EXISTING THEORETCAL APPROACHES AND MODELS OF THE DEDUCTIVE REASONING PROCESSES

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Abstract. *The paper proposes, at first, a classification schema for the existing theoretical approaches and models of the deductive reasoning processes, offering a synthetic view over the state of the art in the deductive reasoning research. In a second step, based on such a synthetic view, the main problematic points and the current impasse in this domain of the cognitive psychology were outlined, and new promising future research direction were identified. A particular attention was given to the emergent dynamic approach of the deductive reasoning, and to its comparison with the symbolic approach that still dominates the scientific literature dedicated to the deductive reasoning topic, in spite of its apparent faults. Finally, the main ideas of this dynamic approach of the deductive processes are refined from several pioneering research works and brought together, aiming to elaborate an inspiring overview regarding its potential explicative power.*

Key words: *deductive reasoning, symbolic approach, dynamic approach.*

Numerous theoretical accounts were given by psychologists in their quest to understand the deductive thinking, which could be systematized in various ways, using multiple criteria. I am proposing the following classification scheme, partially synthesized in *Table 1*.

The current stage of the empirical and theoretical knowledge regarding deductive thinking obtained within the traditional framework of the cognitive psychology is suggested particularly well by the following conclusion of a recent study written by Evans (2006)[1]:

"If the conscious, analytic system is at best only partially in control and in competition with not one but several implicit systems, how come everything works

[1] J. St. B. T. Evans, *Dual System Theories of Cognition: Some Issues*, in: *** *Proceedings of the 28th Annual Meeting of the Cognitive Science Society*, Vancouver, 2006, p. 202–207.

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so well? Understanding how generally adaptive behavior can result from such an apparently chaotic cognitive architecture is one of the great challenges for cognitive science"[2].

Table 1

Traditional theories for deductive processes in cognitive psychology

I. **THE SYMBOLIC COMPUTATIONALIST APPROACH AND ITS MODELS**		
1. Information use theories		**2. Information interpretation theories**
A. *Rules theories*	B. *Analogical theories*	
Syntactic models (Braine & Rumain, 1983, in Bucciarelli & Johnson-Laird, 1999[3]; Rips, 1994, in Bonatti, 2002[4])	Mental models theory (Erikson, 1974, in Miclea, 1994[5]; Guyote & Sternbetg, 1981, in De Vega, 1994[6]; Johnoson-Laird & Byrne, 1991[7]; Stenning & Oberlander, 1995[8], Schaeken, Van Der Henst, & Schroyens., 2006[9])	Conversion theory (Chapman & Chapman, 1959, and Revlin & Leirer, 1978, in de Vega, 1994[10]) or biconditional interpretation (Wagner-Egger, 2007[11])
Pragmatic schemas models (Cheng & Holyoak, 1985[12]; Cosmides, 1989[13])	Case based reasoning models (Vosniadou & Ortony, 1989 and Toretzky & Hinton, 1985, in Sun, 1996[14])	Quantifier interpretation (Roberts, Newstead & Griggs, 2001[15]; Geurts, 2003[16])

[2] *Ibidem*, p. 206.

[3] M. Bucciarelli, P. N. Johnson-Laird, *Strategies in Syllogistic Reasoning,* "Cognitive Science", 1999, 23, p. 247–303.

[4] L. Bonatti, *Raisonnement Predicatif*, in: *Traité de Sciences Cognitives: Le Raisonnement*, G. Politzer (ed.), Paris, Hermès, 2002, p. 137–182.

[5] M. Miclea, *Psihologie cognitivă*, Cluj-Napoca, Gloria, 1994.

[6] M. De Vega, *Introducción a la psicología cognitiva*, Madrid, Alianza Editorial, 1994.

[7] P. N. Johnson-Laird, R. M. J. Byrne, *Deduction*, Hillsdale, Erlbaum, 1991.

[8] K. Stenning, J. Oberlander, *A Cognitive Theory of Graphical and Linguistic Leasoning: Logic and Implementation*, "Cognitive Science", 1995, 19, p. 97–140.

[9] W. Schaeken, J.-B. Van Der Henst, W. Schroyens, *The Mental Models Theory of Relational Rreasoning: Premises' Relevance, Conclusions' Phrasing and Cognitive Economy*, in: *The Mental Models Theory of Reasoning: Extensions and Refinements*, W. Schaeken, A. Vandierendonck, W. Schroyens, G. d'Ydewalle (eds.), Mahwah, NJ: LEA, 2006, p. 129–150.

[10] M. De Vega, *op. cit*.

[11] P. Wagner-Egger, *Conditional Reasoning and the Wason Selection Task: Biconditional Interpretation Instead of Reasoning Bias*, "Thinking and Reasoning", 2007, 13, p. 484–505.

[12] P. W. Cheng, K. J. Holyoak, *Pragmatic Reasoning Schemas*, "Cognitive Psychology", 1985, 17, p. 391–416.

[13] L. Cosmides, *The Logic of Social Exchange: Has Natural Selection Shaped how Humans Reason?*, "Cognition", 1989, 31, p. 187–276.

[14] R. Sun, *Commonsense Reasoning with Rules, Cases, and Connectionist Models: A Paradigmatic Comparison*, "Fuzzy Sets and Systems", 1996, 82, p. 187–200.

[15] M. J. Roberts, S. E. Newstead, R. A Griggs, *Quantifier Interpretation and Syllogistic Reasoning*, "Thinking and Reasoning", 2001, 7, p. 173–204.

[16] B. Geurts, *Reasoning with Quantifiers*, "Cognition", 2003, 86, p. 223–251.

