and the prosody of their native language (Kuhl & Meltzoff 1996 as cited in Meltzoff, 1999, p. 390). Thanks to imitation, humans can pass their learned abilities from generation to generation.



Figure 9.2 Neonatal Imitation. The photographs show that infants around two to three weeks can imitate the facial expressions of an adult. Reprinted from "Imitation of Facial and Manual Gestures by Human Neonates", by A. N. Meltzoff & M. K. Moore, 1977, *Consciousness and cognition, Science, 198*(4312), p. 75. Copyright 1977 by the American Association for the Advancement of Science. Reprinted with permission.⁴⁶

Based on the results from recent studies on mimetic behaviors of both humans and non-human primates, Zlatev elaborated a detailed definition of bodily mimesis (Zlatev, Persson & Gärdenfors, 2005a as cited in (Zlatev, 2008).

A particular bodily act of cognition or communication is an act of bodily mimesis if and only if: (a) It involves a cross-modal mapping between

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⁴⁶ The figure is cited in Meltzoff, 1999, p. 389.

exteroception (i.e. perception of the environment, normally dominated by vision) and proprioception (perception of one's own body, normally through kinesthetic sense); (b) It is under conscious control and corresponds to – either iconically or indexically – to some action, object or event, while at the same time being differentiated from it by the subject; (c) The subject intends the act to stand for some action, object or event for an addressee (and for the addressee to recognize this intention); (d) Without the act being conventional-normative, and (e) Without the act dividing (semi)compositionally into meaningful sub-acts that systematically relate to each other and other similar acts. (Zlatev, 2008, para. 3)

This definition is, in fact, a hierarchy of semiotic capacities that are progressively attained. More precisely, the capacities described in (b), (c), the opposite situation of (d), and the opposite situation of (e) are related to Peirce's classification of signs based on how their object functioned in signification (see 1.3.1.1). According to Peirce, the nature of the object constrains the nature of the sign; these constraints are divided into three classes: qualitative, existential or physical, and conventional or law-like (Atkin, 2013). If the sign reflects qualitative features of the object, then it is an icon; if there are some existential or physical connections between the sign and the object, then the sign is an index; if the connection between the sign and the object is determined by conventions, laws, or social rules, then the sign is a symbol (Atkin, 2013). By definition, the significations of icons and indexes, compared to the significations of symbols, are more direct to access on the physical level; the latter necessarily requires the possession of some abstract forms of knowledge - internal models, theories, etc. Elsewhere, Zlatev (2002) has classified four types of meaning systems of perception/social interaction: cue-based, associational, mimetic and symbolic. He specified that the first two rely on the physical features involved and the last one requires the use of



conventions (Zlatev, 2002). Therefore, it appears that mimetic meaning can be a transitional stage in between.

Accordingly, semiotic capacities of different natures are distinguished in Zlatev's developmental model as five stages of bodily mimesis (Zlatev, 2008).

The first stage of bodily mimesis is called "proto-mimesis (only (a))" and characterized by the establishment of a cross-modal mapping between one's own motor sensations and the perceived movements of others (Zlatev, 2008, p. 4). Proto-mimesis, shown to be present since birth (thus without full conscious control), acts as the basis for intersubjectivity (Zlatev, 2008).

The second stage, "dyadic mimesis ((a) and (b))", reflects the ability of understanding representations, although these representations are coded in a bodily "language" – the movements of body, which is an immediate and pragmatic way to access to the content – intentions (Zlatev, 2008, para. 4). More specifically, this is the ability to distinguish between signifier and signified, under the condition that the sign system is based on physical qualities, not abstract conventions. Two examples are given by Zlatev: (1) An infant opens and closes her mouth to imitate the opening and the closing of a matchbox (the ability to use icons); (2) Children point with their fingers to help to guide their attention (the ability to use indexes) (Zlatev, 2008, para. 4).

The third stage, named "triadic mimesis ((a), (b), and (c))", is different from "dyadic mimesis" on that it involves adding a new element – the purpose of communication (Zlatev, 2008, para. 4). The sign is made to be recognized by a specific recipient; the message carries both the represented intention and the communicative intention (Zlatev, 2008). In this case, a truly shared attention is

created between an individual and others; this individual, therefore, can gain a third-person point of view in understanding his own behaviors (Zlatev, 2008).

