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Abstract

It seems that time is matured enough for computer science to introduce computational models of the mind and brain on its research agenda. The present position statement maps problems that are to be faced on such a quest.

Keywords
Cognitive computing; Artificial intelligence; Computational models of the mind and brain

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Understanding the activities of an animal or human mind in algorithmic terms seems to be about the greatest challenge offered to computer science by nature. In computer science, the respective cognitive information processing systems are studied within a new computational paradigm of cognitive computing recently introduced by L. Valiant [6]. This paradigm faces computer science with a number of new exciting research problems. Below we list ten problems concerning cognitive systems in general and computational models of the brain or mind in particular.

First, it is not easy to be very specific as far as the definition of cognitive systems is concerned. The basic idea is to see a cognitive system as a finite transition system that interacts with its environment with the help of its sensors and effectors.

What makes such a system different from standard interactive information processing systems is its ability to learn the 'right' transitions in the course of its non–trivial, a priori unknown interaction with its environment. A cognitive system should not only take a passive role in this learning process. It should be an evolutionary system with not much of preprogrammed knowledge. After some training, at some level of its development it should start actively communicate with its environment. By doing so it should continuously shape its behavior in order to meet better requirements of its environment or those of its creators. On the other hand, this assumes in some sense cooperative environment.

Second, so far there appears to be no consensus as to what are the fundamental principles of learning of cognitive systems and what are the basic cognitive tasks. One can try to infer a minimal set of learning abilities of non-trivial cognitive systems from what is known in related literature.

The basics seem to be learning by rehearsal. This means that the system must be able to learn to recognize often-repeated sequences of stimuli. It must be able to recognize simultaneously occurring stimuli that have already been acquired. It must be able to recognize similar or partial stimuli and react in a similar way (i.e., enter a similar configuration) as it has acquired for the original or 'full' stimuli. This seems to be enough for a system to model e.g. instances of Pavlovian conditioning known from the work in animal psychology. In order to also model the so-called operant conditioning a system must be able to de-learn, or inhibit any previously acquired behavior. It is important for theoretical considerations that basic cognitive tasks can be formalized in terms of the training sequences of stimuli and the expected input–output behavior of a respective system [9].

Third, there is a mystery of the leap from systems possessing but the basic cognitive abilities to systems indicating some forms of mental life. From computational models of the mind proposed in [3] and [10], it seems that for modeling higher level mental functions, a mechanism of automatic abstraction is needed. Then one can expect an evolution of humanoid mind, assuming than that the system is exposed to humanoid interaction with the world. The respective development will feature subsequently the emergence of essential living habits, development of abstract concepts, of thinking, language understanding and acquisition and, eventually, emergence of consciousness [10].

Fourth, there is no agreed upon definition of higher level mental functions.

Namely, it appears that there is an evolutionary continuum of mental abilities, from rudimentary ones up to fully developed ones like those in the case of humans. In accordance with their purpose cognitive systems may posses any of the related abilities to some extent. For computational mind modeling it would be of interest to identify and investigate the respective hierarchy.

Fifth, in the absence of a formal specification of high level mental functions, there is still an on-going discussion. Especially among philosophers of the mind, there are debates how to 'prove' that a system can think, has free will, is conscious, etc. This might be related to a more general phenomenon of greater expressiveness and richer behavior of interactive systems as compared to non-interactive ones [7]. Their (partial) correctness could be proven only for specific protocols of interaction at specific interfaces and for restricted domains. Turing's test [4] might be seen as a 'probabilistic' instance of such an approach.

Sixth, there is no common opinion as to what is the best framework to deal with artificial mind formally, algorithmically. Neural nets as treated in standard textbooks on neurocomputing appear to be too simplistic, too rigid and too inefficient to serve the multiplicity of learning purposes required by cognitive systems. In this respect systems based on programmable neurons (such as on Valiant's neuroids [5]) offer more flexibility for learning. Unfortunately, for modeling of higher level mental functions even the latter systems still provide only a very low level of abstraction. Devices requiring no explicit programming and concentrating on modeling of mental activities themselves are needed, in a, so to speak, machine independent manner. A step in this direction was taken in [3] and later in [9] and [10]. The respective models present a kind of universal interactive learning device that is able to acquire any of the aforementioned mental tasks, inclusively higher level brain functions. This is achieved by training the devices following a certain scenario, like rising a child.

For a more detailed overview of models of brain-like computing see [8].

Seventh, eventually when efficiency aspects of mind simulation become an issue, it is not exactly clear what kind of computing technology will be suitable. Namely, especially simulation of sizeable, humanoid minds appears to require massively parallel computational machinery that are beyond the reach of current technology. Molecular or quantum computing can be the answer to such needs. Along these lines, the model of the brain as a molecular computer can be of interest [2].

Eighth, in principle all models of mind mentioned so far can simulate each other [8]. Moreover, it appears that cognitive models can be trained to simulate any interactive Turing machine. In order to do so they must be equipped with Turing machine tapes [9]. Thus, from all we know so far, it appears that the mind is a relatively robust phenomenon that can be explained in computational terms and is not dependent on the underlying computational model. A kind of generalized Turing thesis seems to emerge. It states that interactive Turing machines present a computational equivalent of an intuitive notion of the mind. A more complete complexity theory of the respective models is still needed.

Ninth, it is well known that the notion of Turing computability can be formalized in various equivalent logic theories. What kind of logic theory corresponds to 'mental calculus' like that which is performed in the brain?

Tenth: there are no doubts that by discovering effective algorithmical principles of intelligence the road to its practical applications will be opened. Some fifty years ago Turing claimed that machine intelligence would become a common matter for the present modern time [4]. It appears that his hope was premature. Computational mind modelling is still in its infancy (cf. [1]). Nevertheless, has not the time matured enough for theoretical computer science to at least introduce cognitive computing as item No. 1 on its research agenda?

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