Symposium on Problem Solving and Goal-Directed Sequential Activity

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Background and Motivation

Problem solving is one of the hallmarks of human cognition. The term covers a wide range of behaviors, including abilities for solving unfamiliar puzzles, designing new artifacts, generating extended plans, and pursuing complex routine activities. These each require people to carry out sequences of mental or physical steps to achieve their objectives. They can involve reasoning, subgoaling, recognizing alternatives, evaluating them, and guiding search through large spaces.

The study of problem solving played a crucial role in the early development of cognitive science as a field. Research on this topic revealed basic insights about the representations and processes that underlie high-level cognition. Empirical studies of human problem solving provided some of the first evidence for the computational nature of human thinking, and related computational models led to major theoretical advances concerning heuristic search, goal processing, expert performance, and production systems. There is little question that, without its early emphasis on problem solving, cognitive science would be a very different discipline.

In recent years work on this topic has been poorly represented at the annual Cognitive Science meeting. Some might draw the mistaken conclusion that research has stalled or that there remain no open issues. In fact, research has continued and has produced clear advances. Thus, problem solving or, more generally, goal-directed sequential activity is now typically understood within the context of the wider cognitive architecture, including how it uses domain-specific knowledge and heuristics in the service of goals. This symposium will draw together some of the recent work in this area, with the aims of highlighting progress and clarifying outstanding issues and contemporary research questions.

Scope and Organization

The five talks in this symposium will report research that covers a wide range of issues within contemporary problem-solving research, from incubation processes on insight tasks to the use of heuristics by experts in goal-directed design. What the research has in common is a concern with activity over time that is goal directed but also situation aware.

Thomas Ormerod will examine the development and testing of computational models of insight, with a focus on capturing differences between problem-solving tasks with unitary or multiple architectures, the difficulty of modelling apparently non-monotonic processes, and whether insight is governed by special or general cognitive processes. A meta-analysis by Sio and Ormerod (2009) of incubation effects found differences on linguistic puzzles such as Remote Associates tasks and on visual puzzles like the nine-dot problem, and similar task-based differences occur with sleep and analogy. His presentation will examine the extent to which different architectures and mechanisms, such as activation of associative networks (Monaghan et al., 2013) or goal-directed search for problem representations (Ormerod et al., 2013), are needed for different puzzle types, and will report models developed for both types of problem.

Colleen Seifert will discuss creative problem solving in design, focusing on how designers intentionally introduce variation. Consideration of multiple candidate concepts early in the design process is linked to better solution outcomes, but creating divergent pathways within the sequential activity of problem solving requires additional processes oriented to this goal. As in many areas of expertise, use of analogies with past solutions or precedents can be usefully applied in creative problem solving. Her Design Heuristics approach (Yilmaz et al., 2016) distills knowledge of design precedents to serve as generative constraints to guide divergent thinking. The heuristics are captured from studies of successful design outcomes within a wide variety of problem settings, including award-winning products, a longitudinal case study of an industrial designer, and protocol studies of industrial and engineering designers. Compilation of 3450 design outcomes revealed 77 design heuristics that introduce intentional variation into the generation process. These 'cognitive shortcuts' guide processing towards more, and more varied, design solutions.

Dario Salvucci will examine people's ability to perform multiple tasks at the same time. Often, multitasking is viewed as involving two separate and distinct activities, and indeed such multitasking appears often in the everyday world (the literal and metaphorical "walking and chewing gum"). However, multitasking often occurs in service of a single goal, with multiple 'threads' of processing performing different actions that eventually come together to complete a single purpose. Threaded cognition (Salvucci & Taatgen, 2008, 2011) is a computational theory, embedded within the ACT-R cognitive architecture, that aims to explain the power and limitations of human multitasking. In his presentation, he will discuss the theory and implications of threaded cognition for problem solving and other goal-oriented sequential activities, especially in the context of concurrent multitasking and task interruptions.

