Outline of a new approach to the nature of mind

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Abstract

I propose a new approach to the constitutive problem of psychology 'what is mind?' The first section introduces modifications of the received scope, methodology, and evaluation criteria of unified theories of cognition in accordance with the requirements of evolutionary compatibility and of a mature science. The second section outlines the proposed theory. Its first part provides empirically verifiable conditions delineating the class of meaningful neural formations and modifies accordingly the traditional conceptions of meaning, concept and thinking. This analysis is part of a theory of communication in terms of inter-level systems of primitives that proposes the communication-understanding principle as a psychological invariance. It unifies a substantial amount of research by systematizing the notions of meaning, thinking, concept, belief, communication, and understanding and leads to a minimum vocabulary for this core system of mental phenomena. Its second part argues that *written* human language is the key characteristic of the artificially natural human mind. Overall, the theory both supports Darwin's continuity hypothesis and proposes that the mental gap is *within* our own species.

Keywords: Cognitive science, communication, meaning, nature of mind, psychology, representation, thinking, understanding, *written* human language.

1. Foundational issues

Mind is the constitutive problem of Psychology. Psychology's disunity is contrastively interpreted. For some it is inherent (e.g., Koch 1981) for others it is sign of a "would-be-science" in need of unification to achieve the status of a mature science (e.g., Staats 1999). I assume that full unification is not necessarily impossible. At this point the following caveat should be made. If practically possible, the working hypothesis objective is both far away in the future and not achievable along the lines of most current research programs. Therefore, my main objective in this article is to briefly argue for *the need* of the cognitive science community to take *a radically new approach* to the study of mind and subsequently illustrate it by *systematizing* the following three core research areas of the nature and workings of mind: 'thinking', 'representation' and 'communication'. That is to squarely tackle the foundations of cognitive science.

The first explicit statement of the need to discuss the foundations of psychology was Staats (1981, p. 253): "it is important to consider the nature of unified theory and the methods involved in unified theory construction. These are topics our science has thus far not addressed." To date the most comprehensive and theoretically coherent description of the current foundations of cognitive science is contained in Newell's (1990) *Unified Theories of Cognition*.[1] It constitutes the undisputed basis of the still dominant computational paradigm and is squarely based on Turing's (1936, 1950) work and the physical symbol systems hypothesis (Newell & Simon 1976). Recent, more or less, promising alternatives are still much less developed in terms of their foundational descriptions of the nature of mind.[2]

The rest of this section, except the last paragraph, proposes modifications with respect to the received scope, methodology, and evaluation criteria of a unified theory of mind (UTM) in accordance with the requirements of evolutionary compatibility and of a mature science.

Newell (1990 p. 16) was fully aware of the enormity of the task. "Clearly, I can't mean a theory of all that! A unified theory of cognition is just a fantasy." Consequently, he proposed the unification of a subset of behaviour along the lines of the following priority list: Problem solving, decision-making, routine action. Memory, learning, skill. Perception, motor behavior. Language. Motivation, emotion. Imagining, dreaming, daydreaming, …. He was crystal clear. A unified theory "is a cognitive theory that gets significantly further down the list cumulatively than we have ever done before. If someone keeps asking how the unified theory explains dreaming or how it describes personality, I will simply point back to this list. It is right to ask, but wrong to insist." (ibid. p. 15). Although, Newell was right on the cumulative aspect of a unified theory he was mistaken about his priority list. A theory of mind that does not address a minimum core of mental phenomena like meaning, thinking, emotion, and communication should not count as a UTM. As a result, Newell's foundational vocabulary cannot account for phenomena like language and consciousness.

Newell's methodology is probably the most important characteristic of his work and it is widely followed. He argued for unified theories of cognition to be formulated as architectures.[3] The choice of architecture as the theoretical tool for developing a unified theory is conceived to be particularly important because it provides the interface between structure and content (Newell 1990, p. 82) or the abstraction that gets at the essence of mind (Anderson 2007a, p. 7). This position can be based on the familiar philosophical distinction of the personal sub-personal level

(Dennett 1969) and the associated discussions of levels of descriptions and of the relation between psychology and physiology (e.g., Anderson 1987; Broadbent 1985; Changeux & Dehaene 1989; Rumelhart and McClelland 1985).

Nevertheless, such an interface may usefully be employed for AI systems only. As Newell (1990, p. 86), from a slightly different perspective, put it: "[in] any analysis of the architectures of natural systems, the concepts available from computer architectures are useful, although they hardly do the whole job." Currently, cognitive architectures are inadequate as tools for a UTM because they are hardly comparable to either the human nervous system or the individual human architecture at large. Recent attempts to utilise data from imaging research (e.g., Anderson 2007b; Anderson et. al. 2004) are highly commendable. Nevertheless, they do not change the fact of the inadequacy of cognitive architectures as the key tool for unified theories construction for as long as their specifications fall short of accommodating design constraints like evolutionary compatibility and the full temporal scale of human action (in contrast to focusing on the cognitive and rational bands).

With respect to abstraction, neither cognitive architectures nor, more generally, mathematical modelling is adequate for the *current* level of development of cognitive science. It is true that precision, completeness, and self-consistency are the key advantages of computational modelling and indeed, as Abbott (2008) remarks, of equations. Nonetheless, a language-based *system* of time-dependent definitions can have the same characteristics, while at the same time *being enhanced* by the vagueness of human language. As Werner Heisenberg (1959, p. 188) wrote:

> "one of the most important features of the development and the analysis of modern physics is the experience that the concepts of natural language, vaguely defined as they are, seem to be more stable in the expansion of knowledge than the precise terms of scientific language, derived as an idealization from only limited groups of phenomena."

This position should not be seen as being against the use of mathematics or computational modelling. It is only against their premature use. We first need to sort out, and most likely expand and extend, our concepts before formalising them. The human conceptual system is far richer than human language and that in turn is far richer than our formal systems. We cannot put the cart before the horse.

Seeking a UTM across the full temporal scale of human action demands interdisciplinarity, and the latter demands in turn field-wide theoretical constructs. They provide a common reference frame for discussion, facilitate criticism and the finding of gaps or inconsistencies and minimize potential misunderstandings. We do not currently have even a partially complete system of such theoretical constructs for a UTM. The ones proposed in section 2.1 are illustrative of the posits required for bridging biology and sociology.

Evolutionary compatibility demands the variability of both the space of mental phenomena and of particular mental phenomena themselves. For instance, written language was not in the space of mental phenomena of Homo habilis and key phenomena like thinking have been modified in the course of Homo evolution. In addition, the rate of human evolutionary change is, in some important respects, different from that of other animal species. Still, other phenomena like 'representation' go back for hundreds of millions of years and therefore have to be seen in the light of their successive transformations through evolution (cf. Table 3). Furthermore, transformations of different phenomena influence each other by means of multiple feedback loops throughout their evolutionary existence. For a UTM such phenomena include: 'representation', 'thinking', 'communication', and 'language' (cf. Figure 2). Identification of the multiple, distinct but related senses of such phenomena is a requisite first step. The explicit use of the time variable in defining them is a useful reminder of their evolutionary characteristics and a necessary tool in the gradual transition from our vague conceptual apparatus to a less imprecise theory.

Evaluation criteria –by revealing weaknesses- constitute a significant tool in the development of a scientific field. Newell's final list of thirteen evaluation criteria (constraints in his words) fall into two categories: performance requirements and construction constraints (Newell 1990, pp. 18-21).

A revised version of those criteria was used by Anderson & Lebiere (2003) as the Newell test for the evaluation of cognitive theories.[4] Although there was agreement of both the target article authors and commentators that the N-test is not complete (e.g., Agassi 2003, Anderson & Lebiere 2003, Gelepithis 2003, Sirois 2003, Taatgen 2003), and some argued it is not fully appropriate (e.g., Young's (2003) proposal to substitute compliancy for universality, Wang et al.'s (2003) questioning of its theoretical attainability), no-one made the point that the N-test is actually more inadequate than the original list as a basis for evaluating a unified ToM.

The argument is simple. Newell's original list includes two criteria that are absent from the proposed Newell test and which Newell himself considered necessary, namely, "operate autonomously, but within a social community" and "be constructible by an embryological growth process." (e.g., Newell 1990, p. 20). In addition, the first criterion on the original list does address a major human capability while reflecting a performance requirement (ibid. p. 20). In contrast the first criterion on the proposed N-test (computational universality) provides straightforward grading but leads to contradictions (Young 2003).[5] The inadequacy of the original list itself is due to the omission of field requirements like invariant laws and minimum vocabulary. Simon (1990) has elevated the discovery of invariant laws to the status of the fundamental goal of science and has suggested two laws of qualitative structure and four quantitative findings as invariants. Surprisingly, although Newell (1990) strongly believed that the computer hierarchy is an invariant law, he did not included invariant laws as a criterion of a unified theory of mind. I fully agree with Simon. In section 2.1.2.3 I propose the communication understanding principle (CUP) as a psychological invariance.

A minimum vocabulary is a clear sign of the maturity of a science (Russell 1948). Even if not completely attainable, their quest is useful in accordance with the principle of parsimony. Cognitive science needs a minimum vocabulary to serve as its descriptive base and substantially decrease the bewildering multiplicity of terms used. In section 2.3, I propose a set of words that seem to constitute a minimum vocabulary for a small but significant part of cognitive science. It is a consequence of the theory outlined in section 2. Concluding on the evaluation criteria of a UTM, I propose that invariant laws and minimum vocabularies should be an integral part of such a system.

The next section proposes an account of mind that is both in accordance with the constraints identified and breaks away with the long tradition of the intrinsic individuality of mental phenomena traced back to James's conception of Psychology as the study of "finite individual minds". In addition, although there are many specific, contemporary research programs dealing with 'thinking', 'representation', and 'communication', there was none that had attempted to synthesize all these areas as well as a considerable part of the *disparate* underlying research and propose a, much needed, *minimum vocabulary* for this cluster of core mental phenomena. This is the objective that next section approximates. Specifically, in the introduction to section 2 I set out the central working hypothesis of the proposed approach and introduce the key relations among the foundational notions of my theory. Section 2.1 presents the key features of the *exclusively natural mind*, and section 2.2 argues for the key characteristics of the *artificially natural mind*. In evolutionary terms the latter stage is only a fraction of the former. Accordingly, the bulk of the proposed theory is in 2.1 where thinking, meaning, communication and understanding are addressed. This cluster of ever evolving abilities and structures accounts for the continuity between humans and non-human animals. Section 2.2 tackles the issue of representation and argues that the ability to create external representations was the necessary breakthrough for the eventual appearance of *written* human language and the consequent dawn of the era of the artificially natural mind. The uniqueness of modern Homo sapiens is due to this artificiality. Our uniqueness is of our own species construction. Section 2.3 summarizes the key points.