I. **THE SYMBOLIC COMPUTATIONALIST APPROACH AND ITS MODELS**		
1. Information use theories		**2. Information interpretation theories**
A. *Rules theories*	B. *Analogical theories*	
Heuristic rules models: atmosphere effect (Woodworth & Sells, 1935, in de Vega, 1994[17]; Wetherick & Gilhooly, 1990, in Roberts, Newstead, Griggs, 2001[18]), matching bias (Evans, 1998[19]), probabilistic theory of reasoning (Chater & Oacksford, 1999[20]), etc.		Gricean conversational principles, relevance theory (Sperber & Wilson, 1990[21])

II. **INTEGRATIVE THEORIES**	
A. *Unifying theories*	B. *Dual processes theories*
Isomorphism of the mental models theory and rules theory with an algorithm using Euler circles (Stenning & Yule, 1997[22])	Analytic vs associative/heuristic processes (Evans, 1984[23]; Sloman, 1996[24]; Stanovitch, 1999[25]), explicit-implicit theory (Evans, 2006b[26]), cognitive neuroscience theories (Goel & Dolan, 2001[27]; Goel, 2003[28]; Goel, Shuren, Sheesley & Grafman, 2004[29])

[17] M. De Vega, *op.cit*.

[18] M. J. Roberts, S. E. Newstead, R. A. Griggs, *op. cit*.

[19] J. St. B. T. Evans, *Matching Bias in Conditional Reasoning: Do We Understand it After 25 years?*, “Thinking and Reasoning”, 1998, 4, p. 45–110.

[20] N. Chater, M. Oaksford, *The Probability Heuristics Model of Syllogistic Reasoning*, “Cognitive Psychology”, 1999, 38, p. 191–258.

[21] D. Sperber, D. Wilson, *Relevance: Communication and Cognition*, Oxford, Blackwell Publishers, 1995.

[22] K. Stenning, P. Yule, *Image and Language in Human Reasoning: A Syllogistic Illustration*, “Cognitive Psychology”, 1997, 34, p. 109–159.

[23] J. St. B. T. Evans, *Heuristic and Analytic Processes in Reasoning*, “British Journal of Psychology”, 1984, 75, p. 451–468.

[24] S. A. Sloman, *The Empirical Case for Two Systems of Reasoning*, “Psychological Bulletin”, 1996, 119, p. 3–22.

[25] K. E. Stanovich, *Who is Rational? Studies of Individual Differences in Reasoning*, Mahway, NJ: Erlbaum, 1999.

[26] J. St. B. T. Evans, *Dual System Theories of Cognition: Some Issues*, …

[27] V. Goel, R. J. Dolan, *Functional Neuroanatomy of Three-Term Relational Reasoning*, “Neuropsychologia ”, 2001, 39, p. 901–909.

[28] V. Goel, *Evidence for Dual Neural Pathways for Syllogistic Reasoning*, “Psychologica”, 2003, 32, p. 301–309.

[29] V. Goel, J. Shuren, L. Sheesley, J. Grafman, *Asymmetrical Involvement of Frontal Lobes in Social Reasoning*, “Brain ”, 2004, 127, p. 783–790.

II. **INTEGRATIVE THEORIES**	
A. *Unifying theories*	B. *Dual processes theories*
Integration of the syntactic and semantic information trough a process of successive recoding of the linguistic information (Polk & Newell, 1995[30])	
Competence (mental models theory) and procedural theories are interrelated components of a general theory of the logical meaning (Overton & Dick, 2007[31])	

It reflects the impasse the deductive reasoning research has reached. Evans (2006)[32] himself acknowledges that, in the light of the accumulated evidence. He questions himself about the assumed properties of an integrative theory of deduction with two stated reasoning systems, and claims even that “it is far from evident at present that a coherent theory based on two systems is possible” (Evans, 2006)[33]. For example, he provides reasons for not considering the so called “analytic system” to be necessarily “an abstract or logical system”, suggesting that “solving logical reasoning problems is just one kind of strategic thinking that can be undertaken successfully” through such a system “by those of sufficient cognitive ability who are appropriately instructed” (Evans, 2006)[34]. In fact, Evans (2006)[35] disputes the idea that there is a reasoning system that has logic competence, and some of the tenets of the mental models theory (for example, the notion of mental model, and the assumption that people are able to operate with more that one model). In his view, deductive reasoning “may be seen as no more than an analytic-level strategy that bright people can be persuaded to adopt by the use of special instructions” (Evans, 2006)[36]. He has also a reversed perspective in comparison with those sustaining theoretical models based on a logical competence (mental logic theories or mental models theories, particularly). For him, “deductive effort, when made, attempts to modify pragmatic processes, and not the other way around” (Evans, 2006)[37]. A reason for which he supports such a perspective is that, in his opinion, “the brain has been optimized by evolution for distributed processing”, and it is “relatively inefficient when applied to sequential and logical forms of thinking” (Evans, 2006)[38]. Therefore, he pleads not to “see the psychology

[30] T. A. Polk, A. Newell, *Deduction as verbal reasoning*, “Psychological Review ”, 1995, 102, pp. 533–566.

[31] W. F. Overtone, A. S. Dick, *A Competence-Procedural and Developmental Approach to Logical Reasoning*, in: *** *Integrating the Mind. Domain General versus Domain Specific Processes in Higher Cognition*, M. J. Roberts (ed.),New York, Lawrence Erlbaum, 2007, p. 233–256.

[32] J. St. B. T. Evans, *Dual System Theories of Cognition: Some Issues*, … .

[33] *Ibidem*, p. 206.

[34] *Ibidem*, p. 204.

[35] *Ibidem*.

[36] J. St. B. T. Evans, *The Heuristic-analytic Theory of Reasoning: Extension and Evaluation*, “Psychnomic Bulletin and Review”, 2006, 13, p. 392.

