M-S MODEL

A New Approach to Models and Simulations in Artificial Intelligence

ABSTRACT

Computers are formal systems; and the mind is a very complex structure originating in and associated with the brain. This is true especially with regard to cognition and intelligence. In that sense, the basic question of artificial intelligence, "Can a machine think?", refers to the question "is it possible to design formal systems that can imitate the very complex structure of the human mind?" In order to give an affirmative answer to this question, some theoretical models on mind, logic and linguistics should be developed under a unified methodological framework. This methodological framework requires considering the role and the principles of modeling and simulation in artificial intelligence (hereafter, AI). This paper has two aims: firstly, to show the reasons why there is a necessity to consider the principles of simulation and modeling in AI distinct from the classical notions of simulation and modeling in science and in engineering; secondly, to re-formulate the guiding principles of modeling and simulation in AI. There will be three main parts in the paper: In the first part, we will show the general characteristics of modeling processes in science and engineering. In the second part, we will argue that the nature of intelligence requires constructing a new type of model in AI. Finally, in the third part, we will propose the M-S model as a new type of modeling strategy peculiar to AI and explain its certain features.

1- The General Characteristics of Models

Models and simulations are used in various fields of science and engineering in order to understand and examine the (real) target system. There are many discussions on the status and the role of a model in the philosophy of science.[1] The underlying theme in these discussions is how to consider the term "model" in relation to the target system and how to define associated terms, such as formal, simulation, representation, validation, accuracy, realism, in this relation. Despite the varying approaches, there does seem to be a general agreement on certain features of a model.

A model is a representational system of the reality. There are three main stages, namely *target system*, *source* and *simulation*, in the process of constructing a model. In the first place, we make certain observations on the *target system*. Following that, these observations provide *sources* which help us building a theory on the structure and on the mechanism of the target system. And finally, if this theory has a systematized body of law, i.e. codes, formulas, algorithms, hypothetical mechanism etc., then we look for the possibility of the *simulation* of this system. In the modeling process, every target system is an idealization of a circumstance considered to be real or realizable; and *sources* are the derivations on the structure and the mechanism of the target system which can be, in principle, represented in a simulation.

[1] See Achinstein (1965), Black (1962), Bunge (1973), Deutsch (1951), Harré (1970), Henry (1969), Hesse (1966), Max (1962), Wartofsky (1979), Way (1995), Zeigler (1976, 1979).

A model *necessarily* fails to represent everything about a complex system. Therefore, it is a simplification of a complex system. Due to this fact, a model is not necessarily an explanation of a target system even if the model and the target system behave in the same way. Modeling aims at representing the target system in informative, meaningful, symbolic, sizeable and reflective manners. These manners, however, though essential, are not sufficient for a complete comprehension of the very *nature* of target system.

There are different types of models in terms of their application fields. Leatherdale (1974: 50) states some of these types of models as follows[2]: Logical, scale, mathematical, analogue, functional, theoretical, physical, formal, material, archaic, auxiliary, main, *post hoc*, complementary, phenomenological, simplifying, abstract and structural. In this section, scale and analogue models will be dealt in order to comprehend some aspects of the M-S model.

A scale model, such as a model aeroplane, displays the essential structures of target systems. It "cover[s] all likeness of material objects, systems, or processes, whether real or imaginary, that preserve relative proportions" (Max 1962: 220). In a scale model, the model represents the target system in an *iconic*[3] sense. However, an analogue model, such as an electrical circuit model of a mechanical system, does not aim at resembling its target systems in an *iconic* sense. It is a *symbolic* representation of the target system, which is "designed to reproduce as faithful as possible in some new medium the *structure* or web of [internal] relationships in an original [target system]" (*Ibid.*: 222). While a scale model strives to imitate the material and the appearance of a target system, an analogue model attempts to imitate the structure of a target system and thereby is more abstract. Here the difference between scale and analogue models is important as to understand the role of *iconic* and *symbolic* representations in a model. That difference will also help us to comprehend some aspects of the M-S model.

2- Models and Simulations Peculiar to Artificial Intelligence

The general characteristics of a model and the classical process of modeling cannot be used in AI. The aim and the structure of models should be re-formulated in terms of AI. In

[2] There are also different classifications made by Harré (1970), Achinstein (1965), Black (1962).

[3] Charles S. Peirce (1934) coined the term "icon" in order to emphasize its difference from the symbol. Peirce (1934: 247) states that "An *Icon* is a sign which refers to the Object that it denotes merely by virtue of characters of its own, and which it possesses, just the same, whether any such Object actually exists or not." The difference between the symbol and the icon determines the basic character of scale models. Lloyd (2000) explains this difference as follows: "Icons are different from symbols in their relationship to the things represented: symbols are tied to their originals purely by convention, and any thing can serve as a symbol for any other thing; icons, in contrast, bear some resemblance or similarity to the things that they represent to us. That is, there must be something about the icon itself which is similar or analogous to the object or system of which it is a model." In addition to these, as Schultz and Sullivan (1972: 6) mention, the term icon "represents the properties by the same properties with a change of scale."

other words, a new type of a model and a simulation should be constructed. Why do we need to construct a new type of a model peculiar to AI? The answer can be given into two steps. In the first step, the epistemological and methodological roots of modern AI, which we call the "*H-N ideology*", should be examined in order to understand its conception of human intelligence. This examination will show us the reasons of the misconception of modern AI's notion of "human intelligence" and the basic dilemma of its modeling strategy. Secondly, an examination into the certain *conditions* of/for the intelligence will show us the reasons to re-modify the classical modeling processes.

2.1 The H-N Ideology

Artificial Intelligence is the result of the seventeenth century's great scientific revolution. In the history of science, there are many important figures[4] who made certain contributions to this very modern idea. In our opinion, there are two important stages in the emergence of the modern conception of AI. The first stage is Thomas Hobbes' understanding of mind as a material process; and the second stage concerns Isaac Newton's mechanistic approach to the world. The *H-N*[5] *ideology*[6] is the name given to the combination and togetherness of these two stages under an ambitious project which attempts to create a thinking machine. It is the *H-N ideology* itself which gives the very possibility of imagination of simulating human mind. The *H-N ideology* can be considered as the intellectual heritage of AI. AI's theories on intelligence are guided by its underlying metaphors of mind, such as mechanism, machine, computation, topology, symbol, automata etc. In order to understand the strong influence of the *H-N ideology* on modern conception of the human mind, let us examine some of its aspects:

According to Hobbes, mind is matter in motion and it can be examined in a mathematical manner. For him, reasoning is reckoning (i.e. computational operation) and in this sense Pascal's machine[7], for Hobbes, exemplifies the mechanical nature of processes in the human intelligence. Haugeland (1985: 23), acknowledging Hobbes as "the Grandfather of AI", mentions his two basic ideas on thinking as follows:

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[4] These important figures and their contribution to the modern idea of AI can be listed as follows: Pascal (1642, first mechanical digital calculating machine), Leibniz (1673, improved Pascal's machine), von Kempelen (1769, mechanical chess player known as The Turk), Shelley (1778, published the story of Frankenstein), Babbage (1840, programmable mechanical calculating machines), and Turing (1950, introducing the idea of Turing Machines and the Turing Test).

[5] *H-N* stands for Hobbesian and Newtonian.

[6] Here, the term "ideology" is used in the sense that the mechanistic approach of 17th century does not only have a great impact on science but also on culture, metaphysics, society and economy. Therefore, the *H-N ideology* is not only an idea on scientific issues, but rather a kind of characteristic thinking that can be observed in every aspect of our life practices.