2. The Evolving Nature of Mind

Within the scientific community, it is generally agreed that 'mind' is not immaterial and that it is embodied and situated. In essence when one talks of 'mind' it is taken to mean 'the mind of an individual'. Still, it is not in accordance with the widely accepted perspective, in the biological community, of both species and of their constitutive organisms as individuals. The following working hypothesis incorporates this view:

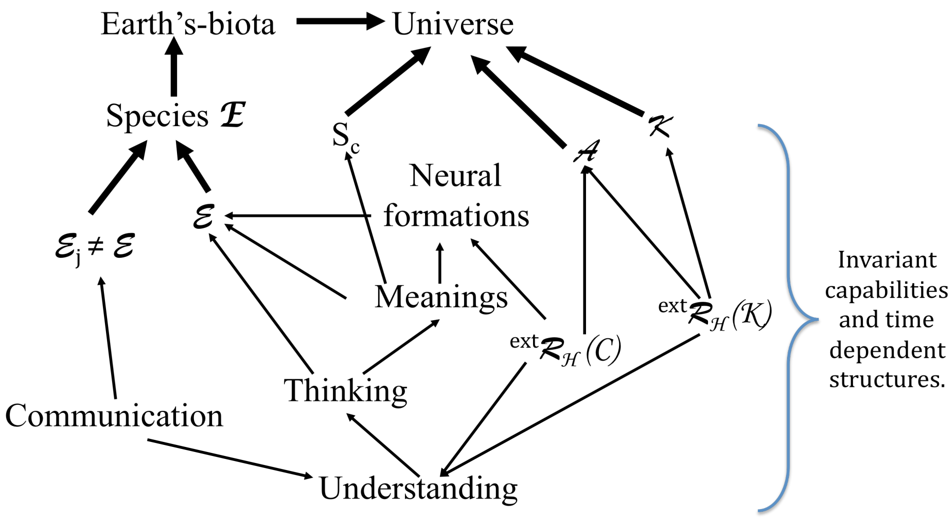
'The mind of individual $\mathcal{E}$ ' ≡ 'individual $\mathcal{E}$ of noémon species $\mathcal{I}$'. [6]

I make use of the adjective noémon (plural: noémona) in order to avoid misleading connotations by the use of 'mental' or 'cognitive'. It is derived from noûs, a Hellenic language noun and it is used in this article in the technical sense introduced by the following definition.

Definition-1: Noémon species $\mathcal{I}$ is a species whose individuals:

a) Possess one or more sensory systems.
b) Possess one or more motor systems.
c) Possess the ability of thinking.
d) Are able to communicate with other individuals of their own species.
e) Possess the ability of creating representations.

My reason for this radical departure from the received wisdom is simple. Within a naturalistic Weltanschauung, 'species' is the essential prerequisite notion for both biological and social sciences and a theory of mind requires the integration of both perspectives. This requisite integration, coupled with the inadequacies of the computational paradigm pointed out in section one, necessitates a re-description of mind. Figure 1 depicts the key relations among the foundational notions of such a theory. This nexus is fleshed out in the subsequent sections.



ε stands for individual of species $\mathcal{E}$.
S_c stands for stimulus within its context. $\mathcal{A}$ stands for artificial construction.
$\mathcal{K}$ stands for an external situation. C stands for conception.
$^{ext}\mathcal{R}_{\mathcal{H}}$ stands for human ability to create external representations.

Figure 1. Relations among key capabilities, structures, individuals and their environment. Bold face arrows stand for 'part of'; regular arrows for 'defined in terms of'.

A first look at Figure 1 gives the impression that the *sought* theory of noémona species ($To^n\mathcal{E}$) is purely cognitive and hence inappropriate for the task. This is not the case. Although the terms 'thinking', 'understanding', 'meaning' and 'communication' are associated with a cognitive (i.e., information processing) approach, the theory redefines them (sections 2.1 & 2.2) in a way that makes the perceptual, affective, cognitive, motivational, and action aspects of mind *inseparable*. To be noted in particular that the sensory and motor systems posited in definition-1 are literally foundational in the sense that all animals possessed bodies before they possessed nervous systems.

Equally important is the time parameter characterising all key elements of the theory that necessitates consideration of the complex developmental aspects of the individual. *All aspects* of an individual (including its unconscious) are *inseparable*. The usual methodological strategy of divide and conquer is fundamentally wrong. We need to consider all aspects of the individual however crudely at first and refine subsequently. Refinement is necessary in order to understand nearly any phenomenon deeply. But such division of labour should be constrained by both *the inseparability constraint* and general overall principles. Naturally, the latter may change when adequate new evidence accumulates. But such a change will reflect deeper understanding rather than patchy additions to the results of a biased strategy. Apart from specific arguments and proposals, an important objective of the proposed theory is to illustrate the potential of this approach.

Finally, I want to make explicit the following two working hypotheses. First, I adopt the mind-brain identity (MBI) hypothesis.[7] Second, I will use extensively a special case of the evolutionary compatibility constraint introduced in section one, namely, the range of problems a 'mental' phenomenon may refer to *depends on the particular evolutionary period and the taxon that one is considering*. This rather obvious point has important consequences that are usually overlooked.

2.1. The era of the exclusively natural mind

Unobjectionably, thinking and communication constitute significant aspects of the human mind. Moreover, each phenomenon and associated notion encompasses a cluster of related mental phenomena and notions. The common key structural element of the two clusters is meaning. This section brings together into a *theoretical system* the constituent elements of these two clusters by proposing:

(i) A naturalistic theory of meaning that for the first time delineates the class of meaningful neural formations (section 2.1.1).

(ii) A hybrid theory of communication that bridges biology and sociology (section 2.1.2).

The inseparability constraint is satisfied by systems of primitives (section 2.1.2.2) that bind together all aspects of the individual as member of a society (with or without a culture).

2.1.1. Thinking

There are three major approaches to the study of 'thinking': philosophical (the oldest), computational (the currently dominant), and biological. Each has contributed its own requirements for a theory of 'thinking'. Philosophy rightly assumes, implicitly or explicitly, that cracking the problem of meaning is the real issue that needs to be accounted for. Consequently, all theories of thinking (and of concepts) end up as one or another of a large number of theories of meaning (e.g., Davidson, 2001; Lurtz 2007; Millikan 1998; Newen & Bartels 2007; Peacocke 2001.

Computational approaches are split between those adopting the strong AI view (thinking is computation) shared by a large number of investigators from Turing (1950) through Newell and Simon (1976) to Dietrich (2007), and a more or less computationally oriented view shaped by the need to incorporate the substantial expansion of research into areas like implicit thinking (e.g., Litman & Reber 2005), motivated thinking (e.g., Molden & Higgins 2005), emotional effects (e.g., Ashby et al 1991; Thagard 2002*2006). The latter perspective is probably best exemplified by Holyoak and Morrison's (2005a) reader. In remarking on the difficulty of providing scientific definitions of mental terms, they illustrate that difficulty with their own preliminary definition of thinking:

> *"Thinking is the systematic transformation of mental representations of knowledge to characterize actual or possible states of the world, often in service of goals."* (Holyoak and Morrison 2005b, p. 2, their emphasis).

As they self-critically remark, their definition introduces "a plethora of terms with meanings that beg to be unpacked, but which we can only hint." (ibid). The implicit requirement is for a theory of thinking within a wider context. Probably, the most general proposal is mental models (Johnson-Laird 1993; 2005).

Biologically, the most elaborate treatment of the nature and basic mechanisms of thought and mind as the activity of the brain is still by Hebb (1949, 1968, 1976, 1980a, 1980b). Subsequent work in this tradition either tried to expand on some of his ideas (e.g., Changeux 1983*1985; Edelman 1987; Edelman & Mountcastle 1978; Freeman 1975; 1999) or moved into the fascinating area of animal thinking (e.g., Bates et al. 2007; Köhler 1925; Norman et al. 2001; Shetlleworth 1998; Sulkowski & Hauser 2001; Premack 1985; Taylor et al. 2007). In both cases no contribution to the nature or basic mechanisms of thought was made. It should be noted that despite Hebb's legacy, his argued view (Hebb 1949, 1980) that the study of mind can be advanced if only we develop biologically constrained *theories* was not really taken up.

The objective of this section is to build on and extend Hebb's theory of thought consistently with the key requirements of the philosophical and computational approaches. Specifically, such a theory should ideally be:

a) Described in terms of a naturalistic theory of meaning.
b) Broad enough to encompass animal, and ideally machine, thinking.
c) Rich enough to be able to account for human thinking.
d) In accordance with observable behavior and biological evidence.
e) An integral part of a (much larger) theory of mind.

The proposed theory makes only two additions to Hebb's classic work. First, it addresses the mind-body problem in terms of neural formations. Second, it extends the notion of 'thinking' to fully cover condition (b).

2.1.1.1 The structure of the animal mind: A biological theory of meaning

The pursuit of a theory of meaning is one of the fundamental issues of cognitive science. Some would argue that it is the discipline's holy grail (e.g., Jackendoff 2002, 2003). Among philosophers, a few claim that it is an eliminable notion (e.g., Searle 1992, meaning as derived intentionality of linguistic elements), others that is the foundation for all philosophy (Dummett 1973). Having accepted its necessity, some have argued for (e.g., Katz 1972) and some against (e.g., Putnam 1988) the possibility of developing a theory of meaning. Table 1 provides a summary of the key advantages and disadvantages of the main theories of meaning along with a succinct presentation of their views on its nature.[8] Despite the immense amount of work though, no widely accepted theory of the nature of meaning exists.

Table 1. Summary of key advantages and disadvantages of the main theories of meaning.

Name and Key proponents	Nature of Meaning	Main Advantage	Main Disadvantage
RTM. Russell 1905, 1919.[9]	The language-world link	Pinpointed the relation of language to the world	Too narrow. It cannot account for e.g., indexicals.
ITM. Grice, 1957, 1968, 1969.	Intended effect on audience.	Distinguishes between linguistic and non-linguistic meaning.	Inability to combine personal with public meanings.
UTM. Wittgenstein, †1953.	Use.	Recognizes the effect of context on meaning.	Ignores underlying mechanisms.
LTM[10]. Katz & Fodor 1963; Chomsky 1965.	Purely linguistic.	Inclusion of syntax to account for meaning.	Excludes context and the world.
TTM. Tarski 1944; Davidson, 1967, 1973, 1974.[11]	Knowledge of truth conditions.	(a) Pinpoints the relation of thought to the world. (b) Succinct representations.	Cannot account for non-truth conditions.
AITM. Jonhson-Laird 1977.	Procedure.	As with UTM. As with TTM (b)	Cannot account for non-executable expressions.
Id.TM. Locke 1690; Saussure †2006; Ogden and Richards 1923.	Encoding.	Considers the close relation of language to thought.	Cannot account for the abstraction problem.
BTM. a) Osgood, 1971, Osgood & McGuigan 1973. b) Dretske 1981. c) Millikan 1984, Macdonald & Papineau 2006.	a) Function of response. b) The condition that typically causes an intentional state. c) Truth conditions of intentional states in terms of the biological functions of these states.	Brings in our relation to things.	Does not recognize perceptual effects on meaning.
STM, Mead †1934*1962.	Reside in social collectivities.	Take into account the sociocultural dimension of meaning.	Ignore the biological dimension.
TM = Theory of Meaning RTM = Referential TM TTM = Truth TM STM = Social TM			

ITM = Intentional TM	AITM = AI TM
UTM = Use TM	Id.TM = Ideational TM
LTM = Linguistic TM	BTM = Behavioural TM

In what follows I propose a theory of meaning that put the MBI hypothesis on an empirical basis.[12] The assumption requires human meanings to be identified with neural formations.[13] Consequently, and most significantly, one has, *first*, to crack the fundamental problem of delineating a class of meaningful neural formations. The following two definitions provide conditions that do just this.

Definition-2: For an animal $\mathcal{A}$, I call neural formation, N, a structure of *interacting* sub-cellular components across nerve cells able to influence the survival or reproduction of $\mathcal{A}$.