The fourth and the fifth stage of bodily mimesis are respectively named as "post-mimesis 1 ((a), (b), (c), and the opposite situation of (d))" and "post-mimesis 2 ((a), (b), (c), the opposite situation of (d), and the opposite situation of (e))" (Zlatev, 2008, para. 5). The added element that distinguishes "triadic mimesis" from "post-mimesis 1" specifies that signs used in the communications should be created based on a set of rules commonly known by the participants, and susceptible to corrections when deviated (Zlatev, 2008). It is argued that convention and normativity give rise to the formation of beliefs (shared by a group of people, or in a society) because they are, in fact, propositional representations "actively held to be true" (Zlatev, 2008, para. 14). The opposite situation of (e) indicating the use of a symbol-based grammar marks the genuine acquisition of human language: inside a grammatical structure, symbols are connected to meanings while opposing to each other (Zlatev, 2008). It is suggested in 2.3.2.2 that compositions and oppositions between symbols are used to create an incredibly large number of signs to match, if possible, all meanings that can come to the human mind ("quantitative shift") (Neuman & Nave, 2008). By using the same system for communication and representation of one's thought, humans excel in cognitive activities such as logical reasoning, inference, and long-term planning (Zlatev, 2008).

Zlatev (2008) classified the five stages of bodily mimesis are also classified based on the periods in humans' ontogenetic development of cognitive/communicative skills (Figure 9.3).



	STAGES	NOVEL CAPACITY	COGNITIVE/COMMUNIC ATIVE SKILLS
1	Proto-mimesis	Mapping between exteroception and proprioception	 Emotional and attentional contagion Neonatal imitation Mutual gaze
2	Dyadic mimesis	Volition and representation	ImitationImperative pointingShared attention
3	Triadic mimesis	Communicative signs	Declarative pointingIconic gestures(Full) joint attention
4	Protolanguage	Conventionality/norm ativity	One-word utterancesHolophrases
5	Language	Semiotic systematicity	- Spoken or signed language

Figure 9.3 The Developmental Stages of Mimesis. There are five stages in the development of children's cognitive/communicative skills. Adapted from "From proto-mimesis to language: Evidence from primatology and social neuroscience", by J. Zlatev, 2008, *Journal of Physiology-Paris*, 102(1), p. 139. Copyright 2008 by Elsevier Ltd. Adapted with permission.

Proto-mimetic skills are present among human infants around eight-monthsold (Barresi & Moore, 2008; Meltzoff & Moore, 1977; Trevarthen, 1979 as cited in Zlatev, 2009, para. 14). By mapping the behaviors of others (adult caregivers, usually) onto their own bodies, infants can experience not only the physical but also the socio-cultural aspects of the world; they can distinguish between people and inanimate objects, and they start to learn the connections between events and emotions (Zlatev, 2008, 2009a). Especially, it is shown that when parent-newborn interactions are disrupted, frustration is felt by the infant, indicating that emotions can be perceived directly – without the help of inferences or representational states (Trevarthen, 1992 as cited in Zlatev, 2008, para. 7). At this moment, the mimetic activities of infants take place without a fully conscious control – generally, the infants are still in lack of self-awareness and the ability to understand representations (Zlatev, 2008, 2009a). However, it is suggested that there may be some sprouts in the comprehension of dyadic relationships (between You and me) – "eye-contact, intense smiling, coyness, 'calling' vocalizations, showing-off, etc." (Reddy, 2003 as cited in Zlatev, 2008, para. 7). On the other hand, studies on autistic children show that they have difficulties in having attentional engagement with others (Reddy, 2005 as cited in Zlatev, 2008, para. 7).

