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Psychological Background for The "4+1" Memory Model.

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Abstract: In this essay-like report I discuss psychological evidence giving reason for a five-element model of memory I call "4 + 1", as it consists of Procedural Memory, Filtering Memory, Semantic Memory, Episodic memory, and Working Memory, where the last one plays the pivotal role integrating all other ones. I argue that the "4 + 1" Memory Model is computational, modular, and evolutionary, hence, it can be a recommended canvas for artificial brain building.

Psychological Background for the "4 + 1" Memory Model

> The causes of our mental structure are doubtless natural, and connected,
> like all our other peculiarities, with those of our nervous structure.
> Our interests, our tendencies of attention, our motor impulses,
> the aesthetic, moral, and theoretic combinations we delight in,
> the extent of our power of apprehending schemes of relation,
> just like the elementary relations themselves, time, space,
> difference and similarity, and the elementary kinds of feeling,
> have all grown up in ways of which at present we can give no account.[1]
>
> —WILLIAM JAMES (1842-1910)

Steven Pinker, MIT psychologist admits, that *we don't understand how the mind works—not nearly as well as we understand how the body works*, adding after all, that *dozen of mysteries of the mind, from mental images to romantic love, have recently been upgraded to problems*[2]. According to Pinker, *the mind is a system of organs of computation, designed by natural selection to solve the kinds of problems our ancestors facet in their foraging way of life, in particular, understanding and outmaneuvering objects, animals, plants and other people*[3]. At least three assumption have been behind this view: (1) that the mind is organized into modules, (2) that the mind's activity consists in a kind of computation, and (3) that the mind has organized itself in the course of an evolutionary process. The assumptions, although they seem to have been accepted by most of cognitive scientists, are not obvious and they don't have to be understood by everybody the same way. In case they are accepted, two major questions appear: First, how the modules of mind are organized, and second, how the mental concepts are represented to be computed. It is also worth some discussion whether the evolutionary view supports the search for an answer to the two above questions.

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[1] James (1890: 688)

[2] Pinker (1997:ix).

[3] Pinker (1997:21).

Computational Theory of Mind

As Paul Thagard, philosopher of science, noted, thinking can best be understood in terms of representational structures in the mind and computational procedures that operate on the structures. Moreover, inspection of the leading journals in psychology and other fields reveals that this approach to cognitive science is currently dominant. For understanding of mind in terms of computation and representation Thagard coined the term CRUM (Computational-Representational Understanding of Mind)[4]. Editors of MIT Encyclopedia of Cognitive Sciences preferred the term CTM (Computational Theory of Mind)[5].

Proponents of CTM assert that information and computation reside in patterns of data in relations of logic that are independent of the physical medium that carries them[6]. This insight was at first expressed by the mathematician Alan Turing, the computer scientists Allen Newell, Herbert Simon, and Marvin Minsky, and the philosophers Hilary Putnam and Jerry Fodor. It is believed that CTM resolves the "mind-body" problem: how entities like "wanting" and "knowing" can cause of physical events. Beliefs and desires are treated as information incarnated as configurations of symbols—the physical states of bits of matter. They symbolize things in the world because of what they do once they are triggered by those things via our sense organs, and because of what they do once they are triggered. *If the bits of matter that constitute a symbol are arranged to bump into the bits of matter constituting another symbol in just the right way, the symbols corresponding to one belief can give rise to new symbols corresponding to another belief logically related to it, which can give rise to symbols corresponding to other beliefs, and so on. Eventually the bits of matter constituting a symbol bump into bits of matter connected to the muscles, and behavior happens*[7]. Indeed, there are several kinds of psychological evidence of mental logic[8].