A clear example of N is a synapse; any type of neuronal synapse. A second example is the type of structure developed by the interaction among astrocytes, pre-synaptic and post-synaptic terminals. I italicized 'interacting' to emphasize the fact that processes are part and parcel of neural formations. As is well known such interactions involve extremely complex reentrants. The reader will also have noticed that I used the word 'structure' rather than system in the above definition. The reason is that I wanted to avoid drawing any connotations of *necessary* completeness and, on the contrary, I wanted to indicate the sense of *potential* fleeting existence. In other words, neural formations may be either sort-term or long-term. Naturally in accordance with standard biology, the cardinality, size, shape, composition and interconnections of neural formations change over time. These characteristics are aspects of what I mean by the term 'complexity' of a neural formation. The time dependence of such neural complexity (i.e., its evolutionary development) gives rise, through phylogenetic changes, to multiple types of, potentially qualitative, complexity. Table 3 tentatively introduces some indicative levels of such neural complexity.

Two more points should be noted. First, the proposed notion is heavily based on Hebb's (1949, 1980) notion of cell assemblies. Their key difference boils down to the former being more inclusive allowing for instance the possibility of non-synaptic plasticity (Kandel & Pittinger 1999; Bollmann & Engert 2009) and non-neuronal correlates of mental abilities (e.g., Bennett 2007). Second, neural formations *are not, necessarily,* mental representations (see definition-16). The next definition delineates the class of meaningful neural formations and therefore extends the traditional sense of meaning. As we shall see it is used to redefine the traditional senses of meaning (definitions 5, 6 and relation (2)). It is thus a truly foundational notion (cf. the memory-meaning postulate in 2.1.1.2).

Definition-3: For an animal with nerve tissue, $\mathcal{A}$, a neural formation is meaningful (symbol N_m), if and only if it is an N that influences the attention of that $\mathcal{A}$.

Two remarks should be made here: (i) on the nature of attention; and (ii) on the verifiability of N_m. My main justification for making attention the distinguishing feature of the class $\mathcal{N}_m$ (the time-dependent totality of all N_m structures) is threefold: its relation to working memory (e.g., Baddeley 2003; Postle 2006); James' attribution of the features of "degree of reactive spontaneity", focalization, and interest, and Freud's attribution of special significance to the link of 'attention' to the unconscious. The very considerable amount of subsequent psychological research has not improved our understanding of 'attention' (Johnston & Dark 1986) but it has confirmed initial conclusions (e.g., Awh et al. 2006). More recently, neuroscientific work both added a significant link to the anatomy of attention (Posner & Peterson 1990) and provided added details (e.g., Knudsen 2007; Nummenmaa & Calder 2008; Reynolds & Heeyer 2009). It should be noted that despite its neuroscientific interest and potential applications neuroscientific research has not, to date, contributed to the elucidation of the nature of attention.

In conclusion and for the purpose of this article, I will assume that 'attention' is proto-characterised by James' features of "degree of reactive spontaneity" and focalization, and subsequently shaped by the special evolutionary compatibility (SEC) constraint. This implies the time dependence of N_m and therefore of attention. In other words, the proposed definition is a definition of proto-N_m. In accordance with the SEC constraint, the $\mathcal{A}$ taxon includes a very large variety of N_m and corresponding attentions. Obviously, this variety cannot reflect the posterior reflection of any single species (not even of the Homo sapiens!). Therefore, human aspects of attention do not enter the definition of attention at the $\mathcal{A}$ level. As the theory develops though and higher complexity levels of N_m are introduced, the space of $\mathcal{A}$ narrows down (i.e., there is a smaller number of species possessing such increasingly higher levels of neural complexity). In accordance to the $To^n\mathcal{E}$ proposed here, exclusively human meanings only appear when we reach external representations (section 2.2). Still humans are an extant biological species and as such their meanings have to share at least some of the earliest developments of nervous systems. In the rest of this section after the next paragraph, we redefine the traditional senses of human meaning and meaning-related notions in accordance with definition-3. In summary, $\mathcal{A}$-meanings are subject to the SEC constraint and a variety of factors may apply to one or more species but not to others. This is particular true of certain human factors like affect, motivation, and scientific curiosity.

On verifiability, as Mike Elstob noted (personal communication), given the inadequate current resolution of fMRI scanning there seems to be a problem in actually linking N_ms to conditions like (a) and (b) above. Although, this is true there appear to be at least two routes to a possible solution. One route may be via exploitation of the bridge between neural formations and homeostasis that glia cells provide.[14] The second route is linking the reproduction or survival of extremely simple animals like sponges to genes in their proto-post-synaptic scaffold. Such a link would seem to provide further justification for the proposed definition through advances in our understanding of the evolutionary transition from sponges who lack neurons with clearly recognizable synapses to earliest nerve systems (Sakarya et al. 2007). To account for the traditional senses of meaning, I first need the following:

Definition-4: I will use the symbol $\mathcal{S}_c$ to stand for a stimulus within its context.[15]

$\mathcal{S}_c$ may be either perceptual or linguistic or a combination of the two. With respect to a human $\mathcal{H}$, an $\mathcal{S}_c$ may be novel (i.e., not previously encountered) or not. If novel, two sub-cases can be distinguished: (i) for whatever reason, no meaning is assigned to $\mathcal{S}_c$ (an N may be created though); and (ii) a meaning is assigned to $\mathcal{S}_c$. The following two definitions address the case of a novel $\mathcal{S}_c$ and previously encountered $\mathcal{S}_c$ in turn.

Definition-5: The meaning of a novel $\mathcal{S}_c$, for the human $\mathcal{H}$ at time t, is whatever N_m is created by the interaction of $\mathcal{S}_c$ and $\mathcal{H}$ at time t.

Definition-6 The meaning of a previously encountered $\mathcal{S}_c$, for the human $\mathcal{H}$, at time t is the *prevailed* N_p of $\mathcal{N}_p$.

Some terminology and a couple of remarks are in order here. $\mathcal{N}_p$ is that subsystem of $\mathcal{N}_m$ that has been relatively permanently developed by the time t. Of course, $\mathcal{N}_p$ is a proper subsystem of $\mathcal{N}_m$. It is only natural to identify $\mathcal{N}_p$ with $\mathcal{H}$'s long-term memory. 'Prevailed' means the particular neural formation, N_p that is eventually selected among its family members $\mathcal{N}_p$. Now, the strength of N_p to $\mathcal{S}_c$ does not necessarily determine whether a neural formation will eventually prevail or not. The term is used to indicate the potential complexity involved in the struggle for selection (e.g., unconscious vs. conscious processes). Needless to stress that both external (e.g., Pavlovian or operant conditioning) and internal (e.g., emotions, understanding) processes are usually involved. Second, the proposed definition does not require of $\mathcal{H}$ to be aware of the previous occurrence of $\mathcal{S}_c$. In other words, it allows the possibility of subliminal stimuli recording.

So far we have introduced the notion of meaningful neural formations and the meaning of external (either perceptual or linguistic) stimuli. When the external stimulus is linguistic, its associated meaning usually comes under the heading of linguistic meaning. When the external stimulus is perceptual, its associated meaning has usually been considered under Grice's notion of natural (or non-linguistic) meaning (see Table 1). To complete the range of senses that 'meaning' does cover we need to move into the partly uncharted waters of thought expression. Warning: thought expression is not the same as language production.

To date, structured utterances or written expressions, ℓ, are taken to convey a person's idea(s) beliefs, desire, emotions, motivations, etc. To refer to any –or any combination of- such mental states, I will use the words 'skepsis' or 'skepseis' for the singular or plural cases respectively in the following technical sense:

Definition-7. Skepseis are structures of neural formations that may or may not involve N_m, although normally they do.

Now the traditional scientific view holds that:

(1) M (skepsis) = M (ℓ).

I hold that (1) can be mistaken and that it usually is especially when a skepsis is unusual, unconventional, half-baked, vague, novel etc. In all such cases:

(2) M (skepsis) ≈ M (ℓ).

The symbol ≈ stands for 'not necessarily equal'.[16]

Barring abnormal circumstances, their divergence is due to the creative aspect of thinking and the constraining character of language. Neural formations have *a history of at least half a billion years*. Genetically, a good number of Homo sapiens sapiens Ns may well be identical with neural formations that existed hundreds of millions years ago. Evolution is a near infinite well that modern humans are capable of drawing upon. And this is a key contributor to the expression of new skepseis (i.e., novelty). Language will never become able to exhaust nervous systems evolution.

Our current models, framed by assumption (1), essentially address the structure and constraining character of human language. I think it is time to adopt a more comprehensive approach: Relation (2) should replace assumption (1) as framework hypothesis for realistic models of skepseis. Any serious neuroscientific account of meanings and thinking should not push under the carpet the huge complexity involved in the creation of utterances or expressions out of skepseis. It has to be realised that language is a substructure of thought.[17]

So, when relation (1) is not the case, what is the M(skepsis)? It is an ℓ whose meaning, even for the speaker or scriber, only approximates her skepsis. My argument is appeal to private evidence. Nevertheless, empirical verification is, in principle, possible by linking a computational system to a human's brain. Furthermore, in accordance with Boden's (1992) distinction between historical and psychological creativity, a historically novel ℓ is more likely to be caused by (N, N_m, $\mathcal{H}$, t,), and a psychologically novel ℓ by (N_m, $\mathcal{H}$, t,). In summary, although we are bound by language we can also extend it thanks to our evolutionary past and our ability to create external representational systems (section 2.2).

The following four definitions and concluding remarks complete the outline of our theory of thinking:

Definition-8: Let ${}^1N_m$ be the first neural formation *created* by the specific triad ($\mathcal{S}_{c1}$, $\mathcal{H}$, t_1). Then the system of all ${}^jN_m$ (j a natural number) of human $\mathcal{H}$ that have been created by time t later than t_1 I call it a concept of $\mathcal{H}$ up to t and I symbolize it by ${}^\varepsilon\mathcal{N}_m$. For simplicity we may use the letter ε to refer to a concept but it has to be understood that ε is identical with ${}^\varepsilon\mathcal{N}_m$. Naturally, a ${}^\varepsilon\mathcal{N}_m$ is a very tiny subsystem of $\mathcal{N}_m$.

Definition-9: σ is a thought of human $\mathcal{H}$ if and only if σ is a flexible and not necessarily permanent structure of concepts and/or N_m (i.e., meaningful neural formations, as per definition-3).

Definition-10: Belief $=_{def}$ A structure of neural formations and meaningful neural formations on the basis of which one is prepared to act, argue, or live by.[18]

Definition-11: Thinking, $\mathcal{T}$, is the interaction of meanings, or concepts, or thoughts, or beliefs, or of any combinations of them.[19]

The meanings and meaning related structures identified by definitions 3, 5-10 correspond to different levels of neural complexity. Collectively, they constitute the semantic structures, $\mathcal{M}$, of an individual's nervous systems. Hebb's theory had a similar structure up to third-level cell assemblies and had also allowed subassemblies of 2-3 neurons. The theory proposed here hardly adds anything to that conception. With respect to actual and potential structural neural complexity the two theories are essentially indistinguishable. Nevertheless, Hebb's theory does not include a theory of meaning and that is a difference of fundamental significance with far reaching consequences.[20] Assuming my theory of meaning holds, the mind-body problem collapses.

Concerning thinking the two theories take the same stance with respect to thinking as a single series of neural formations. Their difference stems from definition-11 that allows for both random and directional thinking. As such thinking operates at any and across any of the complexity levels of an individual's semantic structures ($\mathcal{M}$). When the complexity levels of $\mathcal{M}$ are coupled with the potential number of neural states (of hyper-astronomical cardinality), we get the space of neural thinking. Modern human concepts and beliefs constitute huge subspaces (in terms of the number of N & N_m involved) of this neural space. Still, at the same time, they are the constituents of our conscious attention.

