Evolutionary Control via Sensorimotor Input and Actuation

by *Todd M. Shrider*

Introduction

One of the main goals of the study of robotics today is to understand not only the control systems used to stabilize the position, motion, and other forces of the robot, but also to allow robots to effectively work via sensors and actuators in dynamic environments. Traditionally the task of a control system is to execute a pre-planned sequence in the presence of unforeseen errors. These errors generally arise from inaccuracies in the robot's model of the world and due to changes in the environment. One way to solve these problems is by utilizing theories from cognitive science. This article will provide an overview of a theory of control based on non-traditional theories of artificial intelligence and cognition.

Symbolic Representation?

A symbol or artifact is defined, from the standpoint of cognitive sciences, as an encoded part of knowledge that contains some semantic content. A computer is, in fact, a symbol manipulator, working with ones and zeros. It's one of the most basic hypothesis of the cognitive sciences that the human mind is a type of computer. While it is evident that both computers and the human mind take inputs and manipulate them in some form to produce output (i.e. watching a ball as you prepare to hit it with a bat, or a computer using a scanner to copy an image to the monitor), the importance of the role of symbols containing some sort of semantics in intelligent systems has become questioned.

Pylyshyn's ``Computing and Cognitive Science'' [4] summarizes the classical view of artificial intelligence, which he calls the classical computation or cognitive architecture. He presents three levels, the first being semantics, in which the intelligent systems present knowledge and goals, showing how these are connected in some rational way. The second level is representation by the symbolic, where the semantic knowledge of the first level is encoded into a type of model. This level also assumes the structure of the system and the regularities or rules by which the symbols are manipulated. The third level is the re-realization of the symbolic into that of the physical, where the modeled world from the symbolic level is grounded. Pylyshyn, however, works without the idea that sensors and actuator are a needed part of a system.

Another approach to cognitive science, popularized mainly by Brooks [2] and Varela [7] , abandons the modeling mechanisms. Differing from Pylyshyn's cognitive architecture, these models rely on various other aspects that can be observed in biology [1], and are very dependent on sensors and actuators. The characteristics are as follows:

- *Situatedness*: There is no need for a symbolic modeling of the world. By continual reference, the world can act as its own model.
- *Embodiment*: Unlike computer programs that attempt to mimic intelligence, only an embodied agent can be grounded and therefore bottom out any internal symbolic or other system (there is a definite need for sensors and actuators).
- *Intelligence*: You cannot define intelligence; trying to do so only leads toward regress. One must try to design intelligence from the ground up, letting the agent's actions in its environment speak for themselves.
- *Emergence*: Minsky [3] points to a system in which parts are meaningless, but when working together they form something ``greater than the sum of its parts." In this case, intelligence is an emergent property of the system as it acts and adapts to its environment.

It is important to realize the these four characteristics are very much intertwined. Without embodiment in some fashion you cannot provide a situation for the robot (i.e., there is no way to let the robot know about it's world). Without situation you cannot ground the components of your systems, thereby stunting emergence and destroying your chances for intelligence. Without intelligence it would seem you have nothing to situate.

People studying cognitive science traditionally use the model of von Neuman architectures. These machines are composed of high speed memory and a single high speed central processing unit with a very narrow and slow channel connecting the two. Biological systems, however, tend to process low cost functions in a massively parallel way. Therefore, it would be better to have many low speed processors, each with proprietary memory and high-speed interconnections to each other [1].

Biological Inspiration

When trying to re-create a biological phenomena, it makes sense to look at the biological world for some good initial pointers. For instance, the study of robotic locomotion is aided by observing and imitating biological systems. A robot is limited when using wheels (very un-biological) in rough terrains, whereas a biologically inspired robot would have legs like that of a spider for maneuvering around and over obstacles.

Another example may be how a spider-like robot that loses a leg might adjust its gait to complete a mission-critical task. One can look at an experiment performed by Wilson [8] as an example. Here two legs from opposite sides of a spider were amputated. Two possibilities existed for the spider (*see Fig. 1*): it could either retain a diagonal rhythm of locomotion using four legs, but lose it's ability to balance; or it could move three legs at a time, offsetting its diagonal rhythm. The experiment showed that the spider chose the second alternative, which was more mechanically stable. This apparently has to do with the fact that although the walking patterns are determined in the spiders ``central oscillator," they can be modified by feedback from sensory organs in the legs [5]. In effect, the spider adapted by reprogramming itself.