[7] For more information on Pascal machines, see Bowden (1953: 333-334).

> First, thinking is “mental discourse”; that is, thinking consists of *symbolic operations*, just like talking out loud or calculating with pen and paper –except, of course, that is conducted internally. Hence, thoughts are not themselves expressed in spoken or written symbols but rather in special brain tokens, which Hobbes called “phantasm” or thought “parcels.” Second, thinking is at its clearest and most rational when it follows methodical rules –like accountants following the exact rules for numerical calculation. In other words, explicit ratiocination is a “mechanical” process, like operating a mental abacus: all these little parcels (which, of course, need not stand only for numbers) are being whipped back and forth exactly according to the rules of reason.

Hobbes put two questions into consideration: (i) Is it possible to build arithmetical operations in a mechanistic model and (ii) is it possible to reduce logic into a mechanistic framework. “Analytical Engine”, made by Charles Babbage in 1840, was the affirmative answer to the first question.[8]

Newton’s ideas form the second stage of the *H-N ideology*. The fundamental importance of Newton in the *H-N ideology* concerns his notions of “mathematization of nature” and “mechanization of thinking”. The Newtonian aspect of the *H-N ideology* indicates the perspective of nature as a universal order of mathematical laws. Modern AI’s metaphor of the “universal machine” depends on this very perspective. Metaphorically speaking, for the *H-N ideology*, the universe, as a “grand book”[9], was written in the language of mathematics. Newton’s *Philosophiae Naturalis Principia Mathematica* is a masterpiece in which he tries to establish this language in order to explain the nature. This work allows us to conceive of the very possibility of the mathematical account of intelligence. Moreover, it points out that “no external controlling forces were needed –and no maintenance- because a frictionless mechanism would continue for ever” (Gregory 1984: 125). Another importance of *Principia* originates in its offer of “a model not only for the new category of thinking in general, but also in its rigour and formalism for the special kind of thinking known as reasoning” (Pratt 1987: 18). Considering the human mind in a topological sense (i.e. the geometrical metaphor of mind) is another result of the Newton’s notion of “mathematization of nature”. The *H-N ideology* considers the human mind in a topological manner in which a theory of intelligence should provide a map of the human mind. It tends to address questions about the structure of intelligence (in a functionalist sense) but not about its biological, social and dynamic aspects.

The “mechanization of thinking” can be considered as the epistemological root of the computational approach in AI. The *H-N ideology* takes the “mechanism of the human mind”

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[8] Of course, there were some prior attempts such as Leibniz’s and Pascal’s calculating machines but Babbage was the first thinker who considered the notion of “inserting a program in a machine.”

[9] This expression originally belongs to Galileo ([1957]: 237-238).

in a logical, abstract, formal, symbolic, systematic and geometric (topological) manner. It attempts to reduce all mental phenomena to a few mechanical principles in a systematic approach. It also tries to construct a logical language into which thought processes can be *translated* and then *implemented* in a computation. The notion of "mechanism" in the *H-N ideology* refers to the idea of regularity and representational-level rules of the human mind. In that sense, the *H-N ideology* considers the mind as a "syntactic engine" in which the content of mental states can be represented by formal-symbolic rules.[10]

The *H-N ideology* transforms the idea of mechanism from simple automata (i.e. hydraulic pipes and clocks) to a general account of reality. That is to say, it attributes a metaphysical sense to mechanism. From a metaphysical point of view, the *H-N ideology* looks for the greatest possible perfection based on the "mathematization and mechanization of nature" which presupposes the universal principles of human intelligence.

Machine[11] and automaton[12] are two significant metaphors for the *H-N ideology*. An automaton is a special machine which has a faculty of self-movement. Turing, the forefather of AI, is a modern delegate of the *H-N ideology* who radically modified the notion of machine and automaton. In the *H-N ideology*, the analogy of machine and automaton was used for the body. Turing, however, made a radical change and he used these analogies for the mind. Shanker (1995: 54) emphasizes a different aspect of this change as follows:

> what he [Turing] had really accomplished was to transform machines into a species of "rule-following beasts" in which he achieved this feat was postulating a category of meaningless (sub-)rules which could guide the operations of a machine (and/or the brain), thereby providing the rudiments for a new understanding of 'machine' and thence the creation of artificial intelligence.

General modeling strategy of modern AI depends on the principles of the *H-N ideology*, explained above, and this strategy should be modified when we consider the general *conditions* of/for human intelligence. An examination on these *conditions* will show us the insufficiency of the *H-N ideology* for AI.

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[10] Nelson (1989: 3) states that "Just as a computer circuit has or is guided by an inbuilt logic, so a brain has its inner logic; but the brain is all there is, and its logic is determined by its purely physical make-up. This theory is traceable to…Hobbes and La Mettrie."

[11] Webb (1980: 1) mentions the usage of "machine" in mechanics as follows: "The concept of machine has dual origins in mechanics and human fabrication. A machine was often taken as any device whose behavior can be explained solely by mechanical laws, and often as any man-made device for performing some tasks, and often as both. Machine behavior was assumed to be completely determined by such laws, and as a consequence of this, also *predictable* in principle, for both laws allowed one to calculate its behavior."

[12] In the first half of 20^{th} century, Turing Machines, finite automata, automata for formal languages, McCulloch-Pitts neural networks, and self-reproducing automata are some of the modern automata depending on the *H-N ideology*.

2.2 General *Conditions* of/for Human Intelligence

Although there are many definitions on the essence and the nature of intelligence, there is a general agreement on the impossibility of a single irrefutable and universally accepted list of human intelligence (Miles1957: 155, Gardner 1993: 59, Sternberg 1990: xi). The general approach to overcome the problem of giving an exact definition of intelligence can be shifted to the question that we ask on intelligence. The question can be "what [are] intelligence" instead of "what [is] intelligence". For instance, in his work *Frames of Mind* Gardner (1993) suggests the theory of multiple intelligences in order to show that intelligence is not unitary, but rather composed of eight particular multiple intelligences, namely linguistic, musical, logical-mathematical, spatial, bodily-kinesthetic, naturalist, social (interpersonal), and intrapersonal. Many questions on intelligence originate in certain models or metaphors, which lead the theoretical research on intelligence.[13] For instance, AI seeks to reveal the underlying architecture of the brain and/or intelligence in order to develop certain models for simulating its faculties. Yet, it attempts to achieve this by employing terms that are comprehensively borrowed from the computer-based terminology.[14] That is to say, the representative tools (computer-based terminology) used for simulation and modeling are represented as the real structure of the target system (brain/intelligence) itself.

In order to achieve a successful modeling on human intelligence, AI should initially focus on the "*conditions* of/for intelligence"[15] instead of looking for the prerequisites (brain/cognitive skills) and actual criteria (the Turing Test) for intelligence. These *conditions* involve the inter-relations of biological, physical and sociological situations. Therefore, human intelligence can be defined as a faculty resulted from the *inter-situational conditions*.

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[13] See Sternberg (1990) for a detailed analysis of these metaphors, such as geometrical, computational, biological, epistemological, anthropological, and sociological; and how do they drive the theories on intelligence.