Despite CTM's connections to successful empirical research in cognitive science and its promise in resolving philosophical problems, it is a subject to criticism on a number of fronts. First, often met, results from caricaturing of so called "computer metaphor": *computers are*

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[4] Thagard (1996: 10-11).
[5] Horst (1999).
[6] Pinker (1997: 24).
[7] Pinker (1997: 25).
[8] Rips (1986, 1994).

serial, doing thing at time; brains are parallel, doing millions things a once. Computers are fast; brains are slow. Computer parts are reliable; brain parts are noisy. Computers have a limited number of connections; brains have trillions. Computers are assembled according to a blueprint; brains must assemble themselves. Yes, and computers come in putty-colored boxes and have AUTOEXEC.BAT files and run scree-savers with flying toasters, and brains do not[9], as Pinker notes ridiculing an anti-computational way of thinking of this kind.

Indeed, computers no longer are only serial. Connectionist models, based on artificial neural networks, do not need to be treated as an alternative to CTM because (1) *computational* does not have to mean single-processor-based and (2) logic does not have to mean Aristotelian; logicians invented several unconventional sorts of logics—default logic, non-monotonic logic, fuzzy logic, modal logic, temporal logic—and all of them can be implemented on digital computers. The statement "It's great that X=Y" also can be analyzed in terms of logic. Dynamic behaviors, including chaotic ones, are demonstrated by both continuous and discrete mathematical models, and both of the kinds of models can be run on a digital computer[10], hence dynamic approach also does not need to be treated as an alternative to CTM

More difficult to refute is the charge that much of human thought and behavior cannot be reduced to explicit rules, and hence cannot be formalized or reduced to a computer program[11]. In face of results of experiments using Wason's selection task many psychologists are skeptical about mental logic[12]. The misunderstanding results from a false assumption that an act of logical reasoning on the level of conscious thinking is, from CTM-grounded point of view, a processing a couple of unique items onto a single resulting item. In fact, a decision or a belief can be a kind of compromise achieved by the mind machinery in face of multiplied copies of items representing contradictory results. And even such bizarre, but possible mechanism of reasoning can be implemented on a digital computer.

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[9] Pinker (1997: 26).

[10] Running a continuous model on a digital computer is possible in the course of converting the model onto discrete, but satisfactorily precise one or in the course of using procedures of symbolic calculus.

[11] Dreyfus (1972); Winograd and Flores (1986); Dreyfus (1992).

[12] Wason (1966) invented an experiment in which subjects are informed that they will be shown cards that have numbers on one side and letters on the other. They are given a rule such as If a card has an A on one side, then it has a 4 on the other. The subjects are then shown four cards and asked to indicate exactly which cards must be turned over to determine whether the rule holds. A great many people neglect to check the proper card, which made a number of psychologists believing that people approach such kinds of reasoning tasks with representations and computations quite different than in formal logic (Thagard 1996: 35-36).

Modularity of Mind

Is the mind/brain a general-purpose problem solver, as Allen Newell and Herbert Simon[13] or Jean Piaget[14] asserted, or it is made up of special purpose modules, according to the view by Noam Chomsky[15], Jerry Fodor or Howard Gardner[16]? Both of the views still remain not refuted, however the latter seems to have collected stronger arguments.

As Pinker states, the *mind has to be built out of specialized parts because it has to solve specialized problems. Only angel could be a general problem solver; we mortals have to make fallible guesses from fragmentary information. Each of our mental modules solves its unsolvable problem by a leap of faith about how the mind works*[17].

The publication of Fodor's *Modularity of Mind*[18] set the stage for recent modularity theorizing and provided a precise set of criteria about what constitutes a module of mind. Fodor, as Annette Karmiloff-Smith summarized[19], holds that the mind is made up of genetically specified, independently functioning modules. Information from the external environment passes first through a system of sensory transducers that transform the data into formats each special-purpose module can process. Each module, in turn, outputs data in a common format suitable for central, domain-general processing. The modules are deemed to be hardwired (not assembled from more primitive processes), of fixed neural architecture (specified genetically), domain-specific (a module computes a constrained class of specific inputs bottom-up, focusing on entities relevant only to its processing capacities), fast, autonomous, mandatory (a module's processing is set in motion whenever relevant data present themselves), automatic, stimulus-driven, and insensitive to central cognitive goals. A further characteristic of modules is that they are informationally encapsulated. In other words, other parts of the mind can neither influence nor have access to the internal workings of a module, only to its outputs. Modules only have access to information from stages of processing at lower levels, not from top-down processes[20].