[37] *Ibidem*.

[38] *Ibidem*.

of reasoning as somehow apart from other research in cognitive psychology" (Evans, 2006)[39], as he feels that other cognitive psychologists involved in the deductive reasoning research have done.

In my opinion, Evans (2006)[40] is heading toward a theoretical position in which there is no clear separation between an information interpretation phase and a conclusion derivation phase. Instead, it might be that derivation is obtained through interpretation.

By recognizing that distributed processing is fundamental for reasoning, a step is made by Evans (2006)[41] in the direction of an approach of the deductive thinking from a dynamic perspective. It is a third main theoretical approach of the deductive reasoning, which only relatively recently has coagulated itself in several principles and has attracted attention as a possible alternative view in comparison with the traditional ones. It is centered on notions such as dynamic system[42], attractor structures[43] in its state space, interaction, coupling[44], catastrophic bifurcation[45], coordination, emergence, competition and cooperation.

A comparison between the symbolic computationalist paradigm and the dynamic approach made by Saulnier (2003)[46] emphasizes their most important characteristic differences. They are synthesized in *Table 2*.

[39] *Ibidem*.

[40] *Ibidem.*

[41] J. St. B. T. Evans, *Dual System Theories of Cognition: Some Issues*, …

[42] A **dynamic system** is a system composed of one ore more *dynamic variables* (variables changing in time) that reciprocally interact in real time (the change in time of a variable's value is dependent on the change in time of the other variables' values) and the so called *control parameters*, values of some external variables who control the interactions between the dynamic variables. They are included as constant values in the system of (differential or difference) equations describing the way the dynamic variables interact (in which the dynamic variables appear as unknown variables).

[43] An **attractor i**s a state or a set of states toward which a dynamic system tends to evaluate in time (converge) based on its intrinsic dynamics in the absence of disturbing influences. A *fixed-point attractor* is an attractor with a single attractive state. A *cyclic attractor* is a repetitive sequence of attractive states characterizing the convergence toward a cyclic behavior. A *chaotic attractor* is a set of attractor states having typically a fractal structure (a special geometrical structure with a fractional geometrical dimension, presenting self-similarity at all its scales). The trajectory of a dynamic system through such an attractive region is considered to be the result of two opposing tendencies: toward convergence into a set of states and toward divergence from them. Consequently, the chaotic behavior is characterized by a high level of nonlinearity, by sensitivity to the initial conditions (two trajectories leaving from two neighboring points become divergent in a very short period of time), and a limited predictability (in the absence of disturbing influences, a dynamic system with a chaotic behavior tends to remain indefinitely in the same predictable region of states, but in each moment it is in another new, unpredictable, state of that region).

[44] Two *dynamic systems are* **coupled** when at least one dynamic variable of a system is control parameter for the other one.

[45] *A* **catastrophic bifurcation** is a dynamic process by which the behavior of a dynamic system is qualitatively changed by changing the value of at least one of its control parameters.

[46] B. Saulnier, *Au-delà du représentationnalisme symbolique. La modélisation constructiviste et morphodynamique des systèmes, et le défi de la compositionnalité,* in: *** *Mémoire de DEA (Philosophie des Sciences), 1, Septembre.* J. Gayon (ed), Paris, 2003.

Table 2

A comparison between the symbolic paradigm
and the dynamic approach in accordance with Saulnier (2003)[47]

Comparison criteria	**The symbolic computationalist paradigm**	**The dynamic approach**
The relationship between the cognitive system and its physical support, and environment	Clear separation between the cognitive system, its physical support, and environment, having a distinct, functional, causality in comparison with them	Continuity between the cognitive system, and its physical support, and environment, inclusively at a causal level, because they are dynamically coupled; environment is defined by a cognizant
The goal of the cognitive science	To understand the adaptation of the cognitive system in order to represent an external preexistent reality/environment	To understand the stability, and the internal coherence of the cognitive system
The relevance attributed to the neurophysical processes supporting cognition, which are ontologically dynamic in nature	They have no bearing in what respects the study of cognition as such, as they are placed on an assumed irrelevant implementational level	They are not ignored, since the properties of the cognitive processes are assumed to be dependent on their properties as dynamic processes.
The organization in time of the cognitive processes	It is exclusively a discrete, sequential, serial order of them, with clearly separable stages	It is a continuous temporal coevolution of them
The importance attributed to the corporeal and the extracorporeal environment	It is not essential	It is essential, supporting a “situated”, and “embodied” cognition view
The attitude toward the notion of mental representation	Its necessity is not questioned	Its necessity is questioned, and, if it is admitted, its significance is reinterpreted
The representational format	Symbolic (physical symbols systems)	If the notion of representation is admitted, the representational format is either changed to have dynamic characteristics in such a manner that it would allow stability and context dependency, or there is assumed a way through which symbolic representations are emergent from dynamic processes.

[47] B. Saulnier, *op. cit*.

Comparison criteria	The symbolic computationalist paradigm	The dynamic approach
The type of the allowed compositionality	Universal, "concatenative" (van Gelder, 1990)[48] compositionality	Local, "functional" (van Gelder, 1990)[49] compositionality, securing only a contextual systematicity, since it is not possible that the three constraints: systematicity, unlimited compositionality, and functional relevance for a cognizant organism to be fully satisfied
The attitude toward the state of a system, and its temporal changing	It is centered on the notion of discrete state. Temporal changing allows passing from such a state to another one.	States are considered to be the change medium, but the focus is on changing
The geometry and the structure of a state	Defined through a syntactical, and combinatorial structure	Conceived to be as a point, position, in a state space, geometrically interpretable
The temporal structure	It assumes a successive transformation of a static structure into another one	It assumes the simultaneous existence of several structures that are in interaction.
The serial or parallel nature of a state transition transformation	It is assumed that during a state transition only a (simple or composite) variable changes, and the remaining ones are kept unchanged	It is assumed that during a state transition all variables change simultaneously

[48] T. van Gelder, *Compositionality: A Connectionist Variation on a Classical Theme*, “Cognitive Science ”, 1990, 14, p. 355–384.
[49] *Ibidem*.