[14] Here are some examples for this terminology:

Hardware – nervous system
Software – mind
Information Processors – perceive and respond
Memory – encoding/storing information
Computer programs – brain processes
Computing –thinking
Dysfunction of mechanism – forgetting
"bug" in the program – making mistake

[15] Here, the term *condition* is used in a specific sense. *Conditions* are inherent and imminent to the occurrence of intelligence, though not its cause and prerequisite. In addition to that the expression "the *condition* of intelligence" is used in the sense that *conditions* are the original states of intelligence. Besides, we use the expression "the *condition* for intelligence" in the sense that *conditions* are necessary situations for intelligence. The expression "the *conditions* of/for intelligence" refers to the *aboutness* of the intelligence; not to the necessary components of the physical and/or the organization structure of the intelligence.

There are many scientific and/or engineering models on biological, physical and sociological situations; but the process and the principles that we use in these models cannot be fully applicable (suitable) to (for) modeling human intelligence because human intelligence has *inter-situational conditions* which requires a new modeling strategy distinct from the classical ones.

There is not a single phenomenon or a single process in human intelligence that can be seen as a target system. In other words, there is not any specific brain location or neuro-chemical activity which can be described as the source of human intelligence. Human mind and intelligence should be considered as an open system, which cannot be simulated and modeled by classical types of modeling; and human mind has its own capacity for self-organization, regulation, autonomy, adaptation, growth, and hierarchical organization. Intelligence is not the assemblage of cognitive skills and locations of the brain functioning independently of one another, but is its interacting and integrated structures. In that sense, AI's attempt to build "expert system models" of each cognitive skill and trying to unite them under a system cannot be sufficient to simulate the human mind. Therefore, we need a new type of modeling strategy. But before examining the principles of this new type of modeling strategy, let us explain the basic *conditions* of/for intelligence; namely, self-organization, organism, autonomy, evolution, and interaction.

2.2.1 Self-Organization:

The human mind is a very complex living system which consists of a combination of brain states. The process of this formation is based on highly nonlinear and dissipative[16] mechanisms. The *condition* behind this process can be defined as self-organization[17]. Self-organization as a *condition* of/for intelligence refers to a self-referential quality of the human mind. In other words, self-organization is the origin of the order of internal states of mind. This order has a spontaneous, non-deterministic, dynamic and non-linear character. The combination of "sufficiency" and "possibility" is the ground for the occurrence of self-organization.

Considering the human mind/brain as a machine and trying to simulate it in terms of this consideration is condemned to fail because the mind/brain is a self-organizing living

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[16] Zeleny (1981: 83) defines the dissipative structure of self-organization as follows: "Under conditions far from equilibrium, the processes within the system as well as its exchange processes with the environment assume a distinct order in space and time, called a *dissipative structure*. It constitutes the dynamic regime through which the system gains autonomy from the environment, maintains itself, and evolves. In particular, it is the dynamic regime that keeps the system self-regenerative…"

[17] The term "self-organization" is examined under different titles such as "emergent structuring", self-assembly", "autocatalysis", and "autopoiesis". See (Andrew 1991, Ben-Eli 1981, Valera 1979, Zeleny 1981).

system which cannot be mathematized and mechanized. Self-organization should not be seen as a pure function of the human mind. Its status is more than a function for the mind. We call the status of self-organization of/for the mind as the *performing-structure of mind*. Here, the *performing structure* should be considered in relation to organism, autonomy and evolution, because these are the inherent essential characteristics of self-organization (*performing structure of mind*).

2.2.2 Organism:

Organism as a *condition* of/for intelligence points out the necessity to think of the relation between part and whole in the process of modeling the mind. The part-whole relation and the organizational structure of an organism are completely distinct from a mechanistic understanding of nature. Therefore, this distinction should always be taken into consideration in the modeling processes. In other words, we should not consider the mind as a machine but consider it in terms of its relation to life.[18]

The internal relational structure of an organism provides significant clues in order to comprehend the occurrence of mental states. The basic feature of this structure is that an organism is simply an alteration of the matter and the *condition* of/for this alteration is self-organization. The generation of an organism introduces a new subject, a substance that is neither identical to, nor wholly dependent on, the matter that constitutes it at a moment in time. An organism is not the product of an intelligent design but is the outcome of a process of self-organization and evolution. However, the question concerning whether an organism as a *condition* of/for mind emerges on a given continuum (i.e. evolutionary, ontogenetic or molecular) is not the subject matter of a modeling strategy of human intelligence. Our subject matter, rather, is to find general principles of survival of organism against a disruptive environment. In a modeling process of mind, these principles will be the basic reference points for understanding the autonomous *condition* of/for intelligence.

An organism as a *condition* of/for mind cannot be addressed by pointing to its components. As Burwick (1987: 10) mentions "the relation between the parts and the whole could not be explained by arbitrary principles (mechanisms) nor by appealing to some invisible additive (vitalism); rather biological processes had to be understood in terms of the intimate interaction between parts and wholes." Agar (1951: 2) expresses this idea in a different way: for an organism, "the action of the whole is not merely the sum of the action of

[18] Especially, in the philosophy of mind, concerning the issues on consciousness and language, the causal interaction between an organism and the world seemed attractive to certain philosophers, such as Dretske (1981, 1988), Millikan (1984) and Fodor (1991).

its parts”. All of these statements show the necessity to consider the organismic *condition* of/for mind distinct from mechanistic manner. Nagel (1960: 137) gives us a telling picture of the difference between organismic and mechanistic perspective:

> Organismic biologists have placed great stress on what they call the “unifiedness,” the “unity,” the “completeness,” or the “wholeness” of organic behavior; and since they believe that biological organisms are complex systems of mutually determining and interdependent processes to which subordinate organs contribute in various ways, they have maintained that organic behavior cannot be analyzed into a set of independently determinable component behaviors of the parts of an organism, whose “sum” may be equated to the total behavior of the organism. On the other hand, they also maintain that “mechanistic theories” of organism, which assumes the “addictive point of view” with respect to biological phenomena. What distinguishes mechanistic theories from organismic ones, from this perspective, is that the former do while the latter do not regard an organism as a “machine”, whose “parts” are separable and can be studied in isolation from their actual functioning in the whole living organism, so that the latter may then be understood and explained as an aggregate of such independent parts. Accordingly, the fundamental reason for the dissatisfaction in which organismic biologists feel toward mechanistic theories is the “additive point of view” that allegedly characterizes the latter.

The significant point of this difference for our subject matter is that the brain/mind is a whole and all its parts –its neurons- are in a mutual relation to each other. The mental acts, as causal units, are different than the sum of the causal actions of the neurons in isolation. In other words, the properties of brain/mind are different from the sum of the properties of its constituent neurons. The properties and the genesis of the brain/mind, however, depend on the intrinsic properties of its neurons. The same properties which enable the neuron to enter into combinations also determine the “emergent” properties of the brain/mind. On the other hand, for the machine, which represents the principles of the *H-N ideology*, the arrangement of its parts and the functioning of its system are not based solely on the intrinsic nature of its parts, but also on the factors external to the parts themselves. These factors prevent the machine to house a *condition* of self-organization of/for human intelligence. They are functional relations which have a pre-arranged route.

It is now obvious that in the modeling process of the mind we have to re-define the status of the target system (brain/mind). Especially for AI, brain location or the connections between neurons cannot be the target system in the modeling process of certain cognitive skills, since this kind of a modeling process cannot give us the essential structure of the relation between part and whole, which is the characteristic of an organism as being a *condition* of/for mind, in the cognitive process.