Infants are callable of dyadic mimetic activities around 9-month-old (Trevarthen & Hubley, 1978; Kaye, 1982; Tomasello, 1999 as cited in Zlatev, 2009, para. 14). By the time, the infants have already gained self-awareness and can distinguish themselves from others – thus, they are able to realize the lack of direct control over the bodies of others, as well as the necessity to communicate what is not known by others (Zlatev, 2009a). The period of ontogenetic development is characterized by the increase of the use of icons and indexes on a bodily level: not only do infants imitate, they also use their body to signify something else (Zlatev, 2009a). Imperative pointing is observed among infants in this range of age; but it does not mean that the infants are able to understand triadic relationships (between You, I and an object), because the underlying meaning of the gesture as a sign is not necessarily understood by the recipient (Bates, Camaioni, & Volterra, 1975 as cited in Zlatev, 2009, para. 15). In this case, although the attention is shared between infants and others, the meaning is not.

The capabilities of engaging triadic mimesis appear among infants aged around 14 months (Bates, 1979; Liszkowski et al., 2004; Blake et al., 2003 as cited in Zlatev, 2009, para. 14). Intersubjective activities between the infants in this age range and other people involve three elements – an infant's mimetic behavior, meaning, and the recipient of the meaning – thus can be qualified as instances of communication (Zlatev, 2009a). Infants in this age range can point declaratively,



which is distinguished from imperative pointing on that the hand is used as an iconic sign to draw the attention of a recipient to an intended direction so that it is more likely for the infant and the recipient to share the same meaning (Zlatev, 2009, para. 15). Therefore, dyadic mimesis postulates the ability to see infants themselves from the perspective of other people, as the object of their attention, which indicates a third-person point of view.

The stage of protolanguage is characterized by the ability observed among infants around 20 months-old of using gestural or/and spoken signs that are known to both the senders and the recipients (Bates, 2003 as cited in Zlatev, 2009, para. 14). These signs are conventional ones, meaning that the nature of signification has changed – rules instead of physical relations are used to ensure the successful conveying of meaning by signs; icons and indexes are progressively replaced by symbols (Bonvillian & Patterson, 1999 as cited in Zlatev, 2008). The transition from protolanguage to language is made possible using (syntactic) grammar. On average, children start to use a public language (studies are conducted in both spoken and signed languages) around the age of 27 months (Zlatev, 2009, para. 15). Around the age of 4, they are capable of understanding "false beliefs⁴⁷", implying the establishment of theoretical stances on people's mind (Zlatev, 2008, para. 15).

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⁴⁷ According to Gallagher (2001): "In the 'standard' false-belief task a subject is asked about the thoughts and actions of another person or character who lacks certain information that the subject has." (p. 97). For example, in a room, before someone else enters, a subject is shown with the actual content of a candy box containing – pencils, not candies; when being asked if the other person knows the content of the candy box, four-year-old children generally answer correctly – the person will think that there are candies inside the box; in contrast, three-year-old children cannot formulate the false belief of this person (Gallagher, 2001).

Zlatev (2008) suggested that the development of a theory of mind is closely connected to the development of language because: (1) With language, people gain a third-person point of view to be trained to understand others. (2) Language provides people with the possibility to build an internal model (separated from the physical world) to describe their subjective and/or hypothetical opinions. (3) As a grammatical structure, language is used for its meta-discourse functions to describe the descriptions. There can be comments to disagree, to explain, and to direct the attention of the audience to some descriptions. (4) Language is used to create "narratives" to infer logical explanations on people's behaviors (Gallagher & Hutto, 2008, pp. 26–27).

Regarding the ontological development of infants, Gallagher (2008) believes that while infants grow, non-conceptual perceptions are not replaced by the acquired language and concepts, but associate with them to eventually transform the perceptual experience. According to Zlatev (2009b), the process can be formulated as a semiotic hierarchy consisted of three thresholds: organisms as living bodies, minimal conscious selves, users of non-linguistic signs, and linguistic selves. The transition from the lower levels to the higher ones means that the cognitive reality of an organism can range from what the organism is not fully conscious of to an intelligent and cultural environment (Zlatev, 2009b). Furthermore, as the lower levels are the foundation of the higher ones, there may not be a distinct boundary between the unconscious and the conscious being.



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Conclusion

The aim of this thesis has been to discover the semiotics in biological phenomena and to determine the role of meaning in life throughout the history of the biological evolution. In its three parts, the creation of meaning, the transmission of meaning, and the sphere of meaning have been respectively discussed. It is shown that, in the living realm, physical and chemical changes are directed in a meaningful framework which contributes to the self-maintenance of organisms. We have tried to prove that the semiotic nature of life is not a metaphor, but something that concretely exists, besides the general characteristics of the quality of "being alive" based on energy, matter, and information.