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[13] Newell & Simon (1972).

[14] Piaget (1971).

[15] Chomsky (1980).

[16] Gardner (1985).

[17] Pinker (1997: 30).

[18] Fodor (1983).

[19] Karmiloff-Smith (1999).

[20] As an example one can take the Muller-Lyer illusion, where, even when a subject explicitly knows that two lines are of equal length, the perceptual system cannot see them as equal (Karmiloff-Smith 1999).

Pinker's view of modularity admits that the circuitry underlying a psychological module might be distributed across the brain in a spatially haphazard manner. And mental modules need not be tightly sealed off from one another, communicating only through a few narrow pipelines[21].

Several arguments for modular view of mind come from neurosciences. As Ira Black suggests, modularity of behavior, a concept that arose from the study of humans and subhuman primates, has a physical reality in the brain. Modules may be defined anatomically, as in the cases of Wernicke's speech area and the basal forebrain nuclei. Moreover, in the latter, the module consists of neurons that use a common transmitter, acetylocholone. Finally, this anatomic-transmitter-behavioral module is selectively responsive to a specific tropic agent, NGF. Consequently modularity as a psychologic construct has a physical reality that serves to link molecular mechanisms, including NGF production, with cholinergic stimulation, systems function, and normal associative memory[22]. Karmiloff-Smith[23] writes: *Data from normal adults whose brains become damaged from stroke or accident seem to support the modular view*[24]. *Indeed, brain-damaged adults often display dissociations where, say, face processing is impaired, while other aspects of visual-spatial processing are spared, or where semantics is spared in the face of impaired syntax, and so forth. On the other hand, several authors have now challenged these seemingly clear-cut distinctions, demonstrating, for instance, that supposedly damaged syntax can turn out to be intact if one uses on-line tasks tapping automatic processes rather that off-line, metalinguistic tasks*[25], *and that a single underlying deficit can give rise to behavioral dissociations*[26]. The challenging evidence can be supposedly explained without a rejection of the general idea of modularity—for example in terms of sophisticated relationships among multi-task modules.

Some evidence from idiots savants[27] and from persons having certain developmental disorders[28] not only support the concept of modular mind, but also led to some theorists to a

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[21] Pinker (1997: 31).
[22] Black (1991: 147).
[23] Karmiloff-Smith (1999).
[24] Butterworth, Cipolotti & Warrington (1996); Caramazza, Berendt and Basili (1983).
[25] e.g. Tyler (1992).
[26] Farah & McClelland (1991); Plaut (1995).
[27] Smith & Tsimpli (1995).
[28] Baron-Cohen (1995); Leslie (1988); Pinker (1994).

claim that such modules must be innately specified because they are left intact or impaired in genetic disorders or development[29]. The latter claim has been challenged by researchers who identified serious impairments within the "intact" domain, for almost every case of islets of so-called intact modular functioning[30]. Also in cases of purported singular modular deficits, more general impairments have frequently been discovered[31]. In normal development, too, new research is also pointing to gradual module specialization rather than prespecification[32].

Cognitive View of Concept

As for concepts, maybe nobody in cognitive science community supports the classic Aristotelian view assuming them as sets of necessary or sufficient attributes. This view has been replaced with probabilistic view assuming that most of concepts are fuzzy. The idea of concept fuzziness had its roots in Ludwig Wittgenstein's philosophy[33]. Lotfi Zadeh provided it with mathematical grounds[34], and, finally, in 1970s Eleanor Rosch, psychologist of University of California, Berkeley, confirmed it experimentally within cognitive psychology[35]. In other words, it was showed that people regard some objects as more typical members of a labeled set and classify these more efficiently. Hence, the degree of membership of an object to a given category may be based on similarity between the object and either an abstract prototype or the most typical exemplars. Quickly it was noted that the same applies also to social categories[36], however the debate prototypes vs. exemplars has not yet been settled[37].