2.2.3 Autonomy:

Autonomy is another *condition* of/for human intelligence. In the modeling process of intelligence, autonomy refers to the self-law of the mind. Of course, here, the term "self-law" should be understood in a self-organizational and in an organismic manner. Autonomy as a *condition* of/for intelligence does not refer to a control mechanism of the human behavior. Moreover, the autonomous *condition* of the human mind should not be considered in a phenomenological sense. Varela (1979: 12) states in what sense we have to take autonomy into consideration:

> By discussing autonomy, we are led to a reexamination of the notion itself; away from instruction, to the way in which information is constructed; away from representation, to the way in which adequate behavior reflects viability in the system's functioning rather than a correspondence with a given state of affairs.

In this sense, a modeling strategy of AI should be based on the self-governing activity of the human mind rather than the symbolic and mechanistic representations of mental states.

2.2.4 Evolution:

At the background of human intelligence, there is a long evolutionary process and a very complex genetic structure.[19] Evolution is both a defining *condition* and a creative process of the mind itself. Evolution is a *condition* of/for human intelligence and for a modeling strategy of mind the history of change of the pattern of organization should be the basic concern. Evolution, as a *condition* of/for human intelligence, should be treated as a target system in AI; but it should not be considered in a biological sense.[20] In other words, biological research, examining the principles of series of changes from simple to complex organismic structures, cannot be the issue of AI's strategy of modeling the mind. AI should take evolution into consideration in the sense of providing an essential regulation "strategy" for the adaptation of the mind to a dynamic and a complex environment. That is to say that the regulation of the interaction between the inner states of the mind and the external conditions of the environment is the essential point for understanding the adaptive character of

[19] This genetic structure is one of the essential points to reveal the self-organization of organisms. Mainzer and Müller (1998: 2) describes the significance of genetic structure for an organism as follows: "In biological evolution, genetic information is a key concept to explain the self-organization of living systems, which can, basically, only be generated by some clever combination of conservative and dissipative self-organization of matter. Indeed, a living organism is a complex aggregation of more or less conservative and dissipative systems, equilibrium and nonequilibrium structures."

[20] Here, by biological sense we refer to the doctrine that all forms of life originated by descent, with gradual or abrupt modifications, from preexisting forms which themselves trace backward in a continuing series to the most rudimentary organisms. [Note: *this definition is taken from Webster's Dictionary*]

consciousness. This kind of a modeling approach to evolution, a *condition* of/for human intelligence, allows AI to construct *agents* which can manage under complex environmental conditions.

In our opinion, evolution is not a unique and linear process in the sense that we could cover it under a grand theory. In our view, evolution contains hundreds of small stories taking place independently to each other. Therefore, we do not have a big story (grand theory) to let AI researchers understand the laws of evolution of mind and simulate it by means of a computer. On the other hand, certain features of evolution, such as regulation and adaptation, can be studied by AI researchers. In that sense, evolution is not an empirical issue for AI, but a methodological one. Adaptation, as a methodological issue of AI, provides conductive and intelligible predictions about the organizational structure of the human mind.[21] The importance of the concept of adaptation in AI is that it helps us to understand certain distinctive features of the human mind. Ben-Eli (1981: 177) describes the way in which adaptation may be the subject matter of AI as follows:

> From the cybernetic point of view, the adaptive processes underlying evolution are subject to the laws of control, specifically to the law of requisite variety, and to the possibility, in principle, of amplifying regulations through linkages in hierarchical organizations of interacting controllers. Evolution, from this point of view, is characteristic of a particular type of dynamic behavior in system reflecting the operation of a particular set of constraints. It corresponds to a specific type of regulation, embodied in a particular kind of organization.

Evolution is an adaptive process and "like other adaptive processes, evolution requires both the persistence of stable structures and variability in the procedure by which these structures are propagated" (Sayre 1976: 109). AI's modeling strategy on the simulation of mind should focus on the *conditions* of these processes.

2.2.5 Interaction:

Any form of human performance –including moral, cognitive and artistic- is explicated as a mode of practice in which the individual acts with multiple agencies in complex environmental conditions. In that sense, any mental state is an interactive effect of the organism and the environment rather than of passive external stimuli. Interaction is a *condition* of/for human intelligence which indicates the role of multi-component systems on the mind. In AI, the relation between structural, dynamic, organizational and functional

[21] Evolutionary psychology is the field of cognitive science which focuses on this kind of a study. Certain researchers in evolutionary psychology advocate the idea that adaptation has a methodological and heuristic value in order to comprehend the organizational structure of the mind [See Barkow (1992), Dawkins (1982), and Williams (1966)].

complexity should be discussed in the context of such an interaction. In this context, the mind, as a target system, should be seen as a multiple and intricate *condition* in which a reduction to simpler structures is strictly impossible. Moreover, it is also basically a nonlinear structure due to the multi-*conditional* structure of the human mind. A proper modeling strategy in AI should take this nonlinear structure as the presence of some kind of interaction between the brain and the multi-components of surrounding environment.

Different complex environmental conditions make different demands on the human mind. This kind of differentiation requires determining different types of interactions, but it is not necessary to place these types in a hierarchical framework. In addition, it is necessary to make a conceptual revision in order to define the interactions in a proper way for AI. In this conceptual revision, we have to think of Western metaphysical culture in which substance or matter is primary to the [R]eality while the relationship between matter (substance) and its multi-components stands secondary to the [R]eality. As a result of this, in AI, the mind/brain is considered as a basic and an original source of a target system and the relationship (interaction) between complex environmental conditions and the cognitive system is to be taken as a subsequent source of a target system. Any AI model on the mind, language or reasoning should revise this situation.

Modern AI's modeling strategy considers a target system as a physical entity and regards it as being potentially available to symbolic and formal representations. However, modeling the *conditions* of/for human intelligence calls for a different approach because what we call human intelligence is nothing other than the *interaction* between the environment and the brain as a living organism. In this regard, AI's modeling strategy should not consider the brain as a target system but rather view the *interaction* as a target system. Hence, the subject of the target system should be shifted because this *interaction* provides the self-organizing, autonomous and evolutionary *conditions* of/for human intelligence. Even if the brain, as a physical entity and an original source of a target system, can be represented and simulated in a formal and symbolic model, it does not guarantee to model the main *conditions* of/for human intelligence. Modeling the mind is not an "availability of data"[22] problem; it is the problem of constructing a modeling strategy that provides the *conditions* of/for mind.

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[22] By "availability of data" we mean that we are far from understanding the neuropsychological processes of the brain. Approximately a human brain has 10 billion neurons, and tens of thousands are connected with each other. It is built of hundreds of regions, each with millions of neurons, each neuron with hundreds of thousands of connections. Modern AI and neuroscience do not provide us with the faintest clue to overcome this problem in the future. Margaret Boden (1989: 47) mentions the "availability of data" problem in AI from another point of view: "I assume that there is nothing magical about neurons: they are part of the natural world. That is, they can in principle be described by physics and chemistry, just as bone and steal –and silicon chips- can too. I assume,

3- The M-S Model

The misguiding principles of the *H-N ideology* and the *conditions* of/for human intelligence show that in AI we need a new type of model which goes beyond the representational character of classical modeling principles. Here, we propose the M-S model as a new type of modeling strategy peculiar to AI which helps us constructing mental, linguistic and logical models in order to provide the *conditions* of/for human intelligence. The basic principle behind the M-S model is that we can achieve a significant methodological economy by letting the *conditions* of/for human intelligence themselves play the role of the target system (mind). In addition, there can be no adequate model of the human mind without a dynamic and process-oriented modeling strategy.