Comparison criteria	The symbolic computationalist paradigm	The dynamic approach
Input and output definition	There is a clear distinction between input and output, cognitive processes being strictly delimited in that respect: at first there are processes for the reception of clearly defined inputs, then there are processes for their internal processing, and in the end processes for the generation of an appropriate output	There is no clear distinction between inputs and outputs, since the cognitive process is conceived to be without clear limits, without an identifiable beginning or ending. In each moment an adjusted change occurs.

Regarding the comparison between the symbolic computationalist approach and the dynamic one, three notes are to be admitted. In the first place, as Provonost (2006)[50] noticed, the source of the controversy generated by the two theoretical approaches originates mainly in the conceptual confusions in what respects the meaning of notions like "cognition", "computation", "mental representation". He points out a tendency for the supporters of the both sides to distort the adversary position (by pushing it to ridiculous extreme stands, illicitly radicalizing it, for example) so that it could be easily defeated as a seemingly absurd theoretical stance. In the second place, in Gärdenfors's (1994)[51] opinion, the two approaches could sometimes be viewed as two different perspectives, on different spatio-temporal scales, over the same information processing processes. It is suggested by him that a symbolic perspective ignores the successive transitions between input and output, and uses only the relation between what is represented by them. That relation is interpreted to be a "symbolic inference". Therefore, in his view, the symbolic inferences are emergent from dynamic "associations". In the third place, it is a generally admitted fact that the symbolic processes could be implemented in a dynamic system as it is the brain. But still, that does not mean that the two approaches are totally equivalent. In fact, there is a major difference of strategy between them.

It is true that a symbolic process is always supported by a dynamic one, but in a symbolic cognitive model the dynamic properties of this supportive process are not harnessed, but, on the contrary, its purpose is to minimize their effects, considered to be pernicious for a cognitive process. Instead, in a dynamic model of

[50] S. Pronovost, *Of Computations and Dynamic Systems: An Overview of the Dynamicist Controversy in Cognitive Science*, Carleton University Cognitive Science Technical Report 2006-05.2006 – http://www.carleton.ca/iis/TechReports

[51] P. Gärdenfors, *How Logic Emerges from the Dynamics of Information*, in: *** *Logic and Information Flow*, J. van Eijck, A. Visser (eds), Cambridge, MA: MIT Press, 1994, p. 49–77.

cognition, the computational properties of a dynamic process are rendered profitable, being used in order to understand the information processing. This idea was expressed more saliently by Yamamoto and Kinyioshi (2002)[52]. They showed that there are several properties of the dynamic systems that could be exploited in order to understand the cognitive behavior at any level. For example, the fact that in the state space of the body dynamics there are both unstable and stable regions would allow that the control input to be decreased when the body system is near the stable regions. On the other part, the unstable regions will be used in order to shift the system between two stable regions. That is why the external input will be used only to move the system between the stable regions. Symbols would correspond then to those points in the evolution of a system in which the control input is needed in order to obtain a desired change. So, there are changes produced without effort, based on an intrinsic dynamics, and changes realized through external control, by taking advantage of the unstable regions.

Therefore, in a dynamical approach the appropriate metaphor for a cognizer is not the builder metaphor (with symbols as bricks) but rather the navigator metaphor, who uses the water and wind dynamic forces to lead him to a desired path (although this is too not an altogether appropriate metaphor). Also, the computer metaphor of the symbolic computationalism seems to be rooted in some more primitive metaphors (Faiciuc, 2008[53]): a) the language metaphor (where we have linguistic arbitrary symbols manipulated by syntactic rules), and b) the metaphor of the usual description of our actions with the objects at a macroscopic level (where we have what seems to be static objects with clearly defined borders placed in some space endowed with characteristic properties and distinct forces by which the objects are put in motion), in the terms of the classical mechanics. In comparison, a dynamic approach is rooted in two different metaphors: the physics of complex dynamical systems (i.e. thermodynamics), or the biological organism metaphor.

The dynamic approach is supported by researchers (for example, Van Gelder, 1998)[54] who believe that the only way to link the cerebral processes with the cognitive processes is by adopting a common theoretical framework for both of them. Since it is admitted that brain is a complex dynamic system (as it is admitted also for almost any artificial neural network), the cognitive system should be studied as a complex dynamic system too, using similar conceptual and empirical tools. For example, the concept of *distributed, parallel, processing* is naturally

[52] T. Yamamoto, Y. Kuniyoshi, *Global Dynamics: A New Cconcept for Design of Dynamical Behavior*, in: *** *Proceedings Second International Workshop on Epigenetic Robotics: Modeling Cognitive Development in Robotic Systems* 94, C. G. Prince, Y. Demiris, Y. Marom, H. Kozima, C. Balkenius (eds.), Edinburgh, Scotland, 2002, p. 177–180.

[53] L. Faiciuc, *Are there Reasons to Challenge a Symbolic Computationalist Approach in Explaining Deductive Reasoning?*, "Integrative Psychological and Behavioral Science", 2008, 42, p. 212–218.

[54] T. J. van Gelder, *The dynamical hypothesis in cognitive science*, "Behavioral and Brain Sciences ", 1998, 21, p. 615–628.

linked with a dynamic approach, since if cognition is to be viewed as the result of an interaction in real time of the components constituting a cognitive dynamic system, it means that changes in the system should occur simultaneously in its entirety. Only that "parallel" means here not only simultaneous independent evolutions, but also simultaneous interacting evolutions.

