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Reprinted from the International Journal of Advanced Robotic Systems. 2006;3(3):219–222.

NOTICES

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14. ABSTRACT

This paper describes the ongoing development of a robotic control architecture that was inspired by computational cognitive architectures from the discipline of cognitive psychology. The robotic control architecture combines symbolic and subsymbolic representations of knowledge into a unified control structure. The architecture is organized as a goal driven, serially executing, production system at the highest symbolic level; and a multiple algorithm, parallel executing, simple collection of algorithms at the lowest subsymbolic level. The goal is to create a system that will progress through the same cognitive developmental milestones as do human infants. Common robotics problems of localization, object recognition, and object permanence are addressed within the specified framework.

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Developing a Psychologically Inspired Cognitive Architecture for Robotic Control: The Symbolic and Subsymbolic Robotic Intelligence Control System (SS-RICS)

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Abstract: *This paper describes the ongoing development of a robotic control architecture that was inspired by computational cognitive architectures from the discipline of cognitive psychology. The robotic control architecture combines symbolic and subsymbolic representations of knowledge into a unified control structure. The architecture is organized as a goal driven, serially executing, production system at the highest symbolic level; and a multiple algorithm, parallel executing, simple collection of algorithms at the lowest subsymbolic level. The goal is to create a system that will progress through the same cognitive developmental milestones as do human infants. Common robotics problems of localization, object recognition, and object permanence are addressed within the specified framework.*
Keywords: *Robotic architecture; cognitive architecture; robotic control; cognitive psychology*

1. Problem Statement

What constitutes a mind? How can a mind be developed for a robot? These are obviously difficult questions. The approach outlined here attacks the problem from the cognitive psychological perspective, with the development of the Symbolic and Subsymbolic Robotic Intelligence Control System (SS-RICS).

Cognitive psychologists have made enormous progress in understanding and modeling the human mind over the past two decades; moreover, psychologists have had great success in implementing human cognitive theories computationally (Anderson & Lebiere, 1998). The implementation of human cognitive function in a computational format has allowed cognitive theories to become more bounded, rigorous, and testable. This development has allowed for cognitive theories to be implemented on computer systems, to include robotic systems.

The work described here is a brief overview the SS-RICS. The system is intended to be a theory of robotic cognition based on human cognition. Additionally, a thrust of SS-RICS has been on the integration of theories *within* the field of cognitive psychology - primarily theories of knowledge representation and organization. The field of knowledge representation in cognitive psychology has been embattled in a struggle to quantify knowledge structures as either symbolic or subsymbolic (Kelley, 2003). Symbolic knowledge is characterized as static, discrete, and conscious. Language is a symbolic representation of knowledge. Subsymbolic representations of knowledge has been characterized as dynamic, distributed, and unconscious. Typically, perceptual or motor skills are characterized as subsymbolic knowledge. Riding a bicycle can be characterized as subsymbolic knowledge. Within SS-RICS, these two representations of knowledge are not mutually exclusive, but instead, lie on either ends of a cognitive continuum (Kelley, 2003). SS-RICS is a hybrid cognitive system that allows for a continuum of knowledge that includes both symbolic as well as subsymbolic constructs. It is believed that this integrated approach is the best way to represent the complete spectrum of cognition.

2. Design Principles

In order to guide the creation of the SS-RICS, five developmental principles were established. 1) The lowest level of perception includes algorithms running in a parallel fashion, while the highest levels of cognition are algorithms operating in a serial fashion. 2) At both the low levels and the high levels of cognition, the algorithms are relatively simple. *It is the interaction, processing, and results of simple algorithms which produce complex, intelligent behavior*. 3) Pre-programming SS-RICS should be guided by the algorithms that have been developed through evolution. (For example, algorithms that recognize vertical lines in the environment or cause movement toward light). The pre-programming that is done should allow for the *emergence* of complex behavior, but not be the complex behavior itself. 4) Cognitive development within SS-RICS is principally about the reorganization of memory elements through increasing and decreasing their respective strengths. 5) Cognitive development and change can occur after a given amount of time or after the necessary low level elements are in place to allow for higher level processing.

The first three principles mainly guided the development of the cognitive architecture. Simple algorithms were used, with special care to concentrate on their interactions with each other in a dynamic setting. Also, care was given to mimic the pre-programmed algorithms that a human might have at the lowest levels of their perceptual system. The last two principles describe how cognitive change takes place: through either the strengthening or weakening of memory elements or through changes in goal directed behaviors after certain low level systems have fully developed.