An M-S model is a *stylized*[23] and an *operational*[24] type of model, peculiar to AI, which constructs organizational structures according to certain relational configurations such as *modes*[M] and *status*[S][25]. These relational configurations give rise to construct organizational structures distinct from the target system. In any M-S type of mental, linguistic or logical model, it is necessary to take *mode*, understood as the primary structure, as a *condition* which is essentially dynamic. The *mode* of intelligence (in a mental, linguistic and logical sense) can be described as *conditions*. It refers to the underlying generative *conditions* that make various domains of *status* possible.

In AI, the M-S model of mind, language or reasoning (logic) refers to the manner and the prevailing style of *conditions* of/for human intelligence. The correlative construction of *modes* and *status* is the primary instrument of an M-S model for providing the self-organization, adaptation, autonomy, evolution and interaction *conditions* of an agent system. Each M-S model of mind, language and reasoning (logic) must have different relational

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also, that there is no *special* physical property that is essential to intelligence, which is possessed only by brain-proteins. This second assumption might conceivably be mistaken –but neuroscience gives us no reason whatever to suspect that it is. Quite the contrary: the more brain scientists discover about this remarkable organ, the more they see it as subtly complex physico-chemical system. What this all comes to, then, is that the properties of the human brain that are relevant to its function as an organ of intelligence almost certainly have nothing to do *with what it is made of*. Rather, they concern *how it is organized* and *what it does*."

[23] Here, *stylized* refers to conform a design and style in a model which has a different manner from the original source.

[24] Here, *operational* refers to the dynamic organization of a model in which we can have a capability to carry out complex and situational tasks.

[25] The *modes*[M] and *status*[S], as relational configurations, do not have any correspondence to the *real* connectionist form of the human brain. *Modes* and *status* are relational types which should be *stylized* by the AI researchers. They are the constructed relational configurations which can have various forms in terms of the various cognitive skills. The relational configurations of *modes* and *status* will not be formed in terms of the neuropsychological structure and the organization of the mind but in terms of the *conditions* of/for the mind. In other words, in the modeling process we ascertain the *source* of human intelligence not from the brain but from the *conditions* of/for the mind.

configurations of *modes* and *status* which house different typologies of relations, causes and conditions. Each of these individual relations, causes and conditions accounts for a specific *mode* of *conditioning* interaction. In other words, the structural arrangement of *modes* and *status* can vary in terms of the features of a target system.

The main distinction between an M-S type of model in AI and a classical type of model in science and engineering is that an M-S model does not aim at understanding the target system [certain cognitive skills of the mind] but rather aims at operating specific, natural, or proper actions that belong to the target system.[26] An M-S model is not the simulation of a target system using the hypothesis derived from the target system itself. However, the relational configuration of *modes* and *status* in an M-S type of model of the mind, language or reasoning sets up a conformational and operational prototype whose function is not simply simulative and descriptive but imperative and autonomous. The organizational structure of an M-S type of model is completely distinct from that of a target system in AI. Therefore, an M-S model is not simply a reflection or a representation of certain structures of a target system, but beyond this, an arranged and alleged *mode* of a target system, a representation of anticipatory practice, or a gained *mode* of a target system. In other words, an M-S model is not a type of techno-scientific model trying to discover and imitate the essential features of a target system.

An M-S model does not require the *seminal*[27] view in the modeling process and substitutes the *conditional* view. That is to say that in AI an M-S modeling process transforms the target system from brain/mental states into the *conditions* of/for the mind. In that sense, *conditions* as a target system provide an initiation point for the construction of an agent. Classical AI takes the relation between the material structure of the brain and the formal structure of the mind into consideration as the basic issue of modeling strategy. However, in the M-S model of mind, language or reasoning, this issue will be transformed into the relation between the *conditional mode* and *status* of the mind. Therefore, an M-S model in AI does not shed light on the inner working structure of brain states and their organizational structure.

Unlike the classical types of models, an M-S model is not an imitation, scale version, prototype, and hypothetical construction of the target system. It means more than this. In AI,

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[26] In his famous article “Intelligence without Representation”, Brooks ([1999]: 86) states the same point that we mentioned above “I have no particular interest in demonstrating how human beings [minds] work.” However, in this case, Brooks considers the problem of modeling strategy only as an *engineering methodology*. This is the essential point that we put ourselves in a different position from Brooks because the M-S model that we propose is not a task for an engineering project in AI but a philosophical methodology for AI.

[27] Here, the term *seminal* indicates the primal elements and the origins of a target system which is essential for the simulation and representation of it.

an M-S model is not a scientific or an epistemological model of the mind, language or reasoning but a *conditional* and a methodological one. This *conditional* model does not aim at producing “true”, “valid” and “useful” knowledge, but a “generative cognition” in which AI researchers can have the power to produce and originate the *conditions* of/for human intelligence. At this stage, it is better to examine how an M-S model is applied to each *condition* of/for the human intelligence.

3.1 The M-S Model of Self-organization

In AI, any M-S model of mind, language or reasoning (logic) should consider the self-organization as a collaborative result of *modes* and *status* of the target system. The M-S model of self-organization constructs the relational configuration of *modes* and *status* in order to provide a causal origin within itself. In other words, the M-S model of self-organization cannot be constructed from an external source, but it is already inherent in the correlations of *modes* and *status*. In an M-S model of self-organization, our basic concern is the living organization of the mind. Therefore, our concern will not be the structural features of the components of mind, but an operational and relational reconstruction (in terms of *modes* and *status*) of the organization of the mind. An M-S model is always a reformulation of the mental organization in such a way that *modes* and *status* arise operationally related in its generation. In the M-S model of self-organization, we will take the relational configuration into consideration in which *modes* and *status* must fulfill the conditions and the requirements of mental organization while excluding any identification of its components (brain states).

Any attempt to apply the self-organizational *condition* of/for the mind to any kind of M-S model would be an attempt to reformulate and to reconstruct the nonlinear and dissipative organizational structures that can provide the self-referential quality of an autonomous agent system. In addition, the M-S model of self-organization overcomes the dichotomy of organization and structure discussed in biology, robotics and AI. One of the basic principles in the process of M-S modeling is that there is no need for a specific structure [brain states] of a target system [mind] that can serve to account for the phenomenon [cognitive skills] it generates. The M-S model constructs an organizational structure, depending on the relational configurations of *modes* and *status*, distinct from the mental one; and it satisfies the *conditions* of/for human intelligence. In a classical modeling process, we take the structure of the target system as the basis of its organizational character; and we then try to hypothesize the structural-based-organization. In the M-S model, however, we will re-modify this relation and we will define an organizational-based-structure (i.e. *modes-status*-based-structure) which will provide the self-organizational *condition* of/for the mind.

3.2 The M-S Model of Organism

Although organism is a *condition* of/for the mind, it does not suggest an idea on the necessity of any biological-based model in AI. In the history of AI, there are general approaches using certain biological ideas in the attempts of modeling the mind. For instance, we may mention Von Neumann, Turing, Wiener, evolutionary computation, neural networks and methods inspired by the immune system, insect colonies, and other biological systems. The M-S model of the organism handles the issue from another point of view. In the modeling process, the approaches that we mentioned above consider the biological system as a *source* which can be hypothesized, and then assumed that it can be simulated into a formal system. The M-S model of the organism, however, takes the biological system as a *condition* which can help us to construct the part-whole and the analog-digital correlations of *modes* and *status*. It is not the study of the regulative and causal functions of the biological system, but the study of constructing generative functions of the biological system that can help the agent system to maintain its activities in a disruptive environment. These generative functions, composed of *modes* and *status*, are not subject to any empirical examination, but to a formation of a "systematic whole" in the *Umwelt*. For instance, the generative functions in the M-S model of organism will not allow us to formulate theories of the brain because they do not allow us to decide whether the brain is an analogue-parallel-processing device or not. The M-S model will construct its own original relational configuration in a "systematic whole" which is very different from the brain. Therefore, it is not the representation of the biological structure of an intelligent system, but the embodiment of the internally organized intelligent system in an M-S type of model which maintains life-sustaining activities.