Despite its broad impact, the probabilistic view has its critics. They point out that although there is an influential theory determining the degree of similarity between two objects as a function of the number of features common to both and the numbers of features unique to

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[29] As Karmiloff-Smith (1999) notes, there are, for instance, developmental disorders where understanding of mind of oneself or others is impaired in otherwise high functioning people with autism (Frith 1989), or where face processing scores are in the normal range but visuo-spatial cognition is seriously impaired, as in the case of people with Williams syndrome (Beluggi, Wang and Jernigan 1994).

[30] Karmiloff-Smith, Grant, Berthoud, Davies, Howlin & Udwin (1997); Karmiloff-Smith (1998).

[31] Bishop (1997); Frith (1989); Pennington & Welsh (1995).

[32] Karmiloff-Smith provides here as examples results of Mills, Coffey-Corina & Neville (1994), Johnson (1997), Elman, Bates, Johnson, Karmiloff-Smith, Parsi & Plunkett (1996), and Qartz & Sejnowski (1997).

[33] Wittgenstein (1953).

[34] Zadeh (1965); Zadeh (1975); Zadeh (1978).

[35] Rosch & Mervis (1975), Rosch, Simpson & Miller (1976).

[36] Cantor & Mischel 1979).

[37] Kunda (1999:31)

each, weighted by the salience or importance[38], nobody knows what to count as a feature[39]. Moreover, features can be in mutual relations, while salience and importance of features varies from context to context, and so the perceived similarity among objects also varies[40], hence another problem: How can categories be based only on similarity if similarity varies from one occasion to another?[41] It has been suggested that judgments must be guided by additional information.

Developmental psychologists provided evidence, that even for preschoolers, similarity-based judgments can be overridden by true category membership. It has than been concluded that in use concepts a theory-based knowledge plays an important role[42]. Nevertheless, as Frank Keil—the co-editor of The MIT Encyclopedia of Cognitive Sciences[43]—put it, "Concepts may always be embedded in theories, but part of their structure may always be organized according to theory independent principles."[44] Moreover, there have been few attempts to measure theoretical knowledge and to predict its impact[45].

There has also been considerable work on how concepts may be related to each other. It has been suggested that many concepts are organized in hierarchies, where higher-level categories include all members of the categories below them. Cognitive psychologists proposed to assign one of possible level, called the *basic level*, a privileged status[46]. The basic level may be defined as the highest level at which one can readily create an image representing a given category as a whole[47].

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[38] Tversky (1977)

[39] Murphy & Medin (1985).

[40] Medin, Goldstone & Gentner (1993).

[41] Kunda (1999:35).

[42] Susan Gelman and Ellen Markman (1986) showed children set of pictures in which perceptual similarity and category membership was in conflict. Despite the a drawn similarity between a swallow and a bat, and non similarity between the swallow and a flamingo, most children inferred that the swallow's feeding practices would resemble those of the flamingo (also bird) rather than those of the perceptually similar bat (mammal) (quoted from Kunda 1999:37).

[43] Wilson & Keil (1999)

[44] Keil (1989:278) (quoted from Kunda 1999:41).

[45] Kunda (1999:41).

[46] Rosch, Simpson & Miller (1976).

[47] Rosch (1978). This works well in such a concept hierarchy, as, for example, *animal – dog – Dalmatian – Rover*. Indeed, when we see a picture of Rover, we will most likely refer to him as a dog, rather than as a Dalmatian or an animal (Kunda 1999:43). However, it seems not obvious that people, when seeing a picture of a dachshund, would not call him just 'dachshund' (authors note).