Another example is the concept of *activation of a feature or of a mental representation*. Presently, it is viewed to mean not merely changing the place of a memorized information from the store in which it was placed to a separate work space, i.e. it is not a discrete property of a representation defined by the place occupied at a certain moment of time. Instead, activation is conceived to be rather an actualization process characterized by a continuous, gradual and quantitative evolution in time of a property defining the functional status of a representation in what respects its capacity to influence cognitive processing, its potency as an agent of change. In other words, the representation is not physically moved as an object from a warehouse to a workbench, undertaking only an exterior change. The assumption made is that it passes from a potential, or virtual, passive state to an active, actual state in which it is able to change the activation status of other representations, in accordance with its activation power.

Therefore, the activation of a representation is more like an internal property, by virtue of which it influences or it is influenced by other representations. Therefore, it might be said that, in this case, a feature or a representation acts like an agent, interacting in real time with other agents, forming, in this way, what it is called to be a complex dynamic system that needs no external agent or executive structure in order to explain all its state changes. The semantic networks of the type proposed by Collins and Qullian (1967, in Miclea, 1994[55]), too, are, minimally, primitive dynamic networks in that respect, even though their dynamics completely ignores the internal dynamics of the concepts and of their links (offering an approximate description of some cognitive processes on a higher spatio-temporal scale), and they have a defective interactive architecture. In such networks, representations are not able to change their representational content through interaction, but only their functional status. A real time dynamic interaction could be simulated effectively (not in principle) up to a point through some physical dynamic systems (the hardware of a computer) implementing symbolic processes, as a useful approximation in special cases. But they are not able to replace it altogether, especially when it comes to simulate complex dynamic nonlinear systems, comprising a lot of simultaneous nonlinear interactions between continuous variables, because they rapidly reach the threshold beyond which a computational explosion occurs (see for example, Weiskopf, 2004[56]). That is why a dynamic model of the notion of representation activation is not reducible to a symbolic computationalist one.

[55] M. Miclea, *op. cit*.

[56] D. A. Weiskopf, *The Place of Time in Cognition*, "British Journal for the Philosophy of Science ", 2004, 55, p. 87–105.

Seminal ideas of the new dynamic approach are found in the classical cognitive psychology in several forms (Faiciuc, 2008)[57]. Moreover, "old" phenomena from cognitive psychology, important for the deductive reasoning research, can be "understood and reconstructed" within the framework of the concepts of a dynamic approach (Kriz, 2001)[58]. Of the utmost interest for the understanding of the theoretical grounding of this thesis are the notions of distributed parallel processing in neural networks, activation, priming, or, especially, cognitive schema. In accordance with Ferber's (1996)[59] dynamic explanation for the priming effects, a prime stimulus moves the state of the dynamic cerebral representational system in its state space (or the space of all the possible configurations of a neural network modeling that system) towards the region in which it is placed the attractor structure (the configuration or the set of configurations toward which a neural network tends to evolve in time given a present state based solely on its intrinsic dynamic), correspondent to the target stimulus. Therefore, when the target stimulus is presented, the system arrives in a shorter period of time in the state space region of its representation. Apart from the theoretical proposal made by Ferber (1996)[60], it could be noticed that all the models that have been proposed to explain priming (for a synthesis see McNamara, 2005[61]) share the idea that, one way or the other, the activation status of the involved features or mental representations must have a role in its occurrence. But, as it was argued above, the notion of representation activation is dynamically in nature. Furthermore, several of the proposed theoretical models (McClelland & Rumelhart, 1986, in McNamara, 2005[62]) were implemented in recurrent neural networks whose behavior is known to be analyzable using the conceptual tools of the dynamic systems theory since they are actually dynamic systems.

Cognitive schema is a concept with a contradictory status in the traditional cognitive psychology. Its limits in the traditional theoretical framework will be presented at large in a future section. Priming (of a mental representation, such a cognitive schema is) is also a phenomenon that calls for a rather dynamic theoretical account (Ferber, 1996[63], Becker, Behrman, Moskovitsch, & Joordens, 1997[64]), being intimately related with the notion of activation of a mental

[57] L. Faiciuc, *Abordarea dinamică a proceselor cognitive superioare,* Cluj-Napoca, Argonaut, 2008.

[58] J. Kriz, *Self-Organization of Cognitive and Interactional Processes*, in: *** *Integrative Systems Approaches to Natural and Social Dynamics*, M. Matthies, H. Malchow, J. Kriz (eds.), Heidelberg, Springer, 2001, p. 517–537.

[59] R. Ferber, *Cognitive Dynamics – Dynamic Cognition?*, in: *** *Iteration Theory, Proceedings of the European Conference*, Singapore, World Scientific, 1996, p. 65–76.

[60] *Ibidem*.

[61] T. P. McNamara, *Semantic Priming: Perspectives from Memory and Word Recognition*, New York, Psychology Press, 2005.

[62] *Ibidem*.

[63] R. Ferber, *op. cit*.

[64] S. Becker, M. Behrman, M. Moskovitsch, J. Joordens, *Long-Term Semantic Priming: A computational Account and Empirical Evidence*, "Journal of Experimental Psychology: Learning, Memory, and Cognition ", 1997, 23, p. 1059–1082. They proposed an attractor neuronal network for the simulation

representation. A flavor of dynamicity could be traced in the concept of "bias", too. It seems to imply that there are some forces that lead to bias, that there is a dynamic competition involved. It is used as a convenient label to cover a diversity of phenomena, but usually the nature of the processes leading to it is ignored.

