A BRIEF INTRODUCTION TO BEHAVIOR-BASED ROBOTICS

Rodney Brooks developed the subsumption architecture in the mid-1980s at the Massachusetts Institute of Technology (MIT). His approach, **a purely reactive behavior-based method**, flew in the face of traditional AI research at the time. Brooks argued that the *sense-plan-act* paradigm used in some of the first autonomous robots was in fact detrimental to the construction of real working robots. He further argued that **building world models and reasoning using explicit symbolic representational knowledge at best was an impediment to timely robotic response and at worst actually led robotics researchers in the wrong direction**.
The cornerstone of behavior-based robotics is the realization that **the coupling of perception and action gives rise to all the power of intelligence** and that **cognition is only in the eye of an observer.**

Subsumption architecture

Brooks proposed the use of a **layered control system**, embodied by the **subsumption architecture** but layered along a different dimension than what traditional research was pursuing. Figure 1 shows the distinction between the *sense-plan-act* traditional model (on the left) and the decomposition of the behavior-based or subsumption model (on the right).

The word “subsumption” comes from the verb “to subsume”, which means: “to think about an object as taking part of a group”. In the context of the behavioral robotics, the name subsumption arises from the coordination process used between the layered behaviors within the architecture. Complex actions subsume simpler behaviors.

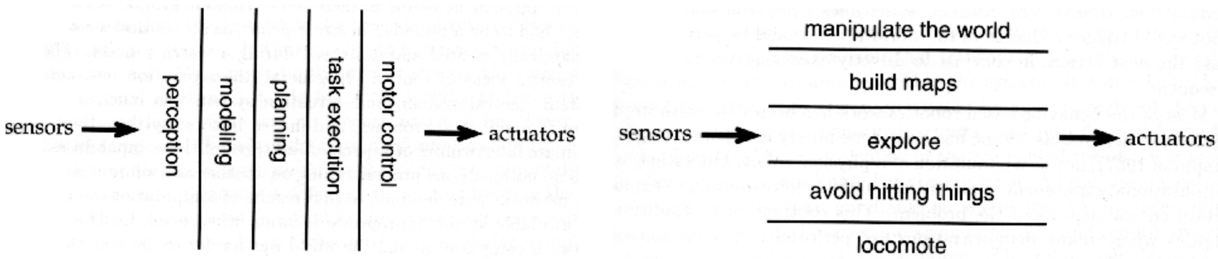

Figure 1 – Traditional and subsumption decomposition (adapted from [2])

Much of the presentation and style of the subsumption approach is dogmatic. Tenets of this viewpoint include:

- Complex behaviors need not necessarily be the product of a complex control system.
- Intelligence is in the eye of the observer.
- The world is its own best model.
- Simplicity is a virtue.
- Robustness in the presence of noisy or failing sensors is a design goal.
- Planning is just a way of avoiding figuring out what to do next.
- Systems should be built incrementally.
- No representation. No calibration. No complex computers. No high-bandwidth communication.

Task achieving behaviors in the **subsumption architecture** are represented as separate layers. Individual layers work on individual goals concurrently and asynchronously. At the lowest level, each behavior is represented using a behavioral module, which encapsulates a particular behavioral transformation function. Stimulus or response signals can be suppressed or inhibited by other active behaviors. A reset input is also used to return the behavior to its start conditions.

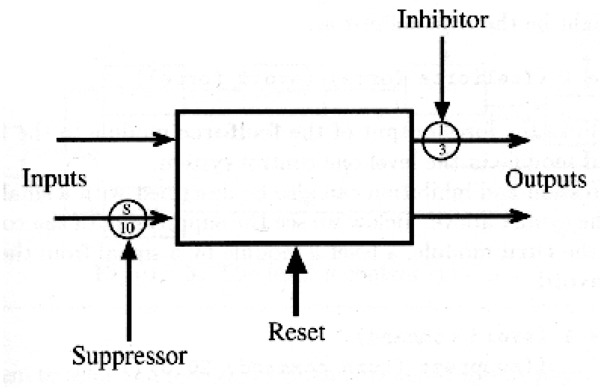

Figure 2 – Behavioral module (from [2])

Each behavioral module performs an action and is responsible for its own perception of the world. There is no global memory, bus or clock. With this design, each behavioral layer can be mapped onto its own processor. There are **no central world models or global sensor representations**. Required sensor inputs are channeled to the consuming behavior.