3. Structure of SS-RICS

SS-RICS is goal directed. Goals lie at the top of the organizational hierarchy. Goals determine the actions of the system and are fed to the production system. Subsymbolic processing occurs in parallel under the production system and the results of the subsymbolic processing are made available to the production system if the production system requires the input. Goals, production system outputs, and subsymbolic processing can all affect robot action. The subsymbolic layer is primarily responsible for creating memories.

Much of cognitive psychology is devoted to the study of creating, storing and retrieving memories. It could be argued that, much - if not all of cognition - is based on the decay and strengthening of memory elements in a systematic fashion. In SS-RICS, the strengthening and decay of memory elements is taken from the activation function described in the Atomic Components of Thought-Rational (ACT-R) cognitive architecture (Anderson and Lebiere, 1998). A plot of the activation function for memory can be seen in Figure 1. It shows the transition of a memory element across different strength levels. Additionally, we have found it very important to have different decay rates for memory items; specifically low-level subsymbolic memories typically decay faster than higher level symbolic memories. Also, instead of using labels such as short term memory (STM) or long term memory (LTM) we have found it more beneficial to implement memory as a continuum of values. In other words, memories can have a range of decay values, and memories don't necessarily fit into the convenient categories of STM or LTM.

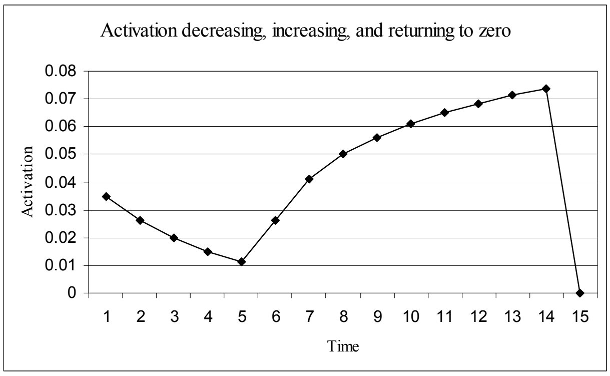

Fig. 1. – Activation decreasing, increasing and returning to zero (RTZ) (Note: The return to zero is not a part of the original base level activation equation from Anderson and Lebiere, 1993)

3.1 Goals

At the highest cognitive level of SS-RICS, there is the psychological construct of a goal. Cognitive psychologists have shown that much of human behavior is primarily goal directed (Frese & Sabini, 1985). Goals for human beings can include: goals to achieve success, goals to procreate, or goals to satiate hunger (Maslow, 1943). Goals in the SS-RICS architecture may include: goals to avoid objects, goals to examine objects, or goals to ask questions about objects. Goal directed behavior is not simply the execution of one goal, but rather the execution of a set of conflicting goals which allow complex behavior to emerge from their dynamic interaction. New goals may be added as behavior matures or develops, or after a set amount of time. Conflicting goals also compete for behavioral control depending on the activation strength of each goal, and the random noise variations of each goal (see Anderson and Lebiere (1998) for more details on the activation function and noise). Additionally, goals are stored as memories, so they have activation values just as memories do. Internal or external stimuli can change the activation strengths of each goal

If a goal is executed once, it is reinforced, and is more likely to execute again. Also, using three key parameters of the activation function (Figure 1), the function can be manipulated so new behavior patterns emerge. First, the length of the asymptotic behavior for the activation function can be manipulated to be long or short. This allows for the strength of a goal to reach an asymptotic level, but the strength will no longer increase; thus allowing the activation of the goal to stay high and perhaps allowing the goal to be repeatedly re-executed. Weather or not the goal is re-executed would depend on the strengths of the other goals. Second, the amount of time a goal takes until it reaches asymptotic behavior can be manipulated. So, an important goal might increase quickly, thus insuring that no other conflicting goals compete for possible selection. Finally, goals within SS-RICS have a Return to Zero (RTZ) parameter (which is different from ACT-R) where their strength eventually returns to a zero value. This insures that a goal will not execute continuously, but instead the strength of the goal will return to zero and perhaps another goal with a zero value, could be selected.

3.2 Production System

Within SS-RICS, below the level of a goal, is a production system architecture. Production system architectures have been used successfully to mimic human behavior (Anderson and Lebiere, 1998), and the production system is the basis of ACT-R, as well as other cognitive architectures (Soar; Newell, 1992). A production system is a deductive reasoning system that uses relatively simple if-then type rules to deduce conclusions. The SS-RICS uses the production system as a rule based problem solving system. For example, if a goal is to identify an object, a production system with a specific set of object identification rules are loaded into the SS-RICS and used to identify the object. Certain object identification rules are loaded because they have the highest activation values. The production system can be thought of as actions which are executed depending on which goal has been selected. Production system facts are stored together as memories with activations associated with the entire fact set. Increased use of a certain production system would cause its increased use in more situations.