As a research filed, biosemiotics is, in fact, divided into different schools. Barbieri (2009a) has concluded that there are (at least) four: physical biosemiotics by Howard Pattee and Terrence Deacon, zoosemiotics, code biosemiotics by Thomas Sebeok and Jesper Hoffmeyer, and hermeneutic biosemiotics Anton Markoš. Since each of them focus on one type of models, it is usually limited in the application to biological phenomena. Over the years, biosemioticians have worked on subjects such as the genetic information, the transition from oocyte to embryo, the immune system, signal transduction, the brain and consciousness, sensorimotor interactions, the Darwinian evolution, the ecosystem, and animal communication (including the human language) (Kalevi Kull, Emmeche, & Favareau, 2011). Works covering different areas of biosemiotics certainly bring a positive impact on the progress of the research filed, but we believe that it is also necessary to show the connections between the theories and the observations made in the biological world which can range from cellular functions to intelligent behaviors. Kull (2003) has suggested the four levels of sign systems: cellular, vegetative, animal, and linguistic. Consistent with this point of view, this thesis has a developmental structure. The content of each chapter is determined according to its position in the hierarchy of knowledge: we start from the universal traits of a biosemiotic system, then move on, step by step, to the particularities of complex behaviors which are characterized as intelligent.

Part I (The Semiotic Nature of Life) is about definitions and frameworks.

In Chapter 1 (*A Biological Definition of Sign*), two models of biosemiotic sign are presented and compared to the classic ones used in the studies of semiotics (the sign models of Saussure and Peirce). One is the code model from M. Barbieri that describes a sign as an Information-Meaning Complex – "two worlds connected by a code" (Barbieri, 2008a, 2008b, 2013b). The other model is a teleological (goal-oriented) one created by V. Alexander made of "Sign, Objective and Response" (Alexander, 2009, 2013).

In Chapter 2 (*Meaning and Life*), the theory of code semiosis is further developed and discussed by the presentation of Pattee's theory of matter-symbol complementarity (Howard H. Pattee, 2008) as well as Neuman and Nave's symbolic value system (Neuman & Nave, 2008). Pattee (2008) believes that life is distinguished from inanimate matter by its dependence on material construction controlled by coded symbolic information. The process is illustrated with the example of the three-dimensional folding of a protein which gives rise to four levels of structure. Using the language of mathematics (category theory), Neuman and Nave (2008) showed that it is not information but value (Saussure's concept of value) "flows" in a sign system based on codes. It is showed that more hypotheses



on the biological relations between DNA, RNA, and protein (besides the genetic central dogma) can be made based on their structuralist relations.

In Chapter 3 (Purpose and Life), teleological semiosis is further developed and discussed by the presentation of van Hatern's theory of modulated stochastic causation (van Hateren, 2015d) as well as Robinson and Southgate's theory on purpose and interpretation (Robinson & Southgate, 2010). Disagreeing with the materialistic, gene-centered, and deterministic view of life, van Hatern (2015d) argued that the mechanism of evolution through differential reproduction is, in fact, a combination of deterministic and stochastic causes; agency and meaning can be created as sign-based and goal-oriented regulations happen inside an organism. The theory is applied to the explanation of the passive transport of substances across the biological membrane. Robinson and Southgate (2010) modified the teleology of Short and developed upon it the definitions of purpose and interpretation. They suggested that the purpose (the goal) of self-maintenance is a general type of outcome thus can be divided into sub-goals; the goal-oriented response to the sign of an object can further be divided too (Robinson & Southgate, 2010). Finally, they showed that although a misinterpretation cannot satisfy the present goal, it can be useful in increasing the chances of survival in the long run (Robinson & Southgate, 2010). The goal-satisfying and interpretative functions of cells are illustrated with the example of passive and active membrane transport.



Part II (The Interactions between Biosemiotic Systems) is about sign interactions in which sign actions with higher levels of diversity and complexity are created.