The immensity of the neural space of thinking creates a problem for directed thinking. To account for that, Hebb (1976) proposed that the exceptionally high frequency of inhibitory neurons may have the essential function of streamlining thought. That may indeed be the case. Given the complexity of the neural processes involved we are somehow agnostic on that line of thought. As a theoretical alternative, we suggest the process of understanding (section 2.1.2.1).

The theory developed so far is only a small part of the $To^n\mathcal{E}$ proposed. As we proceed with the latter's development, aspects of the theory of thinking outlined in this section will be modified. Nevertheless, even this far the challenges are immense and so may be the rewards. The next section focuses on some of these ramifications and challenges.

2.1.1.2 Ramifications and challenges

The proposed biological theory of meaning extends the sense of meaning to include the fundamental class of meaningful neural formations. This has far reaching consequences as it is applicable to all $\mathcal{A}$ species according to the SEC constraint. Some of the ramifications follow.

First, the theory satisfies all of the key points made by the earlier theories of meaning as codified in Table 1 albeit on the naturalistic basis of $\mathcal{N}_m$. On this basis it redefines the traditional senses of meaning and meaning-related notions (definitions 5-11, relation (2)) in terms of empirically verifiable conditions. It also provides grounding to all four bands of the time scale of human action that Newell (1990) identified through the processes of communication and understanding (see section 2.1.2 and in particular subsection 2.1.2.2 on primitives). Being part and parcel of $To^n\mathcal{E}$, the theory plays an ineliminable role in addressing also Loar's (1999, p. 546) requirement: "A fundamental element of a theory of meaning is where it locates the basis of meaning, in thought, in individual speech, or in social practices." In the precise senses given in sections 2.1.1.1, and 2.1.2, the proposed $To^n\mathcal{E}$ explains why meaning is "located" in all three: thought (i.e., $\mathcal{M}$ & $\mathcal{T}$), individual speech and social practices. It follows that since human meanings are constitutively determined by both a human and her or his environment (physical as well as social and cultural), pure internalism and externalism are bankrupt in either their semantic or epistemological variety. This may be glimpsed by the sort of sophisticatedly gerrymandering arguments developed in the recent literature (e.g., Goldberg 2007; Williamson 2006). Similarly, the coupling between $\mathcal{H}$ and her environment (postulated by the dynamicists) can be precisely identified by the links specified in 2.1.1.1.

Second, in contrast to Putnam's (1988) argument against the view that 'meanings' (or 'contents') can be seen as 'theoretical entities', our theory has identified the class of meaningful neural formations as the class of "'psychologically real' entities which have enough of the properties we pre-analytically assign to 'meanings' to warrant an identification." (ibid, p. 4).

Third, definitions 5 & 6 explain word meaning as an inseparable feedback loop combination of contextual learning (of situation, events, and objects) and cellular (primarily neural) mechanisms. Furthermore, the postulated mechanisms get empirical support from Markson and Bloom's (1997) evidence that the system underlying word learning is not specific to language. These two points reinforce each other and taken together weigh considerably against the possibility of word learning being an FLN (faculty of language in the narrow sense) mechanism (Fitch et al. 2005).

Fourth, our analysis provides a naturalistic account of the distinction between token and type meanings that is essentially identical with that of Hebb (1980b for a brief argument). It is therefore unlikely to be convincing to those considering the type-token question a philosophical minefield (Aylwin 1985, p. 44) and even an important topic for serious scholarship (Wetzel 2008). We are though obliged to say that within our theory tokens of a type are identified with ${}^{j}N_m$, and the type itself with ${}^{\varepsilon}\mathcal{N}_m$. It should be noticed that in the case of Homo sapiens *prevailed* N_p of higher order N_ms (definitions 8-10) may well capture multiple characteristics of a complex stimulus like that of a beautiful woman.[21] Here we would enter the overlapping phenomena of generalization, categorization and abstraction but consideration of these issues is beyond the scope of this paper.

Fifth, the proposed so far theory of thinking can be used as a *preliminary* system of criteria for deciding whether a particular animal species qualifies the appellation 'thinking species' and, more importantly, to what degree. On this preliminary basis, I would say that parrots as exemplified by Alex (Pepperberg 1999), bonobos as exemplified by Kanzi (Savage-Rumbaugh et al 1998), cephalopoda as exemplified by the mimic octopus (Norman et al 2001), and dolphins (e.g., Herman 1984 et al.) seem to fully pass them to at least some degree. These criteria can be enhanced by the introduction of animal primitive systems (see 2.1.2.1 justification) and should be seen to be compatible with test in comparative biology (e.g., Lefebvre et al. 2004).

Finally, I propose the following memory-meaning postulate (MMP): The memory systems of an individual constitute a proper subsystem of that individual's semantic system which in turn constitutes a proper subsystem of that individual's neural formations. The first step of my argument starts with the observation that the semantic memory tradition (Collins & Loftus 1975; Collins & Quilian 1969) and its later incarnations as the study of categories and concepts (e.g., Medin and Rips 2005) along with suggestions of meaning theories criteria involving memory (Edelman & Mountcastle 1978), indicate a respectable link between memory and meaning. That link becomes stronger when one further observes that both memory and meaning depend on context, time and the individual concerned. Psychiatry provides numerous cases (e.g., Krystal et al. 1995). Nevertheless, understanding the meaning of an $\mathcal{S}_c$ does not imply memorisation of $\mathcal{S}_c$ (suggestion that the memory system is a subsystem of the meaning system). In addition, there are instances of meaningless utterances or inscriptions producible by an individual (suggestion that the meaning system is a subsystem of the nervous system). Finally, memory traces (materialised at sub-cellular level: Kandel 2006; Koch 1999) can be identified with meaningful neural formations.

Taking seriously the MMP implies that the key issues of memory research become key problems for any theory of meaning (cf. and contrast with Sutton 2004).[22] In return, most, but not necessarily all, of the questions on meaning become obsolete or can be translated in the more rigorous framework of memory research to provide a much-needed breath of fresh air. In the millennium issue of the *Philosophical Transactions of the Royal Society B*, Kandel and Pittenger (1999, p. 2027) reviewed a century of accomplishments in the study of memory along "the two major questions that have dominated thinking in this area: the systems question of memory, which concerns where in the brain storage occurs; and the molecular question of memory, which concerns the mechanisms whereby memories are stored and maintained." Although work at the molecular level has monopolized the research on memory mechanisms, the possibility of non-synaptic plasticity is explicitly stated as one possible direction of future memory research. A second important remark is that "[w]hile human memory, both explicit and implicit, is likely to employ similar basic mechanism as that of simpler animal systems, it is also doubtlessly unique in other respects." (ibid, pp. 2042-3). Nevertheless, no specific suggestions are made for either. Meaning results properly incorporated in the memory field (that may well necessitate the development of new memory terms and ideas) can help with both endeavours. A potential basis for a sketchy modeling answer to the systems question (not a proposal for specific neurophysiological mechanisms though) has been suggested in Gelepithis (1989).

In summary and conclusion, meanings, concepts, skepseis, thoughts and beliefs jointly constitute the semantic structures of an individual's nervous systems. The frequency, architectural modifications and even existence of these structures depend on the individual, the species and their environment (physical, cultural or otherwise). Applied to humans, this simple characteristic gives human 'mind' both its fleeting appearance and protean structure. Nevertheless, recognition of the existence of meaningful neural formations and even of the possibility of a full naturalist theory of thinking does not imply a reductionist conception of the human mind. For, as in evolutionary biology the gene is not the object of selection (e.g., Mayr 2004), so meaningful neural formations, and therefore meanings, do not constitute in themselves the criterion of the mental. They provide a necessary substratum. They are not adequate. Several levels of additional organisational complexity are required as the following sections demonstrate.

Challenges. The reader will have noticed that the key difference between definitions 5 & 6 on the one hand and M(ℓ) on the other lies with the source of meaning. In the former cases the source is external ($\mathcal{S}_c$), in the latter it is internal (N and/or N_m). What is common in both cases though, is the complexity of the mechanisms involved in the creation of the semantic structures of an individual. This complexity is staggering. Its source is threefold: (i) neural; (ii) environmental; and (iii) evolutionary. The rest of this section points out some of its elements. The focus is on some of the distinct and related systems involved.

With respect to the notion of meaningful neural formations, the system of mechanisms, $\mathcal{M}_m$, responsible for the creation and modification of $\mathcal{N}_m$ is very complex. This is due to the interaction between the host of basic memory mechanisms involved and the additional mechanisms of novelty as they may be glimpsed from the brief discussion concerning relation (2). Concerning meaning in its traditional sense (definitions 5&6), at least two systems of creation mechanisms are required. First, a system, $\mathcal{M}_p$, that is responsible for creating $\mathcal{N}_p$. The literature on LTM (long-term memory) should be able to provide some useful models. Second, a system, $\mathcal{M}_{ap}$, that is responsible for the appearance of the *prevailed* N_p of $\mathcal{N}_p$. The literature on recall should be useful in this case. Finally, the system of mechanisms, $\mathcal{M}_s$, responsible for the creation of expressions out of an individual's skepseis should be the most complex of all due to the fact that it is, normally, closely knit to both $\mathcal{M}_m$ and the neural aspects of language. This is definitely not helped by the fact that we are largely ignorant of the derivation mechanisms of ℓ that vary from the routine to the creative.[23] It is worth noticing that current (e.g., Abbott 2006) neuroscientific research on cognitive processing is both at its very beginning and possibly barking on the wrong tree with respect to the level questions posed (e.g., switching of neural circuits).

Focusing on humans, is there a system of *core* mechanisms for semantic structures creation that is at work for all humans (barring pathological cases)? Such a system would be an important human universal. The majority of linguistic approaches postulate syntax or, more recently, the FLN (e.g., Hauser et al 2002) as playing a significant role in human meaning construction. Syntactic considerations do play a role in creating ℓ, and therefore, M (ℓ). Nevertheless, that is a far cry from explaining meaning construction (cf. relation (2)). I think that this is a much more complicated and wide-open issue that FLN may be willing to accept.

The theory of thinking developed so far is wide enough to be applicable to a variety of animal species across the evolutionary bush but it is inadequate to capture important aspects of the mind of a large number of animal species and to account for the richness of human thought as manifested in the range of human activities we are aware in everyday life and scientific pursuits. Its key inadequacies are lack of sociality and of the ability to create external representational systems. The next section proposes a theory of communication (the defining characteristic of the social stage of at least animal evolution). Section 2.2 addresses the latter inadequacy.

2.1.2. Communication

Communication is basic to all members of a society. But, what is it really? Despite its vast literature, the problem of the *nature* of communication is either ignored or 'communication' is used, even within a single discipline, as an orienting term rather than as an explanatory theoretical construct.[24] With respect to the former point, it is both interesting and revealing to note that two comprehensive reference works, the *MIT Encyclopedia of the Cognitive Sciences* Wilson and Keil (1999) and *A Companion to Cognitive Science* (Bechtel and Graham, 1998) do not include an entry on communication itself. Instead, the former refers the reader to three related entries: on animal communication (Hauser and Marler, 1999), on Grice (Bach, 1999) and on language and communication (Duncan, 1999).[25] The latter refers one to cognitive linguistics (Tomasello, 1998). None of these entries considers the nature of 'communication'. The same is essentially the case for any of the contributions in six readers, spanning more than eight decades of research in communication (Cobley 1996; D'Ettorre & Hughes 2008; Haliday & Slater 1983; Pool et al. 1973; Smith 1966; Vaina and Hintikka 1984*1985). It is also true for at least indirectly related work on the social nature of human and animal mind (e.g., Connor 2007; Mead †1934*1962; Moll and Tomasello 2007; Vygotsky †1934*1986).