3.3 The M-S Model of Autonomy

Autonomy is the *condition* of/for human intelligence which points out the basic principal difference between an organism and a mechanism. This difference can be expressed as follows: "*machines act according to plans* (their human designers'), whereas *living organisms are acting plans*." (Ziemke 2001: 170). At this point, the M-S model of autonomy indicates two significant points in AI: First, any AI model of the mind, language or reasoning should intend to design intelligent agents which have to make their own conclusions in continuous long-term interaction within the *Umwelt*. Therefore, we should dismiss the idea of designing just intelligent thinkers which are expert systems that can operate on limited aspects of cognitive skills such as playing chess, calculation, translation, and linguistic communication. Second, the M-S types of models in AI should provide potential compatibility for cognitive (brain/intelligence) and constructive (body) architectures. Let us examine these two points:

Intelligent Agents instead of Intelligent Thinkers:

Brooks ([1999]: 86) is one of the leading figures who proposed the idea of autonomous agents (intelligent actors): “I wish to build completely autonomous mobile agents that co-exists in the world with humans, and are seen by those humans as intelligent beings in their own right.” In his view, (*Ibid.*: 88), “the idea is to first build a very simple complete autonomous system, and *test it in the real world*.” Although we have the same intentions as Brooks, we find his approach very narrow, situated in a robotic form of intelligence. Brooks and his successors in robotics do not take the self-organizational, organismic, interactional and evolutionary *conditions* of/for the mind into consideration. The principles of constructing an autonomous agent should be interrelated with these *conditions* since the autonomy of the human mind is the result of these *conditions*.

There are various definitions of autonomous agent systems. Maes (1996: 136) gives us a clear account:

> An *agent* is a system that tries to fulfill a set of goals in a complex, dynamic environment. An agent is situated in the environment: It can sense the environment through its sensors and act upon the environmental using its actuators. An agent’s goal can take many different forms: they can be “end goals” or particular states the agents tries to achieve, they can be a selective reinforcement or reward that the agent attempts to maximize, they can be internal needs or motivations that the agent has to keep within certain viable zones, and so on. An agent is called *autonomous* if it operates completely autonomously, that is, if it decides itself how to relate its sensor data to motor commands in such a way that its goals are attended to successfully.

The M-S model of autonomy is completely distinct from the classical AI in the sense that:

(i) A classical model in AI is a closed system. It operates in a pre-determined field of a task-world circumstance. On the other hand, as I mentioned before, the human mind should be considered as an open system; and therefore a modeling strategy of AI should be constructed on the relational configurations (such as *modes* and *status*) which provide for an agent’s self-governing activities within a very complex environment and which do not only involve pre-determined problems but various and different types of spontaneously occurring problems.

(ii) A classical model in AI is designed to deal with an exact problem in a given time. On the other hand, the M-S model of autonomy aims at designing agents which can formulate their own problems and gain experience from them in order to provide adaptation to the environment. Therefore, the correlations of *modes* and *status* will intend to create its own problems instead of solving the pre-arranged problems.

(iii) A classical model in AI considers cognition as a framed "knowledge" which can be stated in a formal manner. On the other hand, the M-S model of autonomy orders the relational configurations of *modes* and *status* in order to gain cognition as a "derived-and-acquired-knowledge."

(iv) A classical model in AI intends to design "intelligent thinkers" that specialize on one subject. On the other hand, the M-S model of autonomy intends to create "intelligent agents".

The Compatibility of Cognitive and Bodily [Constructive] Architectures:

It is the main argument of Merleau-Ponty in his *Phenomenology of Perception* that the body is ignored in traditional philosophies. This is also valid for classical AI. The modeling strategies of AI dismiss the body. In AI, the body always remains as a missing piece of the "mind's puzzle". Brooks ([1999]: 62) expresses this issue in a different way:

> The role of AI was to take descriptions of the world (though usually not as geometric as vision seemed destined to deliver, or as robotics seemed to need) and manipulate them based on a data-based of knowledge about how the world works in order to solve problems, make plans, and produce explanations. These high-level aspirations have very rarely been embodied by connection to either computer vision systems or robotics devices.

Our M-S model of autonomy intends to construct *embodied systems*[28] in which the cognitive and the bodily architectures are in harmony. Here, we use the term "architecture" in a *conditional* sense. That is to say that the cognitive and bodily architectures are not considered as a design for the construction of a target system, but rather as a construction for the design of a target system. In other words, the M-S model of autonomy will construct the design of the relations between the sub-parts of the cognitive and constructive (bodily) architectures as distinct from the human behavioral model and it will have its own autonomous *conditional architecture* in terms of correlations between *modes* and *status*. This is one of the essential points that differentiates the M-S model of autonomy from the other intelligent *embodied systems* such as behavior-based robotics.

[28] Tschacher et al. (1999: 77) describes the *embodied systems* as follows: "Interaction with an environment implies that *embodied* systems have to be constructed. Embodiment is a prerequisite of situated cognition. Only if a system is in direct relation with its environment, i.e. only if it has a body of some sort, is it able to act in a situated way. In terms of intelligent systems design and modeling the idea of embodiment has led to a remarkable increase of work with *mobile robots* or *autonomous agents*." Lee and Lacey (2003: 368) give another definition: "Embodiment refers to the agent having a physical structure within the environment itself, which necessarily gives the potential to influence or disturb situations or events."

3.4 The M-S Model of Evolution

The M-S model of evolution requires discussing two main topics; namely, adaptation and the de-centralization of representation.

Adaptation:

Adaptation is a plausible mechanism of evolution, and probably the most significant one. In the M-S model of evolution, we never take other possible mechanisms, such as diversity, fitness, heritability etc., into consideration. In AI, there are many investigations on adaptation under different titles such as generative algorithms, evolutionary computation, and adaptive neuro-robotics. The M-S model of evolution considers the adaptation problem in AI as a problem of designing relational configurations that can give rise to productive, creative, and de-centralized representational systems. Moreover, it aims at constructing *centrifugal principles* by which it is meant “a single control mechanism breaks itself down into number of sub-mechanisms in a process of adaptation and differentiation” (Ziemke 2001: 216). Darwin’s notion of natural selection can be the reference point in the construction process of *centrifugal principles*.

The De-centralization of Representation:

The M-S model of evolution is an organizational logic in which the relational configurations of *modes* and *status* can evolve within the same system. A de-centralized representational model, such as multi-agent systems, can provide the evolution of an *embodied system*. In the M-S model of evolution, there is not any central representation.[29] In an M-S model, we do not consider the representation as a mirror of the structure of a target system, but as a *mode* and/or a *status* distinguished from proper spatio-temporal physical target systems. In the classical view, models are treated as representational objects; but in AI, the M-S models are *conditional* systems in which representations are defined in terms of these *conditions* such as evolution (adaptation).

[29] In his well-known article “Intelligence without Representation”, Brooks ([1999]: 81) argues that “representation is the wrong unit of abstraction in building the bulkiest parts of intelligent systems.” Claiming that there is “no central representation” in the M-S model of evolution is completely different from Brooks’ point of view since the M-S model does not deny representations but de-emphasizes their roles in the correlations of *modes* and *status*.