3.3 Subsymbolic System

At the bottom of the SS-RICS hierarchical structure is the subsymbolic system. The subsymbolic system is primarily characterized by its distributed, parallel nature. This system is a collection of low-level, simple algorithms, which run in parallel and make their results available to the to higher levels of the architecture if needed.

A distinction here must be made between the subsymbolic system used within SS-RICS and other distributed representations traditionally used in AI which are known as neural networks. Neural networks are developed by creating a collection of nodes and then connecting the notes together in a web of connective strengths. Neural networks are then trained by presenting inputs to the net. This allows the weights between the nodes to be tuned, which can then produce the desired output.

Instead of developing neural networks at the subsymbolic level, simple algorithms were implemented which were built to recognize small bits of information. These algorithms all ran in parallel and fed their results up to the next level of the SS-RICS. It is possible that future developments of SS-RICS will use neural network techniques in a more evolutionary context by using genetic algorithms to determine neural network topology and weight strengths. But for now, simple algorithms running in parallel constitute the bulk of the subsymbolic SS-RICS system.

4. Development

The development of SS-RICS has not followed the typical approach in robotics. Typically, robots are designed to carry out one task very well, at the exclusion of other tasks. Typical robotics implementations are of a task specific implementation (i.e. design so that the robot can play a game, or serve as a museum guide). However, we did not develop SS-RICS with a specific task in mind for SS-RICS to accomplish. Instead, we hoped that SS-RICS would be the foundation of a complete mind which will eventually be capable of a wide range of behaviors. SS-RICS is based on ACT-R, which was developed to be a unified theory of cognition. However this approach presents a trade-off: Designing exclusively for one task can show the capabilities of the system very quickly and provide empirical data to support claims. However, designing for generality will allow us to accomplish a wide range of tasks, but perhaps not as well as a system that was designed for optimal performance on one task. Our approach has brought criticism from those who would like to see proof that SS-RICS is capable of accomplishing a task better than using traditional AI techniques. This criticism is justified, and we are hoping to answer this criticism once the architecture is more complete and capable of performing a wide range of tasks. Additionally, a disadvantage of designing a complete mind for general behavior is that the system needs to be relatively complex before task behavior can be generated. Complex behaviors require a wide range of algorithms and systems for complete implementation (i.e. vision systems, memory systems, motor systems). We hope that the increased functionality of complex general behavior verses simple specific behavior will be worth the additional effort. However, we have not steered away from using SS-RICS to accomplish difficult tasks; on the contrary, we are using SS-RICS to accomplish two of the most difficult tasks in AI: object recognition and continuous localization.

Object recognition has been a problem for the AI community for many reasons: objects look different from different angles, objects can be occluded by obscuring objects, and objects look different from different distances. Therefore, one cannot use a template matching system, or a database of items, to match the currently perceived object to every object in the database. SS-RICS uses a different approach to this problem. The psychological approach tells us that people develop rules to identify objects (Biederman, 1985). For example, tigers have stripes and leopards have spots. Additionally, using rules can help a person identify objects they may never have seen before. Furthermore, rules can help identify an object even if it is occluded or seen from an unusual angle. We have also found that object recognition is also the key to the localization problem. Research with animals has shown that cognitive maps are developed around identified objects, or landmarks, and these landmarks serve as anchors for the entire cognitive map (O'Keefe & Nadel, 1978). We have been working to give SS-RICS the ability to use feature sets for object recognition and continuous localization, and we have had some success with this approach. We hope to do additional research to determine how to weight recognized features, and determine why some features of an object are more important than others for object recognition.

5. Conclusions

We have combined theories (symbolic and subsymbolic integration) within the field of cognitive psychology that allow for a more complete representation of cognition, and have applied this approach to robotic cognition. We are using psychological theories to solve hard AI problems, such as object recognition and continuous localization. We have designed a general framework based on the cognitive architecture ACT-R, however, we have made some changes that differentiate SS-RICS from ACT-R. The *complete* cognitive framework, SS-RICS, should provide the basis for a cognitive system which can understand and interact with a dynamic world on a robotic platform. Once the system is complete, we hope to have empirical evidence showing that the performance of SS-RICS on a variety of tasks is as good or better than typical task specific implementations.

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