In Chapter 4 (*The Transmission of Meaning*), the biosemiotic sign models presented in Part I are concluded into a single one – "Meaning Generator System" (Menant, 2003). Menant (2003) further suggested that meaning ("meaningful information") can also be transmitted from one system to another; the communication of meaning may enable interactions and teamwork between these systems. Menant's theories are exemplified with the mechanisms of metabolism. The process of meaning creation is put inside a functional closure with the model of "Self-Regulatory System" (De Beule & Stadler, 2014), which focuses on the abilities of error-controlled regulation. Moreover, they suggested that a self-regulatory system exists in an environment where there are other self-regulatory systems; the interactions between them give rise to the evolution of the abilities of control and regulation (De Beule & Stadler, 2014). The phenomenon is called "Metasystem Transition" and characterized by the creation of a higher level of organization (De Beule & Stadler, 2014; V. F. Turchin, 1977). The theories of De Beule and Stadler are exemplified with the catalytic activities of enzymes.

In Chapter 5 (*The Coordinative Integration between Biosemiotic Systems*), Karatay and Danizhan (2005) further developed the theory of metasystem transition as a means of enhancing control, suggesting that there are two modes of the process: cooperation and optimization. Karatay and Danizhan (2005) also suggested that as systems interact and form a new metasystem level, protocols in the form of codes are created. It is shown that in biological systems, cellular respiration made of individual steps results from metasystem transitions. The interactions between systems do not only give rise to new conventions (the syntactics), as Cariani (1989, 2015) suggested, there would also be evolutions in their semantic organizations.



He believes that the complementarity of syntactics, semantics, and pragmatics is needed for an effective and adaptive semiotic control in semiotic systems (cybernetic and biological) (Cariani, 2015). The process is exemplified with the genetic code (Cariani, 2015), and the syntactic and the semantic evolutions are illustrated with the alternative splicing of RNA.

In Chapter 6 (Goal-directed Synergetic Actions by The Use of Sign), the teamwork of subsystems in the goal of maintaining the bigger system is studied with Heylighen's theory of stigmergy (Heylighen, 2016). He defines stigmergy as an indirect, mediated mechanism of coordination between actions, in which the trace of an action left on a medium stimulates the performance of a subsequent action (Heylighen, 2016). The coordination of actions between sub-systems works in a goal-oriented (for self-maintenance) and error-controlled (with positive and negative feedback control) manner; at the same time, as tasks are distributed to subsystems based on their competence, the whole system's ability of control and regulation can grow in diversity and specificity (Heylighen, 2016). The coordination of actions between subsystems in the biological context is exemplified with the mechanisms by which intercellular signals are communicated. Furthermore, Heylighen (2006) suggested that goal-directedness is intrinsically a problem of control. Generally, there are two types of control: feedback and feedforward. He argued that feedforward control can meet an essential shortcoming of feedback control – the regulation can only occur after the appearance of errors (Heylighen, 2006). He then argued that a better form of control should be the combination of feedforward and feedback control - one for anticipation and the other for perception - which can continuously bring a positive impact on the organisms' ability to adapt their behaviors to the living environment (Heylighen, 2006). This combinatory mechanism is explained with the discussion on how the specificity of a given cell signaling pathway is achieved.

Part III (The Sphere of Meaning for Life) is the about the evolution from the semiosis-based self-regulation observed in all forms of life to human cognition.

The abilities of meaning creation and transmission are obviously related to cognition. Semiotic control implies a rudimentary form of cognition. In Chapter 7 (Cognition Examined from the Biosemiotic Perspective), the discussion on cognition has taken a "biogenic" point of view (Lyon, 2004, 2006), suggesting that human cognition with its complex traits must evolve from simpler forms since the beginning of life thus cannot be separated from its biological basis. The separation of psychology from biology is also criticized by Järvilehto in his theory "Organism-Environment System", claiming that organism and environment are inseparable and form only one unitary system (Järvilehto, 1998, 1999, 2000, 2009). With an example showing that the "cognitive" abilities of an "organism without sensory organs", Järvilehto (1999) argued that environment is not something passively surrounding the organism, but an active part of the system leading to the results of behavior. The theory is further illustrated with the example of immune responses, which is resulted from the interactions between antigens and receptors - namely, between the environment and the organism. Moreover, Järvilehto (2000) suggested that consciousness results from the cooperative organizations between individual organism-environment systems in order to achieve common goals - when "I" exists there must also be a "you"; "I" may be defined only in relation to somebody else. Two types of immune responses (humoral and the cellular) are presented in the explanation on how their interplays give rise to the definition of immune identity (selfhood) - an organism's ability to distinguish its own cells from the foreign ones.