So far, there are no fully fledged dynamic theoretical models as such dedicated to the deductive reasoning. But several authors (Margolis, 1987; Grim, 1993, in Vezerides & Kehagias, 2005[65]; Shastri & Ajjanagadde, 1993[66]; Bechtel, 1994[67]; Gärdenfors, 1994[68]; Goertzel, 1994[69]; Kentridge, 1994[70]; Oaksford & Malloch, 1994[71]; Sabelli, 1995[72]; Eliasmith, 1996[73]; Kataoka & Kaneko, 1999[74], 2000[75]; Dimitrov, 2000[76]; Raffone and Leeuwen, 2002[77]; Tsuda, 2001[78]; Breakspear, 2004[79]) have made theoretical comments and proposals regarding the manner in which a dynamic approach could be useful, in general, in the reasoning study, making reference implicitly, or, sometimes, more explicitly, to the deductive

of the long-term semantic priming, which is attributed to an incremental learning leading to increased stability of an attractor corresponding to a presented pattern playing the prime role.

[65] K. Vezerides, Ath. Kehagias, *The Liar and Related Paradoxes: Fuzzy Truth Value Assignment for Collections of Self-Referential Sentences*, CS Arxiv TR cs.LO/0309046, 2003, http://users.auth.gr/~kehagiat/KehPub/techreps/200309046.pdf

[66] L. Shastri, V. Ajjanagadde, *From Simple Associations to Systematic Reasoning: A Connectionist Representation of Rules, Variables and Dynamic Bindings Using Temporal Synchrony*, "Behavioral and Brain Sciences", 1993, 16, p. 417–494.

[67] W. Bechtel, *Natural Deduction in Connectionist Systems*, "Synthese", 1994, 101, p. 433–463.

[68] P. Gärdenfors, *op. cit*.

[69] B. Goertzel, *Chance and Consciousness*, "Dynamical Psychology. An International, Interdisciplinary Journal of Complex Mental Processes", journal in electronic format, 1996, http://goertzel.org/dynapsyc/dynacon.html

[70] R. W. Kentridge, *Critical Dynamics of Neural Networks and Spatially Localised Connections*, in: *Neurodynamics and Psychology*, M. Oaksford, G. D. A. Brown (eds.), Sand Diego, CA: Academic Press, 1994, p. 181–215.

[71] M. Oaksford, M. I. Malloch, *Dynamic Schemata: Evidence from Cognitive Neuropsychology*, in: *Neurodynamics and Psychology*, M. Oaksford, G. D. A. Brown (eds.), London, Academic Press. 1994, p. 83–106.

[72] H. C. Sabelli, *Non-Linear Dynamics as a Dialectic Logic*, in: *** *Proceedings of International Society of System Sciences*, 1995, p. 101–112, http://creativebios.com/Nonlinea%20Dynamics%20as%20a%20process%20logic.html

[73] C. Eliasmith, *The Third Contender: A Critical Examination of the Dynamicist Theory of Cognition*, "Journal of Philosophical Psychology", 1996, 9, p. 441–463.

[74] N. Kataoka, K. Kaneko, *Functional Dynamics I. Articulation Process*, 1999, http://arxiv.org/ps/adap-org/9907006.pdf

[75] N. Kataoka, K. Kaneko, *Functional Dynamics II. Syntactic Structure*, "Physica D", 2000, 149, p. 147–196.

[76] V. Dimitrov, *Strange Attractors of Meaning*, 2000, http://www.zulenet.com/VladimirDimitrov/pages/SAM.html

[77] A. Raffone, C. Van Leeuwen, *Activation and Coherence in Memory Processes: Revisiting the PDP Approach to Retrieval*, "Connection Science", 2002, 13, p. 349–382.

[78] I. Tsuda, *Toward an Interpretation of Dynamic Neural Activity in Terms of Chaotic Dynamical Systems*, "Behavioral and Brain Sciences", 2001, 24, p. 793–847.

[79] M. Breakspear, *"Dynamic" Connectivity in Neural Systems Theoretical and Empirical Considerations*, "Neuroinformatics", 2004, 4, p. 205–226.

reasoning case, too. They could be viewed to be sketches of some future more elaborated dynamical models accounting for the deductive processes, offering guiding principles in their development. The review of the existing studies from the scientific literature dedicated to the application of a dynamic approach in the reasoning research shows that the dynamic modeling of the deductive reasoning is only in an incipient stage[80].

Synthesizing the above mentioned contributions, the following ideas seem to be fundamental for the present dynamic approach of the deductive reasoning:

• *Deriving a conclusion requires the stabilization of a cognitive dynamic system into a dynamic structure*[81] after receiving the input information given in the premises.

• A stable dynamic structure could be important for a deductive reasoning for two reasons: it brings coherence to the given data and it *allows the needed reduction of the degrees of freedom when selecting the answer for a deductive task through the constraints generated by dynamic interactions*. In the same time, the stabilization into a dynamic structure with no guaranteed constancy in time[82] offers *an elegant way to explain the temporal fluctuations and the context-dependency in an individual's performance when solving a deductive task* and the obvious needed flexibility in approaching it.

• In order to facilitate a dynamical modeling of the deduction, the *classical notions of symbols*, *concepts, relations, rules or cognitive schemata* that are invoked in the symbolic computationalist models of the deduction *could be dynamically interpreted to be such emergent stable dynamic structures, having a meaning partially changed*[83]. In fact, they represent rather conceptual tools to describe the dynamic deductive processes at a higher spatio-temporal scale, without the need to assume an external executive agent charged with the task of manipulating the symbolic representations and with that of applying symbolic rules. A dynamic approach, in some radical versions (Lawson & Luis, 2004[84];

[80] They generally contain reasons sustaining its utility, suggestions or principles supposed to be useful in building dynamic networks capable to solve deductive tasks, or in the interpretation of some empirical findings (for example, the oscillatory behavior that occurs in trying to solve a logical paradox). A few of them actually present dynamic networks with a limited, but encouraging, deductive performance. What is still missing is a systematic theoretical approach at an intermediate level of analysis and a substantial link with empirical findings and the existing theories from the cognitive psychology.