Memory

Any cognitive system must include a device capable of registering information, storing it, and making it available for retrieval. Without this capability, as Alan Baddeley—the distinguished British cognitive psychologist says, we could not perceive adequately, learn from our past, understand the present, or plan the future[48]. The device is called *memory*. What's its structure? Nobody knows. As it acknowledges Endel Tulving, the Canadian memory psychologist, memory is one of Nature's most jealously guarded secrets. In cognitive psychology alone a staggering number of findings and facts about memory has been collected for over one hundred years. However, this success has been somewhat less remarkable in interpreting and making sense of this abundance of data[49].

It can be assumed that the prehistory of memory research lasted from around 1885[50] to 1960. That time researchers concentrated on measuring basic phenomena of learning and forgetting of verbal items in normal adults. The major used concepts were association and "strength" of remembrance. Around 1960, as a result of the "cognitive revolution", the associative verbal learning framework was widely replaced by the "information processing" paradigm. It was the beginning of the second era in memory studies that ended around 1980. That time new issues were investigated, as for example, free and cued recall, recognition, and various kinds of memory judgments—recency, frequency, and the like. Experimental studies led to theoretical distinction between short-term memory (STM) and long-term memory (LTM). The analytical distinction between storage and retrieval was translated into experimental paradigms that allowed the separation of the processes. Conections were established between previously isolated disciplines of cognitive psychology and neuropsychology. The concept of association as the basic theoretical construct was replaced by the concept of multiple processes including encoding, storage and retrieval[51].

The current era of memory research, according to Tulving can be thought of as cognitive neuroscience of memory. It is characterized by further expansion and liberalization of methods, techniques, and choices of questions and problems. The dominant concepts of the era seem to be

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[48] Baddeley (1999: 19).

[49] Tulving (1995).

[50] Ebinghaus (1885).

[51] Tulving (1995).

priming[52] and *memory systems*.[53] There has been a steadily growing convergence between cognitive psychology and neuropsychology; learning and retention is investigated in memory-impaired patients, as well as across subjects' life-span development; psychopharmacological studies and precise neuroimaging let us overcome a lot of previous difficulties. Finally, computer modeling became a legitimate methodology in memory research. Hence, as Tulving points out, this is the age of multidisciplinary study of memory[54].

Combining several dichotomies—memory and habit, STM vs. LTM, episodic vs. semantic memory, procedural and declarative memory, and like—Tulving proposes a more general scheme that allows us to identify at least five major categories of human memory, or "memory systems": (i) procedural, (ii) PRS, (iii) semantic, (iv) primary, and (v) episodic[55].

(i) Procedural memory systems are behavioral or *action* systems, whereas the other four are cognitive *representation* systems. This means that propositional or other symbolic stuff—applicable in all non-procedural memory models—are inadequate in case of procedural memory whose operations are expressed in the form of skilled behavioral procedures independently of any cognition.

(ii) PRS (Perceptual Representation System) facilitates the phenomenon of priming. A perceptual encounter of with an object on one occasion primes or facilitates the perception of the same or a similar object on a subsequent occasion, in the sense tat the identification of the object requires less stimulus information and occurs more quickly than it does in absence of priming. Because biological utility of this capability seems to be obvious, it probably is demonstrated across a wide spectrum of species.

(iii) Semantic memory makes possible the acquisition and retention of factual information in the broadest sense; the structured representation of this information—semantic knowledge—models the world. As Tulving asserts, the designation semantic memory is merely historical accident since the system are not tied either to language or to meaning. It is a conjecture that

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[52] Perceptual priming is a special form of perceptual learning that is expressed in enhanced identification of objects as structured physical-perceptual entities (Tulving 1995); for more detailed review see Schacter (1995);

[53] e.g. Shallice (1979); Warrington (1979); Tulving (1985); Cohen (1984); Mishkin, Malamut & Bachevalier (1984); Schacter & Moscovitch (1984); Weinberger, McGaugh & Lynch (1985); Weiskranz (1987).

[54] Tulving (1995).

[55] Tulving (1995).

human semantic memory has evolved from the spatial learning and knowledge of the ancestors of humans.