In Chapter 8 (Anticipation and Learning), the focus of the study is placed on the functions of anticipation and learning happening within the organismenvironment continuum. First, with Magnani and Bardone's theory of cognitive niche construction, the mechanisms by which organisms seek, select, stabilize even create chances for (survival-related) actions while interacting with the environment are explained (Magnani & Bardone, 2008, 2010). Chances are seen as signs: they specify which actions can be performed under which condition. The process is regulated by interconnected loops of feedback and feedforward control (Del Giudice, 2015), which is further exemplified in the biological context with the homeostasis of blood glucose (Suh, Paik, & Jacobs, 2007). Then, by explaining the motivational mechanism of behaviors based on the central nervous system (brain and spinal cord), Spruijt, Van den Bos, and Pijlman (2001) proposed an economic view on the selection of chances that lead to the actions that yield preferable costbenefit ratios: before any action takes place, it is weighed with others according to their possible effects on the self-maintenance of the organism. Such evaluation is made possible by connecting the actions with a common value – emotion (Spruijt et al., 2001).

An individual is a part of the cooperative organization with the others; at the same time, the body sets the point of view of an individual to the world – it defines the personal participation in the achievement of common results and the personal use of these results in its own action. In Chapter 9 (*Human Consciousness*), van der Weiden, Prikken, and van Haren (2015) explained the neural and the cognitive mechanisms for the distinction of other people's thoughts, emotions, and actions from one's own: the former relies mainly on mirror neurons and the motor system while the latter is based on social conventions and personal beliefs. The presentation of both mechanisms is made with comparisons between schizophrenic patients, people whose self-other distinction functioning is impaired, and healthy controls (van der Weiden et al., 2015). Then, the inquiry on human consciousness moves on to how people understand each other (i.e. the theory of



mind). Three main theories are being examined – theory theory, simulation theory and embodied cognition (Gallagher, 2000, 2001, 2008). The focus is placed on the last one, as Zlatev (2007, 2008, 2009a) argued, the theory of embodied cognition provides explications on the development of intersubjectivity since the very beginning of life. A discussion on children's language acquisition is given based on the process during which the semiotic capabilities are gained in the embodied way (Zlatev, 2008, 2009a).

As it is shown in the nine chapters of this thesis, what the biosemioticians unanimously agree is that semiotics and biology, each domain of studies is incomplete without the other. With this thesis, it is our intention to challenge the methods that separate sign users from signs and to inspire the discovery of new theoretical stances while taking the advantages of both disciplines. Gálik (2013) suggested that applying semiotics to biology can contribute to the reformulation of the Darwinian evolution based on natural selection – the level of genes. Organisms, nevertheless, are self-maintaining agents that actively improve their fitness. Gálik (2013) also believes that applying biology to semiotics can bring significant changes to the linguistics-inspired science. Human language is not a separate event but a part of life that unceasingly evolves. In this sense, semiotics should be considered a general science.

Compromises concerning the depth of the research have been made to highlight the extension. There are: (1) the limitations on the expertise. Although this is an interdisciplinary research, we have put most of the effort in making observations of the semiotic nature of life, rather than questioning its origin; explaining the observed sign-based patterns necessarily requires a background in highly specific areas of physics, chemistry and biology. (2) The limitations that can



be overcome in the future. Biosemiotics with a history of around 50 years is still a young science. While contributing to the development of this research filed, we are cautious in the selection of theoretical contexts – the examples qualitatively but not quantitatively support the hypothesis of the work. Therefore, we look forward to enriching the knowledge on biosemiotics in a systemic way.