Richard Cooper will consider problem solving in terms of a core distinction between routine and nonroutine behaviour. His architecture is based on Norman and Shallice's (1986) dual-systems theory of the control of thought and action. In this account, routine or overlearned behaviour, while goal oriented, is schema driven and controlled by an activation-based 'automatic' system. In contrast, nonroutine behaviour involves higher-level cognitive processes that bias the routine system's activation in a deliberative, goal-directed fashion (Cooper et al., 2014). He will argue that human cognition requires: (a) explicit representation of subroutines, including their goals or effects, (b) hierarchically structured task knowledge, to support flexible and creative combination of subroutines in novel ways, and (c) control mechanisms that monitor progress towards goals, suppress prepotent response schemas, and recall relevant episodic memories to support analogical planning. He will contrast these features with those that underlie recent machine learning accounts of sequential activity.

Pat Langley will present a new architectural theory that addresses four issues typically neglected in accounts of problem solving. One is an embodied agents' need to represent and reason about both qualitative relations and quantitative attributes when describing states. A second is the relation between symbolic goals and numeric evaluation functions, which address different aspects of purpose-driven behavior. A third issue concerns the introduction of agents' top-level goals and their change over time. A final topic is the great variability observed in human problem solving, both across people and task settings. He will present a new cognitive architecture that incorporates ideas from earlier work but introduces new structures and processes that address these challenges (Langley et al., 2016).

In order to ensure coherence, presenters will each consider the problem-solving phenomena of interest, representational issues, and relevant architectural processes, such as retrieval, attention, and goal handling. Cooper and Langley will jointly moderate the session, summarizing the symposium aims, introducing each of the presenters, and ensuring the question-answer session remains timely and on topic.

Concluding Remarks

Taken together, these presentations will offer a broad sample of current research on problem solving and sequential activity. Each speaker has contributed to this area for many years and is well known for his or her accomplishments. Their topics range from creativity and insight to routine behavior on complex tasks. Their research builds on empirical studies of cognition but also contributes to architectural accounts of the mind.

We believe that this diverse set of presentations will convince conferences attendees that problem solving remains a critical area of enquiry within Cognitive Science, with both continuing theoretical progress and outstanding challenges. We further hope that the symposium will motivate audience members to join the quest to understand this fundamental aspect of human cognition.

References

Cooper, R. P., Ruh, N., & Mareschal, D. (2014). The goal circuit model: A hierarchical multi-route model of the acquisition and control of routine sequential action in humans. *Cognitive Science*, *38*, 244–274.

Langley, P., Barley, M., Meadows, B., Choi, D., & Katz, E. P. (2016). Goals, utilities, and mental simulation in continuous planning. *Proceedings of the Fourth Annual Conference on Cognitive Systems*. Evanston, IL.

MacGregor, J. N., Ormerod, T. C., & Chronicle, E. P. (2001). Information-processing and insight: A process model of performance on the nine-dot and related problems. *Journal of Experimental Psychology: Learning, Memory and Cognition*, *27*, 176–201.

Monaghan, P., Ormerod, T., & Sio, U. N. (2013). Interactive activation networks for modelling problem solving. *Computational Models of Cognitive Processes: Proceedings of the 13th Neural Computation and Psychology Workshop*. San Sebastian: World Scientific.

Norman, D. A., & Shallice, T. (1986). Attention to action: Willed and automatic control of behavior. In R. Davidson, G. Schwarz & D. Shapiro (Eds.) *Consciousness and self regulation* (Vol. 4). New York: Plenum.

Ormerod, T. C., MacGregor, J. N., Chronicle, E. P., Dewald, A. D., & Chu, Y. (2013). Act first, think later: Effects of maximization, minimization and lookahead on inferential planning in problem-solving. *Memory & Cognition*, *41*, 1096–1108.

Salvucci, D. D., & Taatgen, N. A. (2008). Threaded cognition: An integrated theory of concurrent multitasking. *Psychological Review*, *115*, 101–130.

Salvucci, D. D., & Taatgen, N. A. (2011). *The multitasking mind*. New York: Oxford University Press.

Sio, U.T. & Ormerod, T.C. (2009). Does incubation enhance problem-solving? A meta-analytic review. Psychological Bulletin, 135, 94-120.

Yilmaz, S., Daly, S. R., Seifert, C. M., & Gonzalez, R. (2016). Evidence-based design heuristics for idea generation. *Design Studies*, *46*, 95–124.