(iv) Primary memory, also referred to as short-term memory or working memory, registers and retains incoming information in a highly accessible form for a short period of time after the input. It makes possible a lingering impression of the individual's present environment beyond the duration of the physical presence of the stimulus information emanating from the environment.

(v) Episodic memory enables individuals to remember their personally experienced past, that is, to remember experienced events as embedded in a matrix of other personal happenings in subjective time. It depends on but transcends the range of the capabilities of semantic memory. The most distinctive aspect of episodic memory is an unique kind of conscious awareness that characterizes recollection of past happenings—unmistakably different from the kinds of awareness that accompany perception, imaging, dreaming, solving problems, and retrieval of semantic information.

As for relations among different cognitive systems, Tulving suggests that they are process specific and proposes a simple model called SPI (*Serial-Parallel-Independent*). According to the SPI view, (1) information is encoded serially, and the output form one system provides the input to another; (2) information is stored in different systems in parallel; thus, what appears as a single act of encoding produces multiple mnemonic effects in different regions of brain at the same time, and (3) information from each system and subsystem can be retrieved without any necessary implications for retrieval of corresponding information in other systems; thus, with respect to the process of retrieval, different systems are independent[56].

Tulving listed the forms of memory in order of their assumed emergence with respect to the phylo- and ontogenesis. He admits that working memory becomes more critical when the demand arises for intra- and interindividual communication—that is, for abstract thought and language. Currently it is admitted that working memory (1) is to temporarily store the outcomes of intermediate computations when problem solving and to perform further computations of the temporary outcomes, and (2) plays an important role in a higher-level cognition[57].

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[56] Tulving (1995).

[57] Smith (1999).

Evolutionary psychology

Steven Pinker, as supposedly a lot of cognitive scientists, sees psychology as 'engineering in reverse' that, unlike forward-engineering consisting in designing a machine to do something, consists in figuring out what a machine was designed to do[58]. The rationale for reverse-engineering living things comes from Charles Darwin who proposed the way how the perfect and complicated organs can arise from the evolution of replicators over immense spans of time. As replicators replicate, random copying errors sometimes crop up, and those that happen to enhance the survival and reproduction rate of the replicator tend to accumulate over the generations. Darwin, as Pinker notes, insisted that his theory explained not just the complexity of an animal's body, but the complexity of its mind, which led to the famous prediction that "psychology will be based on a new foundation". Unfortunately, Darwin's prophecy has not been fulfilled. Moreover, one can note a kind of allergy to evolution in the social and cognitive sciences that has been, as Pinker suggests, a barrier to understanding mind[59].

From the point of view of reverse-engineering of mind, evolutionary thinking is indispensable. Hence, inevitable was the appearance of a research discipline that brings together two scientific revolutions: the cognitive revolution of the 1950s and 1960s, which explains the mechanics of thought and emotions in terms of information and computation, and the revolution in evolutionary biology of the 1960s and 1970s, which explains complex adaptive design of living things in terms of selection among replicators. Cognitive science helps us to understand how a mind is possible and what kind of mind we have. Evolutionary biology helps us to understand why we have the kind of mind we have[60]. The anthropologist John Tooby and the psychologist Leda Cosmides christened the powerful combination "evolutionary psychology"[61].

Cognitive psychologists applied the concepts and methods of the cognitive sciences to nontraditional topics, such as reciprocation, foraging memory, parental motivation, coalitional dynamics, incest avoidance, sexual jealousy, and so on. A Tooby and Cosmides state, evolutionary psychology is unusual in that a primary goal is the construction of a comprehensive map of the entire species-typical computational architecture of humans, including motivational

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[58] Pinker (1997: 21).

[59] Pinker (1997: 22-23).

[60] Pinker (1997: 23).

[61] see Tooby & Cosmides (1992).

and emotional mechanisms, and that its scope includes all human behavior, rather than simply “cold cognition”[62].