Artificial models that simulate the (primary) functioning of the human mind, for example, are purpose-driven systems that contain some data of some part of the world thus can predict changes in the defined domain (Turchin, 1993). In this work, the semiotic devices selected to aid the reasoning toward the characterization of life concern not only the classic theories of semiotics but also sign-based models that are commonly used in mathematics and cybernetics. Our research is both interdisciplinary and transdisciplinary. Its future aspect should include the continuous exploration and the integration of different scientific fields.

Last but not least, with this work, we hope to take part in the philosophical discussions on the relation between (meaningful) information and the material world. Inspirations can be drawn from Neo-Confucianism, a traditional Chinese philosophy based on the concept of Li – translated as the "universal principles of organization" (Chan, 1957). According to the Neo-Confucian point of view, the universe composed of Qi (matter-energy) is ordered by Li (organizing principles); Li, in turns, results from Tao (the cause of being) (Chan, 1957, 1964). In other words, the existence and the changes of matter are driven by a purpose and these processes are governed by the informational laws. In the modern time, inspired by the celebrated double-slit electron-interference experiment in quantum physics, John Archibald Wheeler (1992) proposed the thesis of "it from bit" to explain the origin of existence. As shown in the experiment, a photon has no true reality until being measured. Therefore, information must be included to create the temporal



and spatial dimensions of the photon's interactions (Foschini, 2013). According to the "it from bit" thesis, all physical things – *its* – must derive its existence from *bits* – a informational description in the binary form (i.e. "answers to yes-or-no-questions") (Wheeler, 1992). That is, the world is created when it is described.

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De la molécule à l'homme : recherche sur la quatrième dimension de la vie. Energie, matière, information, sens.

[Résumé de la thèse]

En associant la sémiotique et la biologie, cette thèse veut donner un aperçu exhaustif de l'efficience des signes dans la vie. L'approche se fonde sur les données biologiques qui sont directement utilisées pour étayer l'hypothèse centrale de la présente recherche : la sémiosis est produite à tous les niveaux de vie : les molécules, les cellules, les organes, les organismes et les espèces. Un système biosémiotique nécessite l'utilisation de signes et sert à l'auto-entretien de l'organisme. On l'interprète ici comme une composante modulaire d'un ensemble plus vaste doué de propriétés auto-organisatielles et auto-productives. Adoptant un point de vue développemental sur la cognition, on soutient dans ce travail que les fonctions cognitives - appelées « contrôle sémiotique » - co-existent avec la vie. Différenciés selon leurs capacités cognitives, les organismes vivants créent des modèles de contrôle sémiotique; les traits importants de la cognition humaine tels que les émotions et le langage caractérisent les formes complexes des manipulations de signes. Les sciences de la sémiotique et de la biologie ne peuvent être totalement comprises l'une sans l'autre. Dans cette thèse, en outre, un effort est fait pour relier diverses positions théoriques sur la biosémiotique afin de surmonter les limites des travaux spécialisés en leurs propres domaines. L'intégration entre la sémiotique et d'autres domaines scientifiques est encore à explorer.

Mots-clés : Biosémiotique, Cognition, Information and Communication, Auto-Organisation, Autopoïèse, Agentivité

From molecules to human, a research on the 4th dimension of life. Energy, material, information, meaning.

[Summary of the thesis]

Combining semiotics and biology, this thesis intends to give an extensive overview of the phenomena of signs in life. The approach is more than biology-inspired; it is biologically concrete: data from the biological context is directly used to support the hypothesis – semiosis exists in all levels of life: molecules, cells, organs, organisms, and species. A biosemiotics system requires the use of signs and serves the goal of self-maintenance; it is also a modularized component of a larger whole with self-organizing and self-producing properties. Representing a developmental point of view on cognition, it is argued in this work that cognitive functions – referred to as the "semiotic control" – coexist with life. With different cognitive capacities, living organisms create patterns of semiotic control; prominent traits of human cognition such as emotions and language characterize the complex forms of pattern manipulations. The sciences of semiotics and biology cannot be fully understood without each other. In this thesis, furthermore, an effort is made to connect various theoretic stances on biosemiotics to overcome the limitations of individual works. The integration between semiotics with more scientific fields is yet to be explored.

Keywords: Biosemiotics, Cognition, Information and Communication, Self-Organization, Autopoiesis, Agency