Figure 1 (a) The spider's regular walking pattern. (b) Spider retaining a diagonal rhythm when missing leg R1 and L4 and (c) the spider moving three legs at a time, in a more stable fashion.

For a robot to accomplish such a task, its control software must be more than a pre-planned sequence of motions and forces. Sensors and actuators must be connected in a very direct fashion, and the robot must be able to react immediately to its environment. In such a dynamic environment, traditional cognitive techniques seem unable to deal with the continuity of the environment. The option that is left is control software that is embodied within the robot to continuously sense and adapt to its environment. This allows for software that can develop intelligent reactions over time.

A Sensorimotor Architecture

It is known in neurobiology that patterns of neuronal connections determine the meaning of electro-chemical signals. At first it may seem surprising that the signals themselves cannot be endowed with semantics. However, the brain deals only with external events. This differs vastly from the view of symbols in traditional cognitive science discussed above. The point is that the meaning or quality of the signals are dependent on the origin and destination of the connections between the sensors and the actuators.

This can be looked at in two ways. First, a robot, with a control architecture that directly connects its sensors and actuators, can be said to do meaningful things by processing inputs as signals and parsing them. Second, it can be said that within the structure of the brain, an otherwise meaningless signal can become meaningful when looked at between two neuronal structures, providing a type of micro-relation. Either way, signals collected by sensors are allowed to pass through the system and provide meaningful action.

I propose that such a control architecture may be developed so that through evolution, intelligent actions may emerge from the system over time. Further, I propose an architecture composed of a network of connections which has this evolving quality. The network essentially learns through the ability of its nodes (*see Fig. 2*) to evolve over a period of time.

In our nervous system, we find that neurons in the retina differ vastly from those found in the spinal cord. Similarly, if we allow each node in a network to develop its operational characteristics depending on its environment, we can allow micro-relations between nodes and the possibility of the system to provide meaningful reaction depending on external situations.

Figure 2: An example of a node with one input and one output

A stricter definition of a node follows:

- *Genetic Algorithms*: The genetic algorithm takes data, called chromosomes, which are encoded in strings of n-bits, and uses them to evolve a fitness value of the node, as well as evolve a new chromosome to pass to the next node.
- *Node Timer*: The node timers are co-evolved with the node statistical analyzer, which controls the rate at which a node can fire.
- *Node Statistical Analyzer*: The node statistical analyzer is co-evolved with the Node Timer. It allows the node to control the amount of traffic that the node receives.

Possibly the most influential part of a node to the network is the node statistical analyzer. This allows such an architecture to form topographical structures within the network based on statistics of the traffic the node sees. Over a period of time the network would evolve an ontology, allowing it to perform complex ``intelligent'' tasks in a dynamic environment with less chances for error. Moving the robot from one environment ``type'' to a drastically different environment ``type'' would initially confuse it, but eventually it would adapt its network to the environment.

It is in this way that the Sensorimotor Architecture differs from many traditional systems. An embodied agent, such as the robot, is more apt to learn from its environment. It can more effectively cope if it is allowed to adapt its programming over time, rather than being given an initial set of static commands. In such a system, knowledge is no longer stored symbolically. Here it is represented in a less ordered fashion that depends on the fitness values found within the various Genetic Algorithm nodes and the actual structure of the network. The knowledge and capability of the robot to learn is ever evolving.

Advantages and Applications

Brooks [1] proposes the subsumption architecture to allow a type of emergent quality to inhabit his robots, which are developed for such tasks as mine-removal and planetary exploration. However, the subsumption architecture relies on the development of finite state machines for its network's nodes. This means that for the robot to be able to evolve, it must be adapted by an external agent of some type (namely its creator).

In such situations, like mine-removal or planetary exploration, the robot could possibly be out of human contact for long periods of time, or it might be cost-prohibitive to re-implement the robot's network. The Complex Control Architecture would allow the robot to do the work itself, with little need or no data from its creator.

Future Work

Currently I am exploring two sub-areas of research for the Sensorimotor Architecture: Genetic Algorithms and Node Statistical Analysis. It is important for the genetic algorithms within each node to have quality low-cost fitness values. The work should not be done by the GA itself, but by the network as a whole in a distributed fashion. This allows us to attain the quality of a low cost, massively parallel system. It is also important that the Node Statistical Analyzer be self-driven and not dependent on values provided by the creator. This will allow for independence of the robot itself. It remains to be seen if the relationship between the genetic algorithms and the node statistical analyzers can be co-evolved.

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Biography

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