Evolutionary approach to cognitive architectures consists in treating them as large sets of evolved computational devices that are specialized in function[63], such as a face recognition systems, a language acquisition device, navigation specializations, and animate motion recognition. Evolutionary psychologists are skeptical that an architecture consisting predominantly of content-independent cognitive processes, such as general-purpose pattern associators, could solve the diverse array of adaptive problems efficiently enough to reproduce themselves reliably in complex, unforgiving natural environments that include, for example, antagonistically coevolving biotic adversaries, such as parasites, prey, predators, competitors, and incompletely harmonious social partners. Selection drives design features to become incorporated into architectures in proportion to the actual distribution of adaptive problems encountered by a species over evolutionary time. Hence, evolutionary psychologists are very interested in careful studies of enduring environmental and task regularities, because they predict details of functional design[64].

According to Cosmides and Tooby, a distinguishing feature of evolutionary psychology is that theoretical reasons for considered hypotheses are derived from biology, paleoanthropology, game theory, and hunter-gatherer studies. Owing to this, researchers can devise experiments that make possible the detection and mapping of computational devices that no one would otherwise thought to test. Using this new research program, many theoretically motivated discoveries have been made about, for instance, internal representation of trajectories; computational specialization for reasoning about danger, social exchanges, and threats; female advantage in the incidental learning of the spatial locations of objects; the frequency format of probabilistic reasoning representations; the decision rules governing risk aversion and its absence; universal mate selection criteria and standards of beauty; eye direction and its relationship to the theory of mind; principles of generalization; life history shifts in aggression and parenting decisions; social memory; reasoning about groups and coalitions; the organization of jealousy, and others[65].

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[62] Cosmides & Tooby (1999).

[63] Gallistel CT (1995);

[64] Cosmides & Tooby (1999); Shepard (1987).

[65] see Barkow, Cosmides & Tooby (1992) for review.

Some critics have argued that the field consists of post hoc storytelling and that adaptionist analysis is misconceived, because adaptations are of poor quality, rendering functional predictions irrelevant[66]. According to evolutionary psychologists, the first claim is difficult to reconcile with their practice where an evolutionary model of "explanation" precedes the empirical discovery and guides research to it, rather than being constructed post hoc to explain some known fact. As for the second claim, it is stated, that although selection does not optimize, it demonstrably produces well-engineered adaptations to long-enduring adaptation problems.

Seemingly the most valuable payoff of integrating adaptionist analysis with cognitive science was the realization that complex functional structures (computational or anatomical), in species with life histories like humans, will be overwhelmingly species-typical[67]. That is, the complex adaptations that compose the human cognitive architecture must be human universals, while variation caused by genetic differences are predominantly noise: minor random perturbations around the species-typical design[68].

Conclusions

Seemingly there is no retreat from the Computational Theory of Mind, because, as Pinker points out, *it has solved milenia-old problems in philosophy, kicked off the computer revolution, posed the significant questions of neuroscience, and provided psychology with a magnificiently fruitful research agenda*[69]. As for the modularity of mind, despite several challenges, there is no better working assumption for building a model of mind. Are the modules pre-specified or not, currently neither a return to behaviorist rejection of cognitive structure as a psychological theme, nor the view of mind as a general problem solver, can be seriously taken into account.

The Tulving's 5-element SPI memory model can be is *ex definitione* modular and capable of being considered in terms of computational processes. It is also considered in evolutionary perspective in which the five elements emerge consecutively. Hence, the model can be recognized as a good step towards computational model of self-organizing mind. Unfortunately,

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[66] Gould (1997).
[67] Tooby & Cosmides (1990).
[68] Cosmides & Tooby (1999).
[69] Pinker (1997: 77).

Tulving keeps from suggesting a scheme of interconnections between particular memory systems. And the scheme seems to be next unavoidable step.

Taking into account the specific role of working memory that, in case of humans, not only stores, but also processes information we can try derive a conclusion that links between working memory and other memory systems can be of higher importance than the links between any of the other memory systems. The immediate link between perceptual system and procedural memory facilitating rapid affective reactions is an exception. Hence, working memory becomes yet more important—it can be recognized as a device integrating all other memory systems into a mansion of a conscious mind. Hence, I propose the general scheme of human developed memory as in the Figure 1.