With respect to the ad hoc, discipline-based treatment of communication one may distinguish several perspectives. Act of sharing signs (e.g., Cherry 1978*1980, Dimbleby & Burton 1998, Schramm, 1973).[26] The mathematical theory of signal transmission (Shannon and Weaver 1949). Communication as signalling beneficial to sender (e.g., Slater 1983). "[T]he social mediation of information" (e.g., Hauser 1996; Matessi et al 2008; Roberts 1973). Communication as a means to manage audiences ranging from instructional communication (e.g., Mottet et al 2006) to political communication (e.g., Stanyer 2007). Identification with interaction (e.g., Katz and Danet 1973). Identification with its two commonsense meanings, (e.g., Arlington and Baird's 2005; Benowitz et al. 1984*1985; Murray (1998); Sass (1984*1985); Scott (1996); Tomasello et al 2005).[27] "[A]ny exchange of messages between human beings" (e.g., Runcan 1985). Identification with context (e.g., Sperber & Wilson (1995). Intention-based (e.g., Messer 1994). Intention to produce understanding (e.g., Searle 1999a*2000). The practice of producing meanings and their negotiations by participants in a culture (e.g., Schirato and Yell 2000). Among humans, the process of responding to each other's symbolic behaviour (e.g., Adler and Rodman 2000).

Finally, communication as jointly beneficial signalling (e.g., Maynard Smith & Harper 2003).

Probably, the strongest objection against the use of 'Communication' as a theoretical construct is that it, as opposed to gravity, is claimed to be a socially constructed notion rather than an objective reality and, therefore, any attempt to provide an objective account of it is doomed to failure. Interestingly, this is the view of both those postulating the existence of characteristically social 'facts' (à la Durkheim) and those postulating 'meanings' as the key methodological approach of sociology (à la Weber). This debate in sociology is reflected in the *systems* and *interpretive* perspectives in communication studies (Monge 1977; Putnam 1983). The objection sounds powerful but misses an important point. Both 'gravity' and 'communication' are humanly constructed concepts and both refer to some external phenomena. Their only difference is that 'gravity' has a generally accepted meaning within the Earth-based physicists, whereas 'communication' does not have one within the community of scientists using this notion. It is high time for a conception of communication that could be used as an explanatory tool across the disciplines studying it.

2.1.2.1 A hybrid theory of communication: Sociology and Biology bridged

So far, each disciplinary theory of communication has been built on the basis of a single significant feature of it. Some have chosen the notion of sharing; some the notion of understanding; some the notion of meaning. In addition, no theory has explicitly and consistently taken into account the fact that communication involves persons or other respectable animals and takes time to be completed. The following system of three definitions combines all five fundamental features of communication.[28]

Definition-12: A human $\mathcal{H}_1$ has communicated with $\mathcal{H}_2$ on a topic T if, and only if:

a) $\mathcal{H}_1$ has understood T -symbol: U ($\mathcal{H}_1$, T);
b) $\mathcal{H}_2$ has understood T -symbol: U ($\mathcal{H}_2$, T);
c) U ($\mathcal{H}_1$, T) is presentable to and understood by $\mathcal{H}_2$; and
d) U ($\mathcal{H}_2$, T) is presentable to and understood by $\mathcal{H}_1$.

Definition-13: A human $\mathcal{H}$ has understood something, S, if and only if, $\mathcal{H}$ can think of S in terms of *a* system of human primitives (symbol $\Pi_{\mathcal{H}}$).

Definition-14. π is a primitive of/for $\mathcal{H}$ if and only if the meaning of π is immediate for $\mathcal{H}$.

The rest of this section justifies the proposed system of definitions by providing a full account of the nature of its key notion of understanding in accordance with both the literature and common sense usage.

The philosophical underpinnings of human 'understanding' can be traced back at least as far as the times of Plato and Aristotle and their attempts to provide an account for the human mind. More recently, Locke (1690) and Hume (1758) have written treatises on "human understanding". For both of them, 'human understanding' was essentially taken to be coextensive with the functioning of the human mind. A conception that is more in tune with that of Plato's and Aristotle's rather than any of today's workers in the field of human cognition.[29] Rejecting the coextensive assumption helped in focusing on the process nature of understanding.

As a process, human understanding is applicable to the full time scale of human action. It is observed from approximately 10ms (cf. definition-14) to days, years and more. Most of cognitive science is primarily concerned with phenomena whose duration varies from approximately 100ms to about 10min.[30] The large majority of work on understanding falls within this time scale; it usually comes under the name of comprehension. Orthogonal to the time scale dimension is the analyticity dimension of human understanding. Along the latter dimension schools of thought are distinguished according to whether they consider human understanding as a process to be further analysed into some simpler notions (the analytic school) or consider it as a primitive notion (the hermeneutic school). Most work falls in the analytic-cognitive/rational quadrant (e.g., Greeno 1977; Johnson-Laird 2003; Just & Carpenter 1987; Schank 1972; St. John & McClelland 1990; Winograd 1972).[31] In the analytic-social band quadrant the most important work is that of Pask (1976) and Ziff (1972). Finally, in the hermeneutic-social quadrant the work of Dilthey (1900), Moravcsik (1979), Ricouer (1981) and Habermas (1981*1984; 1987) stand out. Some recent work in the area of mirror neuron systems has attempted to link results in this area to action and in particular the understanding of action (e.g., Jeannerod 2006; Rizzolatti & Sinigaglia 2006). They did not address the issue of understanding per se.

The key conclusion in reviewing the literature on the nature of understanding is that although agreement on its nature has not been reached two attributes of it are virtually universally accepted. First, human understanding always involves the grasp of meaning. Second, human understanding is a process that takes place in human brains/minds.[32] I submit that the reason for the existing disagreements on the nature of understanding stem primarily from having focused on different bands of the time scale of human action. In contrast, the combination of definitions 13&14 and of the analysis that follows cover both the full scale of human action and incorporate all major features of human understanding. In particular it is consistent with both the process nature of understanding and its end result that may be seen as a state. The latter point raises significant philosophical questions that fall beyond the scope of this article.

Now, the important question is 'what are the conditions under which understanding has achieved? Work in the cognitive-analytic quadrant take successful behavior in question-answering tasks, for instance, to constitute an adequate terminating condition. That may be true but it is inapplicable when human understanding is concerned with tasks requiring time scales that fall outside the cognitive and rational bands. Such tasks constitute the bread and butter of the larger part of science (I use the term to include both physical and social sciences and the humanities). Without loss of generality the subsequent development of my analysis will assume tasks of the latter type being the object of human understanding.

Naturally, thinking processes may, and do, terminate somewhere; but not all thinking is called, or can be, understanding. One may, for instance, be interrupted while trying to understand something and subsequently fail to catch again the thread of that particular thinking process. To be sure, there may be future recall of the interrupted process but the point is that at the time of interruption no understanding may be said to have occurred. So, we conclude that not all terminated thinking processes are processes of understanding.

Let us assume then that we witness a case of an undisturbed thinking process. What additional conditions should be fulfilled in order to say that one has understood something? There is a thinking process that will help us to specify these conditions. It may be called alleged understanding, (or misunderstanding), and it occurs whenever people think they have understood something only later to discover that what they had concluded was not the case. The key point in a case of misunderstanding is the fact that one's own predictions or explanations, according to her model or belief system, turn out not to be the case. Assuming there was not any fault in the inference process one concludes that there must have been mistaken premises. We see, therefore, that whenever misunderstanding is reached some mistaken premises must have been involved. We take this fact to be a strong suggestion that to reach understanding one's premises –with regard to the task or phenomenon to be understood- must hold true. Factually, an individual's premises may be a system of primitives or not. Consequently, I distinguish between thinking processes that end up in a system of primitives ($\Pi_{\mathcal{H}}$) or in a foundational belief system (that may include some primitives). The former type of thinking processes I call understanding, the latter reasoning.[33] What both types of thinking have in common is the notion of mathematical validity.[34]

There are six reasons supporting the proposed theory of communication and understanding. First, it provides necessary and sufficient conditions for human understanding which: (a) capture the fact that understanding always involve the grasp of meaning; (b) capture the process nature of understanding; (c) capture the two most significant aspects of the analytic tradition, namely, (c_1) systematicity (since definition-13 implies the existence of a sequence of steps although neither necessarily formal nor necessarily conscious); and (c_2) the requirements of context and motivation as contributing factors in human understanding; (d) are not in conflict with the hermeneutic approach. Second, it does not violate the common sense of understanding as described by most dictionaries and encyclopedias (e.g., Oxford, Longman, Britannica) and used in both scientific and vernacular language. Third, it can accommodate both conscious and unconscious understanding. The former can be quite effortful and take considerable amount of time. Fourth, it naturalises at least part of the process of human understanding by making the end result of it empirically investigable. This may well happen through primitives- or premises- based descriptions and, conceivably, through neural level imaging. Fifth, the integrated character of understanding seems to be in accordance with the integrated character of the brain. Specifically, the context dependence of the end result of understanding in the form of $\Pi_{\mathcal{H}}$ is in accordance with the context-related functions of the right hemisphere while the process nature of it seems to be in accordance with the left one (Bookheimer 2002). Last, and at least equally importantly, the proposed theory can be straightforwardly generalized to any $\mathcal{A}$ taxon. Appropriate taxon primitives can contribute to the design of methodologies that are less biased towards humans, thus addressing Emery & Clayton's (2008) important design requirement of cognitive tests.

Both as a process and at its end result, understanding can be extremely complex depending on the depth that the process is required to go to achieve its end result.[35] The complexity of the process itself is far beyond the scope of this article. The next section looks at the complexity of its end result, namely, systems of primitives.

2.1.2.2 On primitives

Definition-13 is cast in terms of "*a* system of human primitives". It follows that an $\mathcal{H}$ may have understood a particular topic in terms of several different systems of primitives. Such systems may be of their own, of someone else's or of a school of thought (established or not). In relation to reasoning, it is widely recognized how easy it is for someone to reason to different conclusions from those of her fellow if their two foundational belief systems are different.

But what meanings count as immediate? Could the set of human primitives be specified? Suppose we are asked to classify the words set, electron, water and pain in either one of the following two mutually exclusive sets: (i) the set of primitives P; (ii) its complementary P'. It seems that set falls in P electron in P'. What about water and pain? It might seen obvious that H_2O being analyzable to its constituents parts and these in their turn to electrons (among other similar types of entities) should be placed in P'. Still, I can think of no one who would not place water in P. Moreover, set and water are two quite different types of primitives. Set can be a primitive for a mathematician whereas water is a primitive to anyone. What about pain? It might seems obvious to everybody that pain should be put in P, but Dennett (1978) has given a nice, although sketchy, model of pain; it follows that one should put pain in P'. So, we observe that three out of the four concepts can be placed either in P or in P' depending on whom we asked to classify them.[36] So, primitives are of two types linguistic and pre-linguistic or sense ones. The latter are inseparable from the corresponding organism concerned. The former depend on the particular individual $\mathcal{H}$ possessing them. To be noted that as soon as linguistic primitives are expressed they become data and they may only acquire meaning if processed by another human. In summary, $\Pi_{\mathcal{H}}$ is both subjectively and community dependent. More generally, one can convincingly argue that $\Pi_{\mathcal{E}}$ is both individual and species-specific. It becomes obvious now that a $\Pi_{\mathcal{H}}$ or a $\Pi_{\mathcal{E}}$ constitutes an extremely complex system. To get a better idea of this complexity consider the following further characteristics and examples.

