Title
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Journal
Proceedings of the Annual Meeting of the Cognitive Science Society, 15(0)

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Publication Date
1993

Peer reviewed

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Abstract

This article provides a very brief overview of the current status, as of Spring 1993, of Soar as a unified theory of cognition. Moreover, it serves to set the stage for the detailed discussions of individual Soar systems in the three papers that follow. We begin by summarizing the structure of Soar as a cognitive system, and then outline its status as a unified theory of cognition.

Soar

Any number of descriptions of Soar, at various levels of detail and from different perspectives, have already appeared in published work. Many of these descriptions can be found in (Rosenbloom, Laird, & Newell, 1993a; Rosenbloom, Laird, & Newell, 1993b). The most detailed of the recent descriptions can be found in (Newell, 1990) and in the combination of (Laird *et al*, 1990) and (Doorenbos, 1992). Here, we briefly summarize Soar based on a recent description for a cognitive/neural science audience (Polk & Rosenbloom, 1993).

Soar can be characterized via a hierarchy of four levels of description. At the top, Soar can be described at the *knowledge level* (Newell, 1982) as possessing goals and knowledge, having a body that provides perception and action capabilities, and choosing actions which its knowledge says will achieve its goals. This level of description abstracts away from all issues of internal structure and process. The abstraction aids in specifying the desired behavior of the system and in generating some classes of descriptions and predictions of its behavior, but it is also clearly too abstract for many other purposes.

At the *problem-space level*, Soar can be described as a set of interacting problem spaces, where each problem space represents the static and dynamic aspects of a small semi-independent fragment of the internal or external world (Newell *et al*, 1991). Soar approximates an ideal knowledge-level system to the extent that its knowledge – cast as problem spaces – can be used appropriately in selecting actions for its goals.

At the *architecture (or symbol) level* (Newell, Rosenbloom & Laird, 1989), Soar can be described as a hierarchy of four different layers of behavioral control (Laird & Rosenbloom, 1990a), which jointly implement the problem-space level. Behavioral functionality and flexibility increase with the height of the layer, but the minimum cycle time of the control loop also increases correspondingly. Starting from the bottom, the *module layer* provides a set of independent perceptual, motor, and perceptual-motor units. The *association layer* provides a parallel layer of associations – structured as productions – which mediate the interactions among the modules by providing some amount of coordination and communication. The *decision layer* provides the ability to base control decisions on multi-cycle associative stabilization. Behavior at this level proceeds through repetition of a two-phase cycle: first all matched associations are fired until no more are eligible, and then choices are made based on *preferences* retrieved by the associations. The *reflective layer* provides the ability to step back and reflect on impasses in decision making, and to learn from these reflective steps.

At the *technology level*, Soar can be described as a C program on particular hardware, though there are also attempts to move Soar over to an alternative technology based on neural networks (Newell, 1990; Rosenbloom, 1989; Cho, Rosenbloom, & Dolan, 1991).

Soar as a Unified Theory of Cognition

The goal of creating a full unified theory of cognition is both worthwhile and difficult to achieve. As with any endeavor of such broad scope, it requires a long-term commitment to incremental theoretical development. At any point in time, there will be capabilities that the theory supports strongly, those that constitute the leading edge, and those that remain unexplored. The most detailed extant overview of Soar as a unified theory of cognition, captured at one point in time, can be found in (Newell, 1990). The cognitive science community's response to Soar's status at that time, as captured in the commentaries in (Newell *et al*, 1992), provides a list of perceived weaknesses that we have taken as challenges to be met.[1] Though the published response to these commentaries does counter some of the challenges, it is still useful to reproduce the full list here as a way to organize recent advances and indicate new frontiers. Each of the subitems in the list below represents work done subsequent to (Newell, 1990) that is, at least in part, attempting to respond to the challenges. These subitems are derived primarily from the presentations at the Eleventh Soar Workshop (held at Carnegie Mellon University, Pittsburgh, PA, October 23-25, 1992). More exhaustive overviews of recent advances can be found in (Lewis *et al*, 1990; Michon & Akyürek, 1992; Rosenbloom, Laird, & Newell, 1993a; Rosenbloom, Laird, & Newell, 1993b).

- The perceptual-motor system
  - Covert Visual Attention (Wiesmeyer, 1992)
  - Intelligent tutoring in interactive environments (Ward, 1991; Hill & Johnson, 1993)
  - Modeling student education in an interactive microworld (Conati & Lehman, 1993)
- The treatment of psychological data and experiments
  - Verbal reasoning (Polk, 1992)
  - Psycholinguistic phenomena (Lewis, 1992)
- Language
  - Natural language comprehension (Lehman, Lewis, & Newell, 1991; Lewis, 1992; Lehman, Newell, Polk, & Lewis, 1993)
  - Learning from natural language instructions (Huffman & Laird, 1993)
- The undetermined character of psychological theory in Soar
  - Deriving a UTC's constraints on task models (Huffman, 1993)
- The AI bias of Soar
- Consciousness
- Short-term memory
  - Working memory and short-term memory (John, 1991)
- Emotion and noncognitive aspects
  - Modeling agents in organizations (Carley *et al*, 1992)
- Uncertainty
- Integration
  - Planning, execution, and learning (Laird & Rosenbloom, 1990b)
  - Task execution and natural language instruction (Huffman & Laird, 1993)
  - Natural language dialog in the NASA Test Director Model
- Induction
  - Concept acquisition (Miller & Laird, 1991; Rosenbloom & Aasman, 1990)
- Interruption and dual tasks
  - Robot control (Laird *et al*, 1991)
- Individual differences
  - Verbal reasoning (Polk, 1992)
- Skill
  - Skill acquisition in scheduling
  - Modeling the NASA Test Director (John, Remington and Steier, 1991)
  - Modeling pilot behavior (and flying simulated planes) (Jones *et al*, 1993; Pearson *et al*, 1993)
  - Skilled rapid interaction (John, Vera & Newell, 1990)
- Development
  - Number conservation .(Simon, Newell & Klahr, 1991)
- Recall without recognition
- Item recognition

Though this list of challenges and research topics cannot substitute for a systematic analysis of Soar's ability to match the full range of human cognition, it does provide a good snapshot of the current frontiers in Soar's development. Additional topics presented at the Eleventh Soar Workshop that do not respond straightforwardly to the challenges, nonetheless demonstrate further the diversity and vitality of research in Soar as a unified theory of cognition, and provide additional insight into the current frontiers of development:

- Acquisition of abductive expertise (Johnson &

[1] A second list of challenges, stemming more from the artificial intelligence community, can be found in (Stefik & Smoliar, 1993).

Smith, 1991)

- Acquisition of causal knowledge
- Einstellung (Tambe & Rosenbloom, 1993)
- Medical problem solving (Bayazitoglu, Smith, & Johnson, 1992)
- Music cognition (Scarborough, Manolios, & Jones, 1992)
- Interaction with external devices
- Human usability of Soar
- Studies of knowledge acquisition
- Environments for protocol analysis
- Flexible route planning (Stobie, Tambe, & Rosenbloom, 1992)
- Scale-up, efficiency, and computational bounds on Soar systems (Acharya & Tambe, 1992; Doorenbos, Tambe, & Newell, 1992; Doorenbos, 1993; Kim & Rosenbloom, 1993)

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