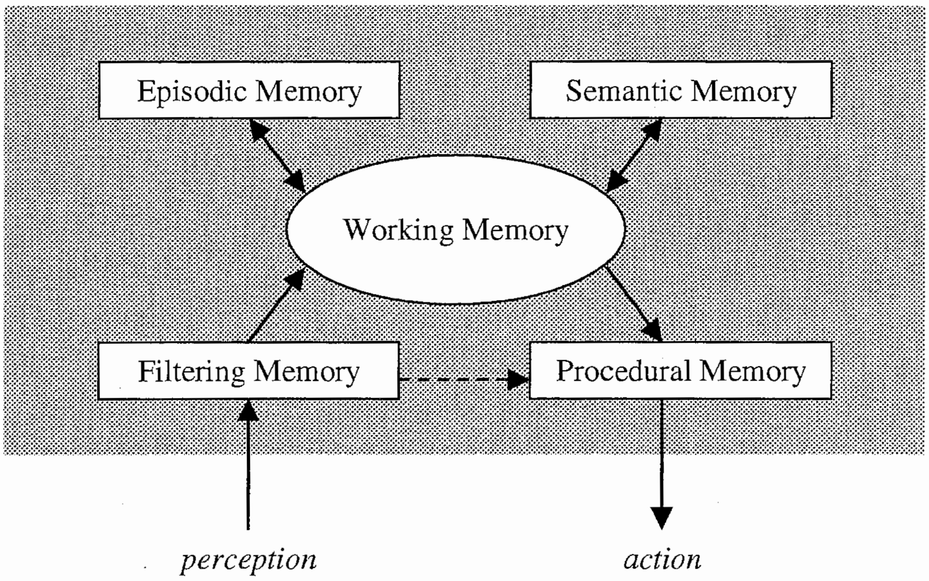

Fig. 1. The proposed "4 + 1" Memory Model

Instead of the name PRS, for the sake of terminological uniformity and flexibility I defining a role of the block, I propose the name Filtering Memory. I christened the entire memory model "4 + 1" in order to emphasis the unique, coordinating role of Working Memory.

The proposed "4 + 1" Memory Model is computational, modular and evolutionary—computational and modular, because it is divided into functional blocks where each of the blocks admits data provided typically by one of other blocks and provides another data to typically one of other blocks; evolutionary, because both onto- and phylogenesis of this system is easy to imagine, and supposedly possible to model computationally. Indeed, the Procedural Memory can exist as an autonomous device taking simple physical stimuli immediately from sensors and processing them onto signals controlling actuators. A selection pressure can add a Filtering Memory responsible for pre-processing of stimuli, rejection of unimportant ones, and processing them onto a set of aggregated, relatively simple signals to stimulate the Procedural Memory. In the next step of onto- or phylogenesis a Working Memory can appear. Owing to this, the whole device can demonstrate sophisticated behavioral patterns resulted from the fact that signals produced in Procedural Memory are calculated based on aggregated external stimuli, as well as on changeable internal states of the Working Memory. Yet more sophisticated behavioral patterns can appear when Semantic and Episodic Memory is added. In face of the evidence discussed in the section devoted to the cognitive view of concept, both the Semantic memory and Working Memory must be capable of fuzzy concept processing.

There is no clear empirical evidence that human memory can be divided this way as Tulving has done it so. Nevertheless, it must be taken into account, that Tulving's view has its grounds in decades of psychological investigation of memory and suggested by unquestionable authority in the subject. As the great Canadian psychologists notes in reference to his proposal: *In science, as in chess, a plan or theory, even a poor one, is better than no plan or theory at all. The confusion that usually prevails in absence of a theory is likely to breed only more of the same, whereas an incorrect theory can always be corrected*[70]. Does not the same apply to the proposed "4 + 1" model? Let us, therefore, take it as a canvas for an artificial brain designing.

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[70] Tulving (1995).

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