3.5 The M-S Model of Interaction

The M-S model of interaction aims at constructing the "situated cognition"[30] in which the following principles are accepted:

-- The *Umwelt* is seen from the position of the agent instead of from the designer's position.

-- The behavior of the agent system depends on the interaction between the M-S model and *Umwelt*.

-- The situated agent can survive in a very complex environment by depending on its own experience. This experience is the form of the aggregate of all external and internal (*modes* and *status*) conditions. This type of experience does not have any phenomenological sense or content.

-- Human intelligence is the adapted form (*condition*) of the mind to the *Umwelt*, which should be considered as *situatedness* since all perceptions, intentions, behaviors, and other mental states of an individual are developed together as a result of the interaction.

-- Interaction is a kind of embodiment in a social and physical activity, and also a contextual appearance within particular settings.

-- Interaction is not a different version of the frame problem. Therefore, it is not a problem of logic, but rather a problem of modeling.

-- Cognition has two sources; namely, the *social* and the *conditional* (self-organization, organism and evolution). Interaction is the *condition* which unites these two sources.

-- Cognition is not a passive form of knowledge, but an *interactional* and *situated* form of knowledge which is based on the interrelated structural, dynamic, organizational and functional complexity of the *Umwelt*.

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[30] The issue of "situated cognition" is raised in the early 80's as a result of many critiques of the classical view of AI in which intelligence is considered as symbol manipulation. The common point in these critiques was that human thought cannot be reduced to the rules of formal systems and these formal systems are not be applicable to all of the human social and physical conditions (See Dreyfus 1972, Winogard and Flores 1986, Dretske 1993). The "situated cognition" approach treated human intelligence as a physically and socially embedded activity. It has been studied under various research areas such as "Situated Action" (Suchman 1987), "Situated Cognition" (Clancey 1997), "Situated AI" (Husbands et al. 1993), "Situated Robotics" (Hallam and Malcolm 1994), "Situated Activity" (Hendriks-Jansen 1996), and "Situated Translation" (Risku 2000). Clancey (1997: 4) describes "situated cognition" as follows: "Situated cognition is the study of how human knowledge develops as a means of coordinating activity *within activity itself*. This means that feedback –occuring internally and with the environment over time- is of paramount importance. Knowledge therefore has a dynamic aspect in both formation and content. This shift in perspective from knowledge as *stored artifact* to knowledge as *constructed capability-in-action* is inspiring a new generation of cyberneticists in the field of situated robotics, ecological psychology, and computational neurosciences."

Conclusion

In this paper, we have seen that the classical modeling process cannot be applied to the endeavor of modeling the mind and therefore we need a new type of model which can be used in mental, linguistic, and logical modeling in AI. The basic reason for this new type of model is the need to look at the *conditions* of/for human intelligence instead of looking at the prerequisites and the actual criteria of human intelligence. Therefore, a new type of model, the M-S model, is formulated in order to construct a system to realize these *conditions* in an *embodied system*. The basic difference of the M-S model from the classical ones is that it does not aim at understanding the target system [certain cognitive skills of the mind] but rather at operating specific, natural, or proper actions that belong to the target system. At this point, two questions arise: Firstly, is the M-S model a kind of functional strategy in AI? Secondly, is the M-S model a kind of black-boxism? The answer to both of these questions is “No”:

The M-S model cannot be simply described as a functional model because the relational configurations of *modes* and *status* cannot be considered as an input-output relation. Even if they are in a kind of input-output relation, the output of the M-S model counts also as an input for the same embodied/situated dynamic system. For instance, in calculation, the algorithmic processes of the machine and the brain are completely different but they provide the same result (Of course, there is a possibility for the brain to make a wrong calculation or for the machine to be misprogrammed). In this case, the calculation of the machine is just a simple function of the algorithmic thought of the mind. However, as Kary and Mahner (2002: 69) note “the more complex and specialized the function, the more it becomes tied to the special properties of specific materials and systems.” Therefore, no mental, linguistic or logical model in AI can be constructed purely in a functional sense since the mind is a very complex structure based on various *conditions*. These *conditions* cannot be functionalized. Moreover, the modeling of the mind cannot be simply reduced to the problem of substance-function (hardware-software) interdependence. Let us give another example: the physical underlying principles of the flight of a bird and an airplane are quite similar. Both are based on the principles of aerodynamics. However, an airplane as a model of a bird cannot be simply considered as a function for flight. It is not a realistic model of a bird. The material structure of an airplane is completely distinct from a bird: it does not flap its wings, nor does it run on two legs. Moreover, the flight capability of an airplane is also open to new developments. Therefore, metaphorically speaking, aerodynamics is the *condition* of/for the flight which does not necessarily depend on structural and organizational components of a bird’s flight. This is also valid for the M-S model. An M-S model is not interested in the structural (hardware) and organizational (software) components of the mind; but it is interested in the *conditions* of/for the mind. The modeling process of these *conditions* is not a functional stage because the M-S model is more than an input-output relation. Therefore, The M-S model will be constructed in such a way that it will have the potentiality to be capable of developing its mental, linguistic and reasoning features.

The M-S model is not simply a black-boxism. Although both the black-box model and the M-S model ignore the internal structure of its target system (mind), the M-S model is distinct from the black-box model. The black-boxism can be a suitable strategy for a component of a system. Yet it cannot be an applicable type of model to the whole system. In addition, while M-S model ignores the structural and organizational character of its target system, it focuses on the *conditions* of/for the target system. A black-box model is sensitive to the stimuli of the target system. Its configuration depends on the connection between the input and output terminals. On the other hand, the M-S model is a kind of an autonomous control system in which the configuration of input-output cannot be situated in a linear and located position.

REFERENCES

Achinstein, Peter (1965). "Theoretical Models", *British Journal for the Philosophy of Science,* 16, pp. 102-120.

Agar, W. E. (1951). *The Theory of the Living Organism*, Victoria: Melbourne University Press.

Andrew, Alex M. (1991). "Auutopoiesis-Allopoiesis Interplay" in *Autopoiesis: A Theory of Living Organization* ed. Milan Zeleny, Oxford: North Holland, pp. 157-166.

Barkow, J., Cosmides, L. and Tobby, J. (eds.) (1992). *The Adapted Mind: Evolutionary Psychology and the Generation of Culture*, New York: Oxford University Press.

Ben-Eli, Michael U. (1981). "Self-Organization, Autopoiesis, and Evolution" in *Autopoiesis: A Theory of Living Organization* ed. Milan Zeleny, Oxford: North Holland, pp. 169-182.

Black, Max (1962). *Models and Metaphors*, New York: Correll University Press.

Boden, Margaret A. (1989). *Artificial Intelligence in Psychology*, Cambridge, MA: MIT Press.

Bowden, B.V. (ed.) (1953). *Faster Than Thought: A Symposium on Digital Computing Machines*, London: Pilman.

Brooks, Rodney A. (1999). *Cambrian Intelligence: the Early history of the New AI*, Cambridge, MA: MIT Press.

Bunge, Mario (1973). *Method, Model and Matter*, Dordrecht: D. Reidel Publishing Company.

Burwick, Frederick (ed.) (1987). *Approaches to Organic Form*, Dordrecht: D. Reidel Publishing Company.

Byerly, Henry (1969). "Model-structures and Model-objects", *British Journal for the Philosophy of Science*, 20, pp. 135-144.

Clancey, William J. (1997). *Situated Cognition: On Human Knowledge and Computer Representations*, Cambridge: Cambridge University Press.

