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Computational modeling/cognitive robotics complements functional modeling/experimental psychology

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ABSTRACT

This position paper explores the possible contributions to the science of psychology from insights obtained by building and experimenting with cognitive robots. First, the functional modeling characteristic of experimental psychology is discussed. Second, the computational modeling required for cognitive robotics is described, and possible experiments with them are illustrated. Next, we argue that cognitive developmental robots, robots that "live" through a development phase where they learn about their environments in several different modes, can provide additional benefits to the science of psychology. Finally, the reciprocal interactions between computational modeling/cognitive robotics and functional modeling/experimental psychology are explored. We conclude that each can contribute significantly to the other.

Experimental science progresses via a theorize → predict → experiment → theorize cycle during which a theory is built, predictions made from the theory are tested by experimentation, and the theory is revised in light of empirical findings, tested again, etc. (Beveridge, 1957; Losee, 1980; Salmon, 1990). All scientific theories are, to some extent, both functional and mechanistic in nature. A *functional* theory describes *what* can be expected to occur in a given situation. A *mechanistic* theory speaks to the *how* of the occurrence, the mechanism that brings it about.

Psychological theories are typically functional in nature (Angell, 1907; Block, 1980; Meissner, 1966). Psychologists build functional models that are intended to both explain psychological processes and predict their functionality, that is, what can be expected to happen under various conditions. Although

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these functional models are useful, even essential to understand human cognition, they do not reliably yield insight into the mechanisms underlying the cognitive processes. Additionally, they typically model only small pieces of cognition (e.g. memory and attention; Logan, 2002).

In contrast, the control system of any robot, by its very nature, must be fully integrated. That is, it must choose its actions based on incoming exogenous or endogenous stimuli utilizing *all* needed internal processes. Also, the control system of a robot must act through its underlying mechanisms (i.e. sensors and effectors). Almost by definition, the architecture of a cognitive robot, a robot that employs a cognitive architecture to select its next action, is derived from integrated models of the cognition of humans and/or other animals. Its control system is designed using that integrated cognitive architecture and is structurally coupled to its underlying mechanisms. Because the control system of such a robot cannot be restricted to small pieces of cognition, it would have to be sufficiently broad so as to encompass basic cognitive processes such as perception, episodic memory, selective attention, action selection, and action execution. Higher-level cognitive processes such as deliberation, volition, problem solving, developmental learning, and metacognition may be modeled as well. Additionally, it may be necessary to establish computational frameworks for feelings and emotions to serve as motivators and learning facilitators.

Like other experimental scientists, a roboticist may work through a theorize → experiment → theorize cycle. A robot is designed and built, but experimentation shows that it does not perform as desired. Therefore, its control system and underlying mechanisms are redesigned and rebuilt. More experimentation takes place resulting in more redesigning, etc.

The two theorize → experiment → theorize cycles (of experimental psychology and cognitive robotics) can be amalgamated by means of a cognitive robot that is able to participate in or replicate a psychological experiment. The cognitive architecture of the robot would functionally model the psychological process being experimented with on humans or animals. The computational architecture is essentially the same model acting through the underlying mechanisms. The computational architecture yields insight into the mechanisms underlying the process. The human or animal experiments together with the cognitive robot experiment serve to test both the functional model and the computational model. Both the high-level functional model and the underlying computational model can then be brought more in line with the results of these experiments. After alterations to the robot suggested by the new version of the architecture are made, new psychological experiments can be designed and carried out to test the current version. The amalgamated cycle continues.

The overall goal of this paper is to explore the possible contributions to the science of psychology from insights obtained by building and experimenting with cognitive robots. We begin by discussing several of the benefits to psychology afforded by computational models of human cognition. We then describe several shortcomings associated with computational modeling of human cognition that can be alleviated by the use of cognitive robotics. The paper then evaluates possible design paradigms for the control structure of a cognitive robot and argues for basing the control mechanism on computational models that are consistent with known psychological evidence. We then describe a number of "new" AI (artificial intelligence) techniques to simulate several of the cognitive processes required for the development of a cognitive robot that may be used in experiments to advance our understanding of human cognition. The paper then argues that cognitive robots that "live" through a development phase, during which they learn about their environments in several different modes can provide additional benefits to the science of psychology. Next we briefly discuss the feasibility of cognitive robotics and highlight several robotic simulation environments that may be useful for rapid development and experimentation. Finally, we explore the reciprocal interactions between computational modeling/cognitive robotics and functional modeling/experimental psychology.

1. Cognitive robotics as an extension of computational modeling

The fundamental goal of cognitive science is to obtain a better understanding of human cognition. Towards this end, psychologists and cognitive scientists have proposed theories and hypotheses, formulated research questions, designed and conducted controlled experiments to evaluate such hypotheses while systematically addressing confounds and alternatives, and have subsequently accepted, rejected, or revised their theories.