[81] Such dynamic structures could be attractors of various types or configurations of attractors together with trajectories linking them, resultant from chaotic itinerant processes.

[82] Such dynamic structure is vulnerable to noise or fluctuating due to an intrinsic dynamic in the case of the cyclic or chaotic attractors.

[83] For example, a rule is thought to be a regular transition between stable states, whereas a cognitive schema is meant to be a stable state (i.e. a configuration in a multidimensional space) or a configuration of such stable states together with the trajectories linking them.

[84] J. Lawson, J. Lewis, *Representation Emerges from Coupled Behavior*, in *Workshop Proceedings of the 2004 Genetic and Evolutionary Computation Conference*, June 26th–30th, 2004, Seattle, WA, 2004.

Chemero, 2001[85]; Portugali, 2002[86]), admits the possibility of a deductive reasoning even without rules, or even without the classical notion of representation. In such a theoretical framework, even the border between semantic and syntactic processes is erased.

•*The truth values of the statements or the semantic meanings involved in a deduction might be interpreted to define continuous or discrete dynamic variables, which evolve in time through their mutual interactions until a conclusion is generated*. The dynamics of the truth variables could be coupled with the semantic dynamics defined by temporally evolving meanings (at various levels of abstraction) of the concepts involved in a deductive task, *accounting for the interaction between the so-called syntactic and semantic levels in deriving a conclusion*.

•*Logic in a dynamic context is conceived to be of a different type than the classical static logic, having changed principles*[87]. Therefore, *the deduction is not*

[85] A. Chemero, *Dynamical Explanation and Mental Representation*, "Trends in Cognitive Science", 2001, 5, p. 140–141.

[86] J. Portugali, *The Seven Basic Propositions of SIRN (Synergetic Inter-Representation Networks)*, "Nonlinear Phenomena in Complex Systems", 2002, 5, p. 428–444.

[87] In the first place, *the identity principle* in its classical form looses its meaning. *In a symbolic theoretical framework*, this principle reflects the demand that a symbolic representation has to be discrete and to preserve its semantic and referential meaning throughout a deductive process. Such a requirement stems in fact from the clear separation between a relation representation and the representation of its arguments, and consequently between a semantic and a syntactic level that imposes a serial application of rules in successive steps. Therefore, symbolically, thinking, in a deductive reasoning process, is progressing through chains of relations (operational through rules) that must have common points of contacts in order to be bound together. It is a linear, additive process. Even the building of an integrative symbolic mental model from precursor models is based on the same assumption that its symbolic constituents (symbolic tokens) have the same meaning in all the precursor models, as a necessary condition of their integration in a unified model. So, the bounding link between two relations must be a common argument that is to be found in both of them as a symbolic representation having the same meaning, separated from the meaning of the relations in which it was included.

Instead, *in a dynamic theoretical framework*, if the idea of representation is admitted, a so called dynamic representation does not have any clear identity in the traditional sense, because it rather has continuous, fluid borders and a context-dependent actualization of its meaning constituents. At most, its identity could be defined in what respects the continuity of its dynamic coupling or interaction with a referent system, or of its states changing in time. It has, therefore, temporal borders (i.e. when the transition from a state to the other do not passes through intermediary states, i.e. it is not gradual, and sudden jumps occur in the evolution of a system through its state space). Moreover, a dynamic representation is able to change itself and other representations not solely by an external intervention (by changing the value of some control parameters), but also by virtue of its intrinsic dynamics. In consequence, its semantic meaning incorporates an inseparable relational meaning. So, there is no need of a distinction between the representation of a relation and that of its arguments, between a semantic level and a syntactic one. Because it is assumed that thinking is progressing not by concatenation, but by parallel, simultaneous interactions, in a nonlinear fashion, the supposition of a common constant link is in a dynamic context rather irrelevant. Deriving a conclusion dynamically requires continuity in time, finding a trajectory towards a stable state leaving from an unstable one, *any more explained in the terms of the constraints stemming from the classical logical principles, but in the terms of the constraints stemming from the definition of a dynamic system and its related concepts.* They are temporal constraints generated through the interaction between dynamic variables, and the competition for actualization of a state or dynamic structure to the detriment of another state or dynamic structure.

• A *temporal code for information at the level of the transition between states or the dynamic coupling between systems* (leading to relationships of synchronization), by its intrinsic properties could be beneficial for a dynamic modeling of the deductive reasoning.

• In explaining deductive reasoning *it would be preferable to assume the existence of at least two dynamically coupled systems that are operating on a micro and, respectively, macro spatio-temporal scale, which are able to control (by providing control parameters) the dynamic behavior of the other one*. Through this physical separation, it is possible that the circular influence existing between different levels of organization in what respects their dynamics to be altered and, consequently, controlled.