Dawkins, R. (1982). *The Extended Phenotype*, San Francisco: W.H. Freeman.

Deutsch, Karl W. (1951). "Mechanism, Organism, and Society: Some Models in Natural and Social Science", *Philosophy of Science*, 18, pp. 230- 252.

Dretske, F. (1981). *Knowledge and the Flow of Information*, Cambridge, MA: MIT Press.

Dretske, F. (1988). *Explaining Behavior: Reasons in a World of Causes*, Cambridge, MA: MIT Press.

Dretske, Fred (1993). “Can Intelligence Be Artificial”, *Philosophical Studies*, 71, pp. 201-216.

Dreyfus, H. (1972). *What Computers Can’t Do*, New York: Harper and Row.

Fodor, Jerry A. (1991). *A Theory of Content*, Cambridge, MA: MIT Press.

Galileo, G. [1957]. *The Assayer in Discoveries and Opinions of Galileo*, by Stillman Drake, New York: Doubleday.

Gardner, Howard (1993). *Frames of Mind: The Theory of Multiple Intelligences*, London: Fontana Press.

Gregory, Richard L. (1984). *Mind in Science: A History of Explanations in Psychology and Physics*, New York: Penguin Books.

Hallam, J.C. and Malcolm, C.A. (1994). “Behavior:Perception, Action and Intelligence –The View from Situated Robotics”, *Proc. Royal Society Land A* 349: pp. 29-42.

Harré, Rom (1970). *The Principles of Scientific Thinking*, London: Macmillan and Co Ltd.

Haugeland, John (1985). *Artificial Intelligence: The Very Idea*, Cambridge, MA: MIT Press.

Hendriks-Jansen, H. (1996). *Catching Ourselves in the Act –Situated Activity, Interactive Emergence, Evolution, and Human Thought*. Cambridge, MA: MIT Press.

Hesse, Mary, B. (1966). *Models and Analogies in Science*, Indiana: University of Notre Dame Press.

Husbands, P., Harvey, I., Cliff D. (1993). “An Evolutionary Approach to Situated AI” in *Prospects for Artificial Intelligence*, eds. A. Sloman, D. Hogg, G. Humphreys, A. Ramsay and D. Partridge, IOS Press, pp. 61-70.

Kary, Michael & Mahner, Martin (2002). “How Would You Know If You Synthesized A Thinking Thing?”, *Minds and Machines*, 12, pp. 61-86.

Leatherdale, W.H. (1974). *Analogy, Model and Metaphor in Science*, Amsterdam: North-Holland Publishing Company.

Lee, M.H. & Lacey, N.J. (2003). “The Influence of Epistemology on the Design of Artificial Agents”, *Minds and Machines*, 13, pp. 367-395.

Lloyd, Elisabeth A. (2000). “Models”, in *Routledge Encyclopedia of Philosophy*, ed.Edward Craig.

Maes, Pattie (1996). “Modeling Adaptive Autonomous Agents”, in *Artificial Life* ed. Christopher G. Langton, Cambridge, MA: MIT Press, pp. 135-162.

Mainzer, K. & Müller, A. (1998). "From Simple to Complex Systems: Some Preliminary Ideas on the Order of Reality" in *From Simplicity to Complexity* ed. Klaus Mainzer, Achim Müller and Walter G. Saltzer, Wiesbaden: Vieweg Publishing, pp. 1-6.

Merleau-Ponty, Maurice [1945]. *Phenomenology of Perception*, London: Routledge, 1962.

Miles, T. R. (1957). "On Defining Intelligence", *British Journal of Educational Psychology*, 27, pp. 153-167.

Millikan, Ruth G. (1984). *Language, Thought and Other Biological Categories*, Cambridge, MA: MIT Press.

Nagel, Ernest (1960). "Mechanistic Explanation and Organismic Biology" in *The Structure of Scientific Thought* ed. Edward H. Madden, Boston: Houghton Mifflin Company, pp.132-141.

Nelson, R.J. (1989). *The Logic of Mind*, Dordrecht: Kluwer Academic Publishers.

Pierce, Charles S. (1934). *Collected Papers of Charles Sanders Pierce, Vol. II*, Cambridge, MA: Harvard University Press.

Newton, I. (1972) *Isaac Newton's Philosophiae naturalis principia mathematica* (from the 3rd edn of 1726) with variant readings, eds. A. Koyré and I.B. Cohen, with assistance of A. Whitman, Cambridge, MA: Harvard University Pres.

Pratt, Vernon (1987). *Thinking Machines: The Evolution of Artificial Intelligence*, Oxford: basic Blackwell.

Risku, H. (2000). "Situated Translation und Situated Cognition: Ungleiche Schwestern" in *Translationswissenschaft. Fertschrift für Mary Snell-Hornby*, eds. M. Kadric, K. Kaindl and F. Pöchhacker, Tübingen: Staaffenburg, pp. 81-91.

Sayre, Kenneth M. (1976). *Cybernetics and the Philosophy of Mind*, London: Routledge & Kegan Paul.

Schultz, R.L. & Sullivan, E.M. (1972). "Developments in Simulation in Social and Administrative Science" in *Developments in Simulation in Social and Administrative Science*, ed. H. Guetzkow, P. Kotter & R.L. Schultz, Prentice Hall.

Shanker, Stuart (1995). "Turing and the Origins of AI", *Philosophia Mathematica*, 3, pp. 52-85.

Sternberg, Robert J. (1990). *Metaphors of Mind: Conceptions of the Nature of Intelligence*, Cambridge: Cambridge University Press.

Suchman, L.A. (1987). *Plans and Situated Action: The Problem of Human-Machine Communication*, New York: Cambridge University Press.

Tschacher, Wolfgang & Scheier Christian (1999). “The Perspective of Situated and Self-Organizing Cognition in Cognitive Psychology” in *The Nature of Concepts: Evolution, Structure and Representation* ed. Philip van Loocke, London: Routledge, pp. 68-90.

Varela, Francisco J. (1979). *Principles of Biological Autonomy,* Oxford: North Holland.

Wartofsky, Marx W. (1979). *Models: Representation and the Scientific Understanding,* Dordrecht: D. Reidel Publishing Company.

Way, Eileen Cornell (1995). “An Artificial Intelligence Approach to Models and metaphors” in *From a Metaphorical Point of View: A Multidisciplinary Approach to the Cognitive Content of Metaphor* ed. Zdravko Radman, Berlin: Walter de Gruyter, pp. 165-198.

Webb, Judson Chambers (1980). *Mechanism, Mentalism, and Metamathematics,* Dordrecht: D. Reidel Publishing Company.

Williams, G.C. (1966). *Adaptation and Natural Selection,* Princeton: Princeton University Press.

Winograd, T. and Flores, F. (1986). *Understanding Computers and Cognition,* Norwood, NJ: Ablex.

Zeigler, Bernard P. (1976). *Theory of Modelling and Simulation*, Toronto: John Waley and Sons.

Zeigler, Bernard P.; Elzas, Maurice S.; Klir, George J. and Ören, Tuncer I. (ed.) (1979). *Methodology and Simulation*, Amsterdam: North-Holland Publishing Company.

Zeleny, Milan (1981). *Autopoiesis: A Theory of Living Organization*, Oxford: North Holland.

Ziemke, Tom (2001). “The Construction of ‘Reality’ in the Robot: Constructivist Perspectives on Situated Artificial Intelligence and Adaptive Robotics”, *Foundations of Science*, 6, pp.163-233.