First, the fact that the meaning of the elements of a $\Pi_{\mathcal{H}}$ is immediate does not imply that they are necessarily atomic (i.e., not able to be split into simpler ones). Qualia constitute an important class of atomic $\Pi_{\mathcal{H}}$. The second, related, feature is that $\Pi_{\mathcal{H}}$ can change with time. A human may split some of the elements of a $\Pi_{\mathcal{H}}$ into simpler ones or she may actually abandon some. An important special case of $\Pi_{\mathcal{H}}$ modification is usually involved in conceptual change (e.g., Vosniadou & Verschaffel 2004). Third, $To^n\mathcal{E}$ allows acquired primitives in contrast to Fodor's (1994) strongly innatist account according to which primitives are inherited as part of the structure of the brain. Fourth, the systems of $\Pi_{\mathcal{H}}$ are not in accordance with either Fodor's (1983) modularity thesis or Tooby and Cosmides (1992) massive modularity one. Contra Fodor systems of $\Pi_{\mathcal{H}}$ are interrelated via thinking or understanding and therefore not encapsulated. Contra massive modularity, a large number of $\Pi_{\mathcal{H}}$ systems are ontogenetically specific and therefore not adaptations. Fifth, a $\Pi_{\mathcal{H}}$ system is fundamentally different from formal systems of primitives like those identified with pixels or curves (see Schyns et al. 1998 for a discussion). Sixth, since primitives are meanings, a $\Pi_{\mathcal{H}}$ is a subsystem of an $\mathcal{N}_m$. Moreover their characteristics imply that they are quite diverse and diffuse systems of $\mathcal{N}_m$. This claim is in accordance with fMRI results of brain's semantic organisation (Bookheimer 2002). Seventh, primitives are age- individual- cultural- and species-specific. An example of age-related primitives is 'electricity'; it can be a primitive for a toddler but not a primitive for an electrician or quantum physicist. With respect to individuals, 'water' was a primitive for my grandmother throughout her life but it is not a primitive for those knowing that 'water' can be thought of in terms of H_2O. Actually, what may be a primitive for someone may be part of a very complicated theory for another. As an example of cultural primitives consider the host-guest relationship. In India and Hellas for instance, when a potential host invites a potential guest with an expression like ‘come at any time’, she expects such an invitation to be taken literally. Interestingly, if the recipient is an outsider from, say, the Anglo-Saxon culture such an invitation will definitely not be taken literally but simply interpreted as a kind of friendly invitation. Finally, smile seems to be a primitive of humans and of some other primate species only.

To conclude, there is no single definite set of human primitives. Primitives vary both ontogenetically and phylogenetically. Primitives’ variability applies to both sense and linguistic ones. Only linguistic primitives can be acquired. Humans and other animals are born with a range of sense primitives. Sense primitives (i.e., qualia) are atomic. Linguistic primitives (barring those that are names of sense primitives) may be atomic but humans have no way to know that. Finally, a human’s understanding of a particular topic is in terms of a minimum vocabulary for that topic and human.

2.1.2.3 Summary and the Communication-Understanding Principle

First, understanding is a prerequisite for human communication that, in turn, is at the very basis of the existence of the human society. Second, there are multiple levels of understanding corresponding to multiple levels of primitives-based descriptions. Third, the systematic and structured characteristics of understanding makes it a prime tool in the acquisition and (re)-structuring of knowledge and consequently of the shaping of human mental structures. Fourth, the very close relation between understanding and explanation, the fact that they constitute necessary elements of human reasoning, and their role in shaping the cognitive structures of both learners and tutors (Gelepithis and Goodfellow 1992). Fifth, since primitives may, equally well, be either formal or informal, understanding bridges the formal-informal interface. Sixth, understanding and therefore communication can operate across both the conscious/unconscious divide and the linguistic/pre-linguistic stages of human development providing the integrated characteristic of human behaviour. Finally, *the process* of understanding (not its end result) is independent of both any animal capable of understanding and of time.

Of course, this is not to say that the actual process does not take time; only that however long it may take its defining characteristics remain invariant. These two features of understanding: time independence and applicability throughout the evolving space of understanding entities makes understanding an invariant of that space. In particular, of course, the process of *human* understanding is a human cognitive invariant.[37] It is worth noting that the invariance of the understanding process does not imply that understanding is a characteristic of human nature in the sense employed by evolutionary psychologists (e.g., Tooby and Cosmides 1992). For the understanding process is not a developmental program. It *is* a complex brain process affected by both ontogenetic and environmental factors.

Along similar lines of reasoning, the process of communication should also be an invariant.[38] It is important to be noticed that the proposed invariance of communication does not entail the claim of the invariance of human nature (e.g., evolutionary psychology; Wilson 1998). Whether it is a universal in Brown’s (1991) sense fall outside the scope of this article.

On the basis of the above, I propose that the processes of communication and understanding are the fundamental processes shaping the structure of mind both in the exclusively natural era and the era of the artificially natural mind. This I call the communication-understanding principle (CUP). The next section accounts for the additional characteristics of the latter era.

2.2. The era of the artificially natural human mind

This section identifies the key characteristic of the artificially natural human mind and the subsequently derived uniqueness of *very* modern humans (i.e., modern humans not later than seven thousand years ago –symbol $\mathcal{H}_{7\text{kya}}$). Specifically, I propose that written human language (WHuLa) is the key characteristic of $\mathcal{H}_{7\text{kya}}$. It is the novel result of the combination of two considerably earlier human traits: speech and external representations. WHuLA is the necessary breakthrough for the consequent dawn of the era of the cumulatively artificial (i.e., the ever increasing totality of the human-made systems and structures).

2.2.1 The nature of human representations

The literature on 'representation' is daunting and controversial.[39] Dietriech (2007, p. 1) remarks that "no scientist knows how mental representations represent". What is worse though is, that it is still the case that what counts as representation is unclear (Boden 1994). Actually, the literature on representation conflates human thinking and mental representations with knowledge representation (KR) schemes. The result is stalled progress on both. This section identifies both important similarities and the key difference between mental and external representations. The identified key difference is partly responsible for the uniqueness of human mind within the continuity of animal evolution.

All approaches to 'representation' draw upon or combine, in varying degrees, two fundamental ideas: (i) aspects of Peircian semiotics; and (ii) the mathematical notion of isomorphism.[40] Von Eckardt (1992) made explicit the common view of the nature of representation adopted by the majority of cognitive scientists. That view is a simplification of Peirce's theory essentially identifying his notion of "interpretant" to a "thought or series of thoughts in the mind of the interpreter" (ibid). Computational formalisms, whether logic- or graph-based, try to explicitly describe the "interpretant". Within the theory outlined in 2.1.1.1, the latter is usually a concept and sometimes a skepsis. To refer to either of these, I use the symbol $\mathcal{C}$ (cf. Figure 1). The connectionists' representational tools (vector spaces) and the dynamicists' differential equations share exactly the same objective. Newell (1990) added to this Peircian view the notion of mathematical isomorphism that he calls "the representation law". This is a pretty simple and useful picture but not the whole one. It is a conception avoiding Peircian complexities but biased towards KR schemes and tool-based reasoning. This has contributed to relatively powerful computational models but impoverished conceptual interaction with other fields. The next few paragraphs clarify the above points.

Consider the following ubiquitous examples of external human 'representations' $\mathcal{A}$ and try to think of the *underlying processes* that created them:

a) Designs of all sorts and small scale models like those used to re-present a major urban development, a spacecraft or a teddy bear.
b) Logic expressions, camera images, geometrical diagrams, computer programs, equations.

c) Ubiquitous artistic forms in theatre, painting, sculpture, or cinema to name the most obvious ones.
d) Certain patterns or behavioural acts like those involved in speech, sign or written language.

In all these cases, $\mathcal{A}$ are characterised by the following properties: (i) they are simplifications of some situation $\mathcal{K}$; (ii) they aim to preserve the essential characteristics of $\mathcal{K}$; (iii) they can be processed by humans; and (iv) they are part of a physical material. Therefore:

Definition-15: For a human $\mathcal{H}$, an external representation of a situation $\mathcal{K}$ *is* an artificial construction $\mathcal{A}$ characterised by the properties:

a) $\mathcal{A}$ is a simplification of $\mathcal{K}$; and

b) $\mathcal{A}$ has been designed or constructed by $\mathcal{H}$ in order to preserve the essential characteristics of $\mathcal{K}$.[41]

We now face two questions. One, what are the essential characteristics of $\mathcal{K}$? Two, how does one decide that X is one of the essential characteristics of $\mathcal{K}$? The received answer to the first question is straightforward: what counts as 'essential' depend on the objective(s) of the representation. Within a given KR scheme this is realised by the following two parameters:

(i) The aspects of $\mathcal{K}$ that $\mathcal{H}$ has decided to represent (technically known as the scope of a representation); and

(ii) The amount of their detail (technically known as the grain size).

This standard analysis clarified by definition-15 is quite powerful and adequately addresses Van Fraassen's (2008, p. 15) query: "We confront here the general question of how an item such as a picture can correctly represent, misrepresent, caricature, flatter, or revile its subject." Notice for instance that "correctly represent", "misrepresent" etc are all representations (as defined above) differentiated by the parameters of scope and grain.

The second question though falls outside the standard analysis and leads one to distinguish between thinking (definition-11) and tool-based reasoning. The latter, although ultimately depends on human thinking and primitives, is characterized by a system of rules which –after having been specified by $\mathcal{H}$ - enable anyone to draw conclusions mechanically. Naturally, such tool-based reasoning whether it is carried out by grammars, graph theories, or in general, mathematics- either ignores the psychological mechanisms of thinking or identifies them with the inference mechanisms of a particular KR scheme.[42]

At this point, if not earlier, one may question the significance of our second question. So, let us be clear about it. Its significance stems from the need to distinguish between 'the human ability to create (systems of) external representations' (${}^{ext}\mathcal{R}_{\mathcal{H}}$) and the end result of that/those process(es). Finding out the mechanisms of ${}^{ext}\mathcal{R}_{\mathcal{H}}$ would be a major breakthrough, studying or using its end results (e.g., grammars and other formal systems) is useful to the extent of their applicability. In view of the analysis in this and the previous sections, I am tempted to suggest that an investigation of the mechanisms of ${}^{ext}\mathcal{R}_{\mathcal{H}}$ through the process of understanding and its associated systems of primitives may be worth pursuing.

The next step in the study of human representations is even more demanding. What are the neural mechanisms of $\mathcal{R}_{\mathcal{H}}$ (i.e., the ability to create *neural* representations)? The added difficulty may easily be seen when one realizes that $\mathcal{R}_{\mathcal{H}}$ may well involve unconscious processes while at the same time its end results lack the specificity and concreteness of external representations or KR schemes (end results of $^{ext}\mathcal{R}_{\mathcal{H}}$). Still, assuming the continuity of the Homo genus (and therefore of some relation between neural and external representations) and, furthermore, taking into account the notion of perceptual image, we find it reasonable to adopt the following working:

Definition-16: For a human $\mathcal{H}$, a neural representation of a situation $\mathcal{K}$ *is* an $\mathcal{N}_m$ structure such that:

a) It is a simplification of $\mathcal{K}$; and

b) It tends to preserve the essential characteristics of $\mathcal{K}$.