Figure 3 shows a simple mobile robot with three behavioral layers. The lowest behavior layer, *avoid-objects*, either halts or turns away from an obstacle, depending upon the input from the robot's infrared proximity sensors. The *explore* layer permits the robot to move in the absence of obstacles and cover large areas. The highest layer, *back-out-of-tight-situations*, enables the robot to reverse direction in particularly tight quarters where simpler avoidance and exploration behaviors fail to extricate the robot.

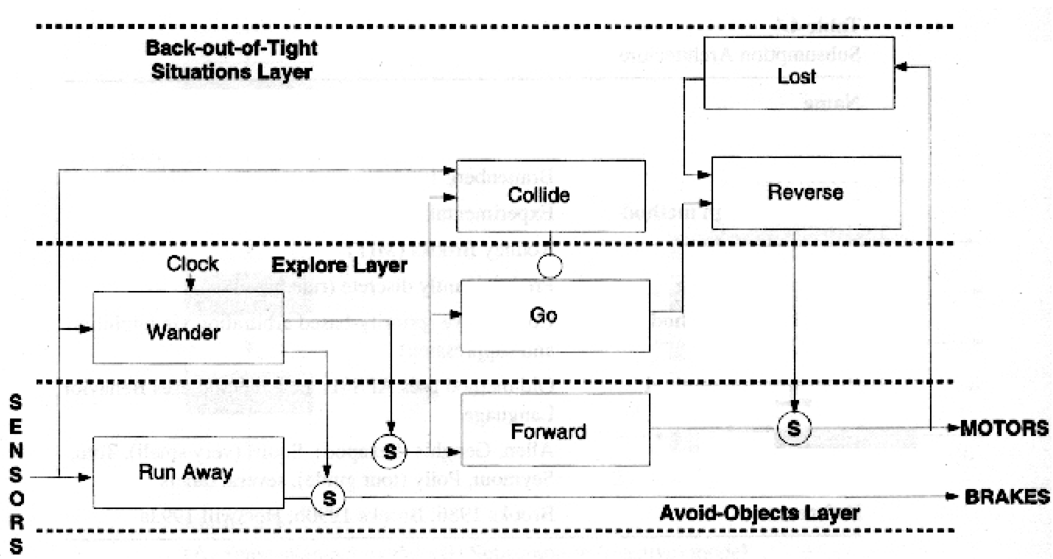

Figure 3 – Simple three-layered robot architecture (Brooks 1987)

A **priority hierarchy** fixes the topology. The lower levels in the architecture have no awareness of higher levels. **This provides the basis for incremental design.** Higher-level competencies are added on top of an already working control system without any modification of those lower levels.

Coordination in subsumption

Coordination in subsumption has two primary mechanisms:

- **Inhibition**: used to prevent a signal being transmitted along a behavioral module's wire from reaching the actuators.
- **Suppression**: prevents the current signal from being transmitted and replaces that signal with the suppressing message.

Subsumption permits **communication between layers** but restricts it heavily. The allowable mechanisms have the following characteristics:

- Low baud rate, no handshaking
- Message passing via machine registers
- Output of lower layer accessible for reading by higher level
- Inhibition prevents transmission
- Suppression replaces message with suppressing message
- Reset signal restores behavior to original state

The world itself serves as the primary medium of communication. Actions taken by one behavior result in changes within the world and the robot's relationship to it. New perceptions of those changes communicate those results to the other behaviors.

The key aspects for design of subsumption-style robots are situatedness and embodiment. **Situatedness** refers to the robot's **ability to sense its current surroundings** and **avoid the use of abstract representations**, and **embodiment** insists that the robots be physical creatures and thus **experience the world directly rather than through simulation**.

References

[1] RONALD C. ARKIN, *Behavior-Based Robotics*, The MIT Press, 1997

[2] RODNEY A. BROOKS, *Cambrian intelligence*, The MIT Press, 1999