Synthetically speaking, in my view, the core of a dynamic approach of the deductive reasoning could be founded on a link between the definition of a dynamic system and the definition proposed by me for the deductive reasoning. *Through a dynamic system, the variation in time of one variable is bound to the variation in time of other variables, their way of bonding being controlled by some set values of other variables*. It is this property of a dynamic system which, in my opinion, is fundamental for an understanding of the logical processes if those

and not continuity in the meaning of the involved symbols from an external representation of a given information. In fact, if ones introspects herself/himself, it is possible to discover that, for example, in a syllogistic reasoning, the meaning of the middle term is changing from the first premise to the second one (in accordance with its particular relations with each extreme term, or simply by acquiring the status of middle term at its repetition in the second premise). Similarly, if deduction means knowledge progress, it is reasonably to assume that the meanings of the two extreme terms are also changed in conclusion in comparison with their meaning in the given premises, incorporating the knowledge regarding the derived relation with the other extreme term. The *emergence phenomenon*, through which a totally new entity results on a higher level of organization by the interaction of dynamic entities placed on a lower level of organization, emphasizes the fact that in a dynamic system new information could be obtained through sudden jumps, without an uninterrupted semantic chain of links between the precursor concepts and the resultant concept. An emerged concept is not compositionally approachable in a traditional sense.

In the second place, there is no need of *the principle of non-contradiction*, also, since representations could have a fluctuating meaning and truth values for assertions are allowed to vary continuously. In a dynamic version, this principle would mean that a system could not be in two different states at the same time.

Finally, *the "tertium non datur" principle* is not any more tenable, from the same reasons, in general, as the previously mentioned ones (for the .non-contradiction principle). Its dynamic version would be that a dynamic system could be only in one of the two (or more) competing attractors.

processes are to be modeled dynamically[88]. As it was stated before, in the general definition proposed for the deductive reasoning, deriving a conclusion means practically to determine an unknown value for a relational variable based on the values of some other variables. Since, in our mind, reasoning processes are not instantaneously, but take place in time, it might implicitly mean that the involved values are values that are changing in time.

Therefore, taking in view the above mentioned property of a dynamic system, it would be reasonable to assume that the values determined on a certain point in time through a deductive reasoning process for the variables included in a logical conclusion (for example, truth values or meanings) are the result of the evolution in time of a subjacent dynamic system in which they are included as variables together with other relevant variables (such as those whose values occur in the stated premises).

As a consequence, it could be said that the time at which an involved dynamic variable takes a certain value has a cognitive significance (Van Gelder, 1998)[89], directly contributing to the result of the considered cognitive process given the temporal constraints expressed by its inclusion in a dynamic system.

In comparison, in a process based on a symbolic system, time as such has no cognitive relevance, being considered only for pragmatic reasons linked with the so called implementation level, or with aspects of the human deductive performance. A symbolic system is a static one, because symbols and the semantic or syntactic rules through which they are manipulated are not changing in time, and do not interact. Rules provide constraints regarding the allowable transitions (from the entire set of possible transitions) from a symbol of the system to another one (inclusively from a rule to another). But these are not fully temporal constraints for two reasons. The first one is that they operate as constraints only if an external mysterious agent puts them to use, in a physical system (which is, in fact, a dynamic system). The second one is that they do not determine a relative duration in time of a transition in comparison with the duration of other transitions, but only an allowed temporal order (a rudiment of temporality) in the context of a certain goal (therefore, the time length of a transition is considered to be only an implementation matter). A process linked to a symbolic system is initiated and driven from outside, by such a mysterious agent capable of choosing and applying only successively the relevant rules to an array of symbols, substituting and rearranging them serially, in order to obtain another array of symbols. So, the resulting temporal order implicitly existing in that process is not ascribable to that symbolic system, but to an agent who uses that system in order to attain a goal of her/his own, since a symbolic system has neither goals, nor agentic power. Without

[88] It offers a natural and elegant manner to explain the way a variable is settled into some particular value based on the values of other variables within a particular process, by assuming that all the involved variables are linked into a dynamic system.

[89] T. J. van Gelder, *op. cit*.

the possibility of ascribing states (as temporal properties having values variable in time) to the symbols (even only with binary or discrete values), through which they could gain the status of a dynamic variable, symbolic systems are inert.

In a symbolic process, what could be defined to be its state is the array of symbols that are allowed to be at a certain time in an operational state (defined by their activation status or their presence in a work space that are properties variable in time). But this state does not have cognitive significance, does not lead by itself to another state, if the symbols are not allowed to interact autonomously. Without an external agent and its goals, the process would remain indefinitely in that state. From a dynamic state of view, it is a state of neutral equilibrium, not of dynamic equilibrium.

Symbolic systems could be conceived, at most, as being simply languages for an idealized descriptions and formalization of the behavior of some dynamic system (of whatever nature they might be) when it is projected onto a geometrical space. It is known that it is possible to define the state of a dynamic system at a certain time as the set of values taken by its dynamic variables at that time. Therefore, the behavior of a dynamic system is describable in a state space having as coordinates its dynamic variables with their allowed variation intervals. The points of that space represent all the possible combinations of the values from the domain of variation of each dynamic variable with the values of the domains of the remaining dynamic variables of that system, i.e. all its possible states. But given the interaction between those dynamic variables, not all those states are actually attainable, and their status differ in what respects the time the systems remains in them without an exterior influence, or in what respects the necessary power of that influence in order to change that state**. In other words, there is a dynamic property ascribed to each state, named stability, indicating its power to retain the system in it**. Through the interactions among the dynamic variables of a dynamic system, there are also restrained the possible transitions between a state from its state space to the neighboring states. Expressed differently, it means that they determine all the possible trajectories of a system through its state space. If the states with a significant stability and the trajectories linking them are symbolized in some way, then the behavior of a dynamic system becomes describable using a symbolic system in which the primitive symbols represent states in the state space, and the syntactic rules are actually transition rules from such a state to other states.

Therefore, a dynamic approach of the deductive reasoning could have integrative virtues in what respects the symbolic theories with which it is in competition, although it cannot be reduced to them, having a supplementary contribution of its own. It is my belief that there are reasons for which that contribution has the potential to overcome the above mentioned impasse, in which the deductive reasoning research seems to be caught for quite some time.