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Cognitive Systems: Goals, Approaches, Applications

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Abstract: In this survey, cognitive systems are characterized in contrast to standard approaches of artificial intelligence and to psychological approaches of cognitive modeling. Arguments for the relevance of symbolic approaches for the development of cognitive systems are presented. After a short overview of current cognitive systems and their applications, the system IGOR will be introduced. IGOR addresses the problem of knowledge level learning, specifically, the inductive acquisition of productive rules from example experience.

Keywords: Cognitive systems, knowledge level, inductive rule learning

A Characterization of Cognitive Systems. Cognitive systems research is of interest not only in the context of artificial intelligence research. Making systems more cognitive can facilitate human interaction with complex software by adapting software to humans instead of making humans adapt to complex software systems [FH06]. For a natural or artificial system to be called cognitive, it typically has to have the ability of high-level cognition, such as reasoning and planning, based on structured knowledge representation rather than simple features [La12]. As research in standard artificial intelligence (AI), most problem domains of interest can only be tackled using heuristic approaches.

In contrast to standard AI, the development of cognitive systems has to be related to models and findings of human cognition and it has to be conducted on system level rather than providing a tool box of unrelated techniques. However, in contrast to the cognitive modeling method of cognitive science, the relation should be qualitative and on the level of general principles rather than quantitative, on the level of detailed comparison of human performance and simulation in a narrow empirical setting. In consequence, research in cognitive systems often needs to be exploratory and cannot only depend on the comparison of methods to measure progress [La12].

Many aspects of cognitive systems are to complex to be described or modelled on the level of neural processing [FP88]. Furthermore, a crucial characteristic of human cognition is the ability to reason over explicit representations and to verbalize and communicate results of such reasoning processes [SK11]. In consequence, statistical models as well as standard black-box machine learning are not sufficient for cognitive systems. While it is indisputable that motor learning, attention and perception are fundamental for higher level cognition, to fulfill the aim to generate software which adapts to humans, the focus of cognitive systems research has to be on the knowledge level.

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Current Cognitive Systems. Early AI research had its focus on the identification and simulation of general principles of intelligent behavior [NS63]. Over the years, research more and more focused on specialized approaches in different areas such as machine learning or automated planning. However, during the last decade, there is a growing interest in cognitive system research, also under the labels of human-level AI and artificial general intelligence. Two prominent systems are Forbus's Companion Cognitive Systems [FH06] and Langley's Icarus architecture [La06]. The companion system is based on concepts of analogical reasoning and applied as tutor for qualitative physics and as game agent. The Icarus architecture addresses the problem of grounding higher cognition in perception and action and was applied to driver simulation in urban environments. Another cognitive system is IGOR [SK11] which addresses the learning of productive rule sets from example experience. The human ability to generalize over observed regularities is prominent in language learning (e.g., grammar rules) but also in learning relations (e.g., ancestor) and generalized problem solving routines (e.g., Tower of Hanoi). However, machine learning as well as learning in cognitive systems is often restricted to learning flat concepts or reinforcements of observation-action patterns. IGOR is based on an inductive programming approach which identifies regularities in symbolic patterns and provides a recursive generalization. It was successfully applied to learning in problem solving, learning recursive relations and learning simple grammars and it also can solve number series problems as included in many intelligence tests.

Conclusions. When we compare the performance of current cognitive systems with specialized standard AI systems, most current systems cannot compete. However, to advance the goal to make future software adapt to humans, to assist them and to even help to extend human cognition, it will be crucial to focus on the development of systems which integrate different abilities and skills and which rely on principles similar to those on which human cognition is based.

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