This is both in agreement with neurobiological requirements of internal representations (e.g., Blakemore et al. 2002, Moser et al. 2008) and avoids Ramsey's (2003) criticisms of receptor representation. It is also straightforwardly generalisable to hold for a good number of animal species in full agreement with Bickerton's (1990) argument that a primary representational system, developed in various forms, exists in all higher animals and Hurford's (2003) argument of powerful neural representational systems. Finally, it is compatible with the classical ethological finding of relative uniqueness of nearly every species through their species-specific representational capabilities. Similarly to $^{ext}\mathcal{R}_{\mathcal{H}}$, specification of the mechanisms of $\mathcal{R}_{\mathcal{H}}$ (in contrast to mere identification of its end result) is a significant open question in the study of mind. As with $^{ext}\mathcal{R}_{\mathcal{H}}$, it appears that $\mathcal{R}_{\mathcal{H}}$ may well be related to understanding. In contrast to $^{ext}\mathcal{R}_{\mathcal{H}}$, such understanding, if indeed related, may, more often than not, be unconscious and hence hardly accessible with the current state of technology. Whether they do, and if yes, exactly how they are related is a second important question.

It is worth noting that neuroimaging experiments, incorporating the notions of scope and grain size of a representation, may just be possible to indicate potential neural structures that preserve certain characteristics of $\mathcal{K}$. Kurto & Itskov's (2008) work on group cells and their relationship to the Kantian concept of space may be seen as an example of such work. It should be stressed though that the issue of neural representations, even in the special case of spatial representation with its nearly forty years history (e.g., O'Keefe & Dostrovsky 1971), has far too many open questions (e.g., Moser et al 2008) for definitive conclusions on its nature to be drawn.

In conclusion, additionally to characteristics derived from their common root in neural thinking (cf. section 2.1), mental and external representations share the crucial feature of 'preserving the essential characteristics of $\mathcal{K}$.[43] The key difference between the two kinds of representations is the potential permanence of external representations. This is partly responsible for the uniqueness of human mind. The next section identifies its complementary part.

2.2.2 The mental gap is *within* our species

The aim of this section is to briefly argue that WHuLa is the key characteristic of $\mathcal{H}_{7\text{kya}}$ and therefore the mental gap is *within* our species; Darwin's continuity hypothesis is sound despite recent challenges (e.g., Penn et al 2008; Premack 2007).

WHuLA is the novel result of the combination of two considerably earlier human traits: speech and external representations. Its unprecedented power stems from the combination of speech's compositionality with the potential permanence of external representations. Its continuous development, along with communication and appropriate corresponding species actions, eventually led to the era of the cumulatively artificial. Figure 2 depicts the both the ultimate causes of WHuLa and the key relations among the requisite abilities and tools that contribute to the ever-increasing development of human-made structures and systems.

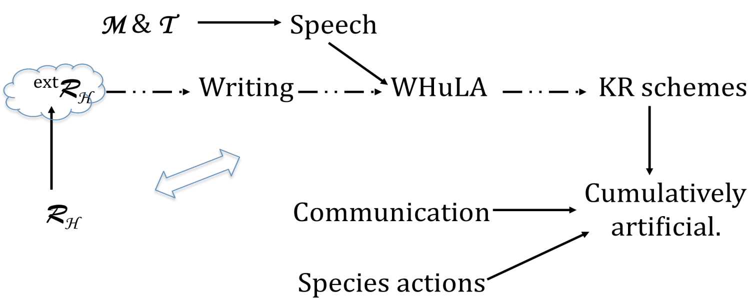


Figure 2. The becoming of modern humans. Symbols are explained in text.

The processes involved are extremely complex with several multiple, time-dependent and intra-species interactions. Some of them operate in ontogenetic time, some in phylogenetic time (the double arrow in Figure 2 stands for reminding us of the significance of such interactions). The following paragraphs intend only to clarify and strengthen my claim rather than describe the posited process in any detail.

I start with a terminological point. I take writing to be a human communication system that uses conventional visible marks. This is essentially Gelb's (1963) definition of writing and is substantially different from Diringer's (1968 p. 8) definition: [w]riting is the graphic counterpart of spoken language." For the latter notion I use the abbreviation WHuLa.[44] Furthermore, I assume that writing has a psychological basis and an artefactual existence.[45]

It is widely agreed, especially in the linguistic and anthropological communities, that 'human language' is the defining characteristic of Homo sapiens (e.g., Sapir 1929; Deacon 1997; Donald 1991). Because of the established historical, functional, and biological priority of speech over written language (Lyons 1981), the former is subsequently considered the original defining characteristic.

I stated my disagreement and claim earlier. Here are the reasons for it. WHuLa is transforming human mind and human society in ways that speech is, *in principle*, unable to do.

Skepseis (definition-7) can be expressed in oral, sign, or written form. In the first two cases they are either lost in the air or, at most, they may affect the state of a close-by listener or recipient. The third case has a unique characteristic though: relative permanence. *Written skepseis are a sort of a neural fossil.* They may well outlive the person who expressed them.

In the era of the exclusively natural mind, individuals –even with the help of complex speech- were extremely weak in terms of short-term memory although, comparatively, very powerful in terms of long-term. The latter feature could and did support traditions but no substantial philosophy, science, technology or history. The creation of WHuLa resolves both the ephemeral and extremely limited range of short-term memory and the restricted and potentially distorted permanence of long-term. Consider, for instance how oral tradition while extending ontogenetic durability at the same time eventually distorts the transmitted information (for better or worse).

WHuLA enables deeper understanding of a phenomenon, claim, or description by enabling one to juxtapose and scrutinize ideas independently of the time and place of their production. Such a technology allows then the transition from speech (a capability enabling the transfer of 'useful' traditional knowledge among generations) to the stage of knowledge accumulation. Finally, WHuLa enabled tool-based reasoning in the form of mathematics and eventually KR schemes.

When skepseis are written, they can act as an $\mathcal{S}_c$ to any person who may read them at any point in time. In particular, of course, they act as a stimulus to their creator. Therefore, a feedback loop is originated that becomes a *system* of feedback loops if related skepseis and the their written expressions are further created, or if the person has 'second thoughts' on the precision of her translation. I call such interactions *hybrid* ontogenetic loops (HOLs).

A remark concerning *hybrid* ontogenetic loop systems should be made here. Clark (2008 p. xxviii), building on Clark & Chalmers (1998), claims that such systems "are not all in the head". He is partly right and partly wrong. He is obviously right when he claims that human technology is enhancing human thinking. This is indeed the case and happens through HOLs. This is a rather well known view (e.g., Ong 1982; Gardenfors 2003*2006). He is wrong nevertheless, in claiming that thinking itself is literally realised externally in the form of symbolic or material re-arrangements.[46] For, the external parts of HOLs are fossilized *skepseis*. Without a person to interpret and think about them, they will forever remain inert. Clark & Chalmers (1998*2008 p. 222) write that: "If we remove the external component the system's behavioural competence will drop, just as it would if we removed part of its brain." This is true but beside the issue in hand. The question is what does happen when there is no brain at all. And the answer is nothing at all. In HOLS, persons are necessary for the loop to be operational; the external parts of HOLs, on their own, do not realise any thinking at all. They exclusively *record some* aspects of the skepseis of an individual.

Less general than WHuLa, but at the same time much more powerful in their predictive and design capabilities, are the various KR schemes that modern Homo sapiens has developed. Their invention/discovery and their further creative use by *very* modern humans brought us straight into the era of the cumulatively artificial. The era of computational systems, electron microscopes, implants, world-wide web, and robot scientists. Still, their extreme significance and novel consequences should not disguise the fact that, on their own, they are useless.

It follows that the structural complexity of the *modern* Homo sapiens is not going to be found materialised in human brains. Not because the human mind is immaterial –which is not. Not because part of human thinking is realised outside an individual's brain –which as we saw it is not. But because the development of $\mathcal{H}_{7\text{kya}}$ is causally shaped by the development of WHuLa and the associated development of science and technology. They provide the artificial component of the nature of human mind. Of course there large dissimilarities between human and animal cognition (e.g., Premack 2007), my claim is that they are due to WHuLa.

2.3. Summary

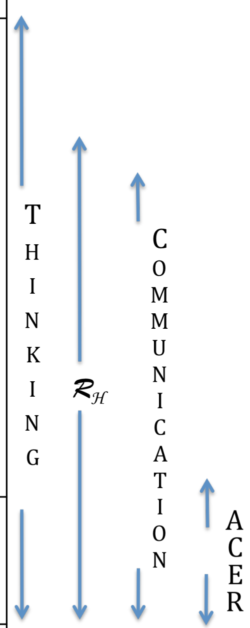
To facilitate commentary, the complementary Tables 2 & 3 summarize most of the major points. The following paragraphs either clarify a particular point in the Tables or state a major point that I could not include in them.

Table 2. Mapping of sections to primary results of To$^{n}\mathcal{E}$.

Sections	Primary results
Section 2.1.1.	∗ Proposed theory of meaning provides empirically verifiable conditions for delineating class of meaningful neural formations. ∗ Neurolingusitic structures constitute substructures of $\mathcal{M}$. ∗ Proposal of the MMP.
Section 2.1.2.	∗ Proposed theory of communication bridges the collective and individual aspects of human action and mind in terms of $\Pi_{\mathcal{H}}$ that span their full scale from the biological to the socio-historical bands. ∗ Continuity of human and non-human animal minds, through partly shared $\Pi_{\mathcal{E}}$ (see below). ∗ Proposal of the CUP as a psychological invariance.
Section 2.2.	∗ WHuLa is the key characteristic of H_{7kya}. The discontinuity is *within* our species. It is caused by the development of the artificially natural human mind.

Table 3. Rough mapping of key animal abilities to Eras and posited nervous systems.

Posited types of Nervous Systems (NS)	**Era**
Simplest NS (i.e., structures of $\mathcal{N}_m$)	Exclusively natural mind.
NS incorporating meanings NS incorporating thinking NS incorporating memories	
NS originating and externalizing actions	
NS incorporating concepts	
NS incorporating representations	
NS incorporating thoughts	
NS originating and externalizing representations	Artificially natural mind.
NS enabling writing	
ACER = Ability to create external representations = $^{ext}\mathcal{R}_{\mathcal{H}}$	



Finally, it appears that the following words: {species, individual of species, Earth's biota, attention, neural formations, interaction} constitute a minimum vocabulary ($\mathfrak{V}$) for the small but significant part of mental phenomena considered in this article.

3. Open Issues

Of the many remaining open issues the following seem to me among the most important. First, there is the problem of the appropriate formulation of a *'mental phenomenon'*. If the theory proposed here is accepted a good number of accepted distinctions will cease to exist and a significant number of new problems will appear. Among the latter probably the most important is the task of understanding more thoroughly and deeply the extremely complex interactions between the social and biological aspects of humans as well as the much more difficult tasks of the relations among human communities and the emerging new era of the artificial. Among the former, it seems that the mind-body problem will be the first that will have to be abandoned with a domino-effect ramifications.

Second, there is the issue of the suitability of our current tools for developing a theory of individuals as parts of noémona species. It seems to me that most current mathematics is inadequate for such an endeavour. The precision of equations and computational systems is at odds with the precise vagueness of the mammalian nervous system. To describe the $\mathcal{M}$ and $\Pi_{\mathcal{H}}$ structures, as well as the systems of fundamental processes and associated loops identified earlier, 'the mathematics of thinking and communication' is required. This is a branch of knowledge humans have not yet developed. It is always good to be kept in brain that even order is not a prerequisite for phenomena like emotion. As James (1890, Vol.2, p. 146) factually remarked: "Different feelings may coexist in us without assuming any particular spatial order." I would therefore urge that for the foreseeable future the methodology outlined in the introduction is to be preferred to the usual mathematical tools employed. Development of a fully-fledged language-based definitional system compatible with as many field-wide empirical data and regularities as possible seems the best way to proceed in the present state of the art. This may be one way towards 'the mathematics of thinking and communication'. Assuming that such mathematics is possible.

Third, there is a need to try to identify invariant laws for cognitive science. Simon (1990) has elevated this objective to the status of the fundamental goal of science and has suggested two laws of qualitative structure and four quantitative findings as invariants. Newell (1990) strongly believes that the computer hierarchy is an invariant law. Nevertheless, the issue is far from straightforward. Relations to universals and classification are just two of these.[47]

Fourth, cognitive science needs a minimum vocabulary to serve as its descriptive base. The one proposed in the previous section may be taken as a first step. An appropriate $\mathfrak{V}$ must be able to account for at least the following areas of an augmented cognitive science: knowledge, consciousness, emotion, culture, motivation, ethical values, and beauty. It appears that consciousness and knowledge may be explainable in terms of the theory proposed here. To demonstrate such a hunch and modify or not $\mathfrak{V}$ is the major task I intend to address next.

Fifth, mental neuroscience needs to map observed types of NS complexity to fundamental animal abilities and semantic structures ($\mathcal{M}$). In speculative mode, I posit several such types in Table 3. Empirical evidence may collapse/expand some of the posited types. Their rough correspondence to fundamental animal abilities and loops may help the design of neuroscientific experiments.

Finally, as a community, we should pay careful consideration in the emergence of, and the consequences brought by, the era of the artificial. Definitely, it is not an exclusively cognitive science issue; not even of an augmented cognitive science. It is also a political and most importantly an ethical issue. All the more so, that we need to pay very careful attention to it.

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[1] Whether cognitive science is a perspective rather than a science (Hunt 1989) or whether it constitutes a renaming of the field of psychology (Newell 1990) raise potentially important issues beyond the scope of this article. In what follows I use the two terms interchangeably.

[2] Within the cognitive architectures approach examples include: Anderson 1983; Anderson & Lebiere (1998); Anderson et. al. 2004; Grossberg & Kuperstein (1989); Smolenski & Legendre (2006); Sun (2002). Alternative approaches include: vector spaces (e.g., Bunge 1980); modularity (e.g., Chomsky 1980a, 1980b; Fodor 1983); extended mind hypothesis (e.g., Clark & Chalmers 1998; Logan 2007); the dynamical hypothesis (e.g., Van Gelder 1998); mind as a decision-making organ (e.g., Gintis 2007); the Pleistocene mind hypothesis (e.g., Tooby & Cosmides 1992); the theory of neuronal group selection (e.g., Edelman 1987); brain-inspired non-linear dynamics (e.g., Freeman 1999).

[3] As a result of this a lot of AI systems have been proposed as cognitive architectures (for a recent survey see Vernon et. al 2007).

[4] For an earlier, different, list of criteria and comparison of Act-R (e.g., Anderson 1990, 1993), AuRA (e.g., Arkin 1990), Soar (e.g., Newell 1990,1992) and TNGS (e.g. Edelman 1987), see Gelepithis (1999).

[5] Anderson and Lebiere's argument for computational universality is essentially based on earlier views of Newell (1980). But Newell made references to his earlier work including Newell (1980) whenever he thought it appropriate and he most definitely did not do that in the case of the first criterion. For more on the overlap among the various proposed criteria see Gelepithis (2003).

[6] Interestingly and importantly, the posited hypothesis is consistent with the indterdependent construal of self characterising non-western cultures as well as parts of western psychology and social sciences (e.g., Markus & Kitayama 1991). A good example of the latter is the increasing interest in social cognition and, in particular, collective memory (see editorial (Barnier & Sutton 2008) and associated theoretical and empirical papers in a special issue of *Memory*).

[7] It should be noted that acceptance of the MBI is a minority viewpoint. The majority view, outside the computational paradigm, is that mental processes are *caused/produced* by the firing of neurons (Searle 2007 for a brief argument). See Borst (1970) for a still excellent provision of the main variants of MBI (or identity theory as it is alternatively known). For some important recent work see Chalmers's (2002) collection of readings.

[8] Table 1 is a lightly revised version of a similar one in Gelepithis (1988). It does not include new names for earlier theories (e.g., experience-grounded semantics, conceptual role semantics or model-theoretic semantics for the TTM, functional role semantics for essentially the use theory of meaning, or informational semantics for essentially Grice's theory of natural meaning), since newer theories have not modified the nature of earlier ones. For a recent technical survey the reader may consult Wang (2005) and, in particular, the third part (nature of meaning pp.151-389) of Lepore & Smith (2006).
[9] He changed his mind in 1921.
[10] Chomsky's Aspects of the theory of Syntax was the last major work in generative linguistics before the appearance of a fundamental split in transformational-generative grammar. The split concerns the relationship between syntax and semantics. The result was the appearance of two diametrically opposed conceptions concerning the nature of semantics: interpretative semantics and generative semantics. Proponents of the former approach believe that basic syntactic structures can be specified independently of semantic considerations. Adherents to the second conception claim the inverse to be true.
[11] Davidson's (1999, 2001) more recent theories have not substantially enhanced his previous work.
[12] A couple of important early seeds of this theory were presented in Gelepithis (1984, 1989).
[13] It should be noticed that the stated identification does not imply membership to the individualist tradition (e.g., Chomsky 1995, Fodor 1980, Stich 1978).
[14] For a recent survey of their roles see Allen and Barres (2009), Barres (2008).
[15] Subsequent definitions are in terms of human animals. Generalisations to non-human animals and machines are straightforward.
[16] It should be noted that the phenomenon indicated by relation (2) is significantly more complex than the phenomenon of semantic underdetermination (e.g., Bach 1994; and Saul 2002; Speaks 20008 for more recent discussions). Actually, the latter (explicitly introduced by Grice 1968) is a special case of the former. Naturally, skepseis (and more fundamentally N_m) constitute a third class of meaning in addition to the natural/nonnatural (Grice 1957), or the natural/conventional (e.g., Stevenson 1944) distinctions.
[17] A slightly weaker claim has been argued by Hebb (1980b, p24), namely, verbal language is «an adjunct to a primarily nonverbal mechanism.» For a similar conclusion to Hebb's argued from the philosophical viewpoint see Lurz (2007); for a recent debate Heyes (1998).
[18] This is a minimalist definition of belief. It could have been stated in a way that it explicitly included any combination of concepts, thoughts and skepseis. Since all three of the latter are defined in terms of N and/or N_m, the minimalist definition was thought to be more appropriate.
[19] Clearly, the proposed theory of thinking is in sharp contrast to both major approaches, namely the standard psychological view of concepts (e.g., initially Fodor 1975; recently Margolis & Lawrence 2007) and the propositional (equivalently, Fregean or semantic) view (e.g., Peacocke 1992).
[20] The same is true for major recent work both in the Hebbian tradition (e.g., Edelman 1987) and in biologically inspired non-linear dynamics (e.g., Freeman 1999).
[21] Thanks to Yiannis Kontos for raising this point (personal communication).
[22] Acceptance of the MMP is not in conflict with Roediger's (2008) conclusion of lack of memory laws. It is actually compatible with the huge complexity and interactivity of memory phenomena that is fully recognized by the science of memory community.
[23] Wittgenstein's (1953*1976) investigations may be illuminating in this respect if they are read as such rather than as an argument for the nature of meaning.
[24] Mattelart and Mattelart (1995*1998) state eleven disciplines involved with its study: Philosophy, history, cybernetics, geography, psychology, biology, sociology, ethnology, economics, political science, and the cognitive sciences!
[25] Essentially, Grices's important work is primarily on meaning (Table 1).
[26] It should be noted that perceived in this way, 'communication' gives rise to numerous further splits of interest. As Schramm remarks: such a relationship is very complex and due to the lack of "general theoretical insights, researchers have typically worked on parts of the relationship".
[27] a) To make (opinions, feelings, information, etc.) known or understood by others; and b) to share or exchange opinions, feelings, information, etc. (Longman, 1987).
[28] The earliest conception of definition-12 can be found in Gelepithis (1984).
[29] An exception in tackling understanding as a specific cognitive phenomenon can be seen in Sanford's (2003) reader.

[30] That is, in Newell's terms, phenomena covering all of the cognitive band and most of the rational one.

[31] Johnson Laird's (2003) thesis is that human understanding depends on the construction of mental models from perception, imagination and the comprehension of language.

[32] Moravcsik (1979) has argued that understanding should be seen as the state of mind that yields the insight that unites one's knowledge required to arrive at the solution to a problem.

[33] The literature on reasoning has not defined its very object of investigation. We therefore feel justified to use the term in this rather iconoclastic way.

[34] Is mathematical validity materialised in the nervous system? My hunch is that it is. It appears that it only needs the following two basic capabilities to have been neurally materialised: (i) recognition of identities and differences; and (ii) sense of direction. Concerning the former, it appears that the existence of neural inhibitions and the hierarchical semantic structures identified in 2.1.1.1 offer a reasonable ground for the recognition of identities and differences by the individual. Hebb does not seem to have addressed this issue and I am not aware of relevant literature. My strongest reason for this suggestion is its reasonableness and the lack of any logical objections to it. With respect to directionality, I have no better reasons than Hebb's (1976) and Russell's (1921) mnemic causation.

[35] Part of this complexity, and probably its power, is due to its unconscious nature. We are in full agreement with Kandel's (2006, p. 375) remark: "most students of the brain believe, as Freud did, that we are not conscious of most cognitive processes, only of the end result of those processes." Gelepithis (2005) stated a number of factors contributing to the complexity of the process of understanding.

[36] Electron is the only one of the four that cannot be placed in P. Moreover, the class of concepts like electrons which can be placed in P' but not in P is not a singleton. The distinction cannot be swept away as a single oddity. Nevertheless, one should notice that if we were able to distinguish electrons we could place 'electron' in P (future technology may enable us to do that).

[37] For Herbert Simon's view on cognitive invariants and a critical review of it see Simon (1990) and Gelepithis (1992) respectively.

[38] Within the theory proposed here, chorum sensing (e.g., Williams, et. al. 2007) does not constitute communication.

[39] Even the existence of 'representation' has been debated (e.g., Brooks 1991, Kelso 1995 against; Bechtel 1998, Clark & Toribio 1994 for). Stufflebeam (1998) sits on the fence with a leaning towards the against side.

[40] There is a large number of scientists whose view of 'representation' is based on the assumption that if a structure is regularly and reliably activated by a distal condition then that is adequate reason to believe that structure as representing the distal condition. This assumption of «receptor representation» has been effectively criticized by Ramsey (2003).

[41] This definition is in accordance with both Aristotle's (4th BCE*1984) views on poetry and drama as human endeavours to mimic (i.e., re-present) *the essence* of human actions and the standard cognitive science view stated earlier.

[42] Some early work on semantic networks attempted to address some of the psychological mechanisms of thinking but it was soon forgotten and abandoned.

[43] Some further interesting similarities and consequences follow that are beyond the scope of this article.

[44] Evidence of writing marks of an expressive and presumed ritualistic nature goes back to about 32kya. Closer to our times geometrical and property markings have been found that have been interpreted to have been used as devices for reckoning time and for counting. Nevertheless, these markings are substantially different from even the elements of a writing system since they lack any sequencing or hint of narrative. They are static and self-contained (Barton & Hamilton 1996). The first link of visible marks to the original Sumerian cuneiform writing system has come with the work of Schmandt-Besserat 1978, 1980). Such marks (in the form of tokens) are dated back to ~10kya.

[45] Barton & Hamilton (1996) provide an excellent clarification of this relationship and of associated issues like the language-thought debate and potential evolutionary mechanisms.

[46] And so is Chalmers to the extent he accepts their active externalism thesis (Clark & Chalmers 1998*2008).

[47] For a recent philosophical discussion see Silverberg (2003).