4 *The Reactive Paradigm*

Chapter Objectives:

- Define what the reactive paradigm is in terms of i) the three primitives SENSE, PLAN, and ACT, and ii) sensing organization.
- List the characteristics of a reactive robotic system, and discuss the connotations surrounding the reactive paradigm.
- Describe the two dominant methods for combining behaviors in a reactive architecture: *subsumption* and *potential field summation*.
- Evaluate subsumption and potential fields architectures in terms of: *support for modularity, niche targetability, ease of portability to other domains, robustness*.
- Be able to program a behavior using a potential field methodology.
- Be able to construct a new potential field from primitive potential fields, and sum potential fields to generate an emergent behavior.

4.1 Overview

This chapter will concentrate on an overview of the reactive paradigm and two representative architectures. The Reactive Paradigm emerged in the late 1980's. The Reactive Paradigm is important to study for at least two reasons. First, robotic systems in limited task domains are still being constructed using reactive architectures. Second, the Reactive Paradigm will form the basis for the Hybrid Reactive-Deliberative Paradigm; everything covered here will be used (and expanded on) by the systems in Ch. 7.

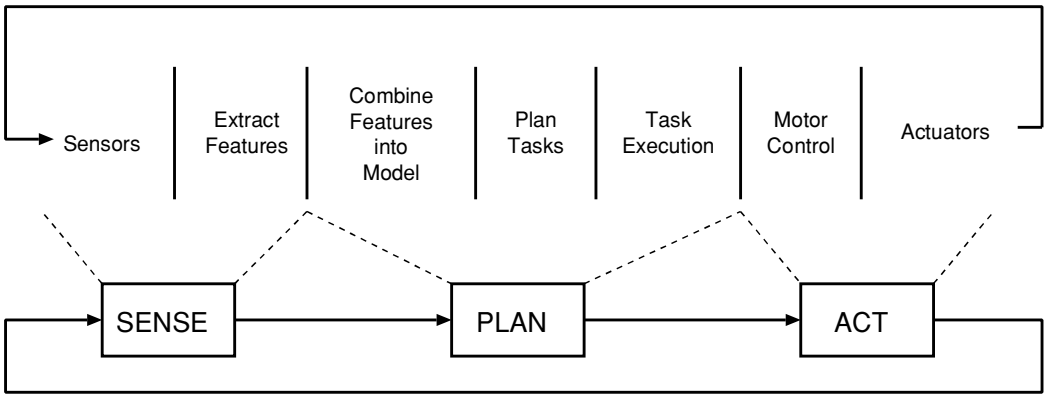

Figure 4.1 Horizontal decomposition of tasks into the S,P,A organization of the Hierarchical Paradigm.

The Reactive Paradigm grew out of dissatisfaction with the hierarchical paradigm and with an influx of ideas from ethology. Although various reactive systems may or may not strictly adhere to principles of biological intelligence, they generally mimic some aspect of biology. The dissatisfaction with the Hierarchical Paradigm was best summarized by Rodney Brooks,[27] who characterized those systems as having a *horizontal decomposition* as shown in Fig. 4.1.

HORIZONTAL DECOMPOSITION

Instead, an examination of the ethological literature suggests that intelligence is layered in a *vertical decomposition*, shown in Fig. 4.2. Under a vertical decomposition, an agent starts with primitive survival behaviors and evolves new layers of behaviors which either reuse the lower, older behaviors, inhibit the older behaviors, or create parallel tracks of more advanced behaviors. The parallel tracks can be thought of layers, stacked vertically. Each layer has access to sensors and actuators independently of any other layers. If anything happens to an advanced behavior, the lower level behaviors would still operate. This return to a lower level mimics degradation of autonomous functions in the brain. Functions in the brain stem (such as breathing) continue independently of higher order functions (such as counting, face recognition, task planning), allowing a person who has brain damage from a car wreck to still breathe, etc.

VERTICAL DECOMPOSITION

Work by Arkin, Brooks, and Payton focused on defining behaviors and on mechanisms for correctly handling situations when multiple behaviors are active simultaneously. Brooks took an approach now known as subsumption and built insect-like robots with behaviors captured in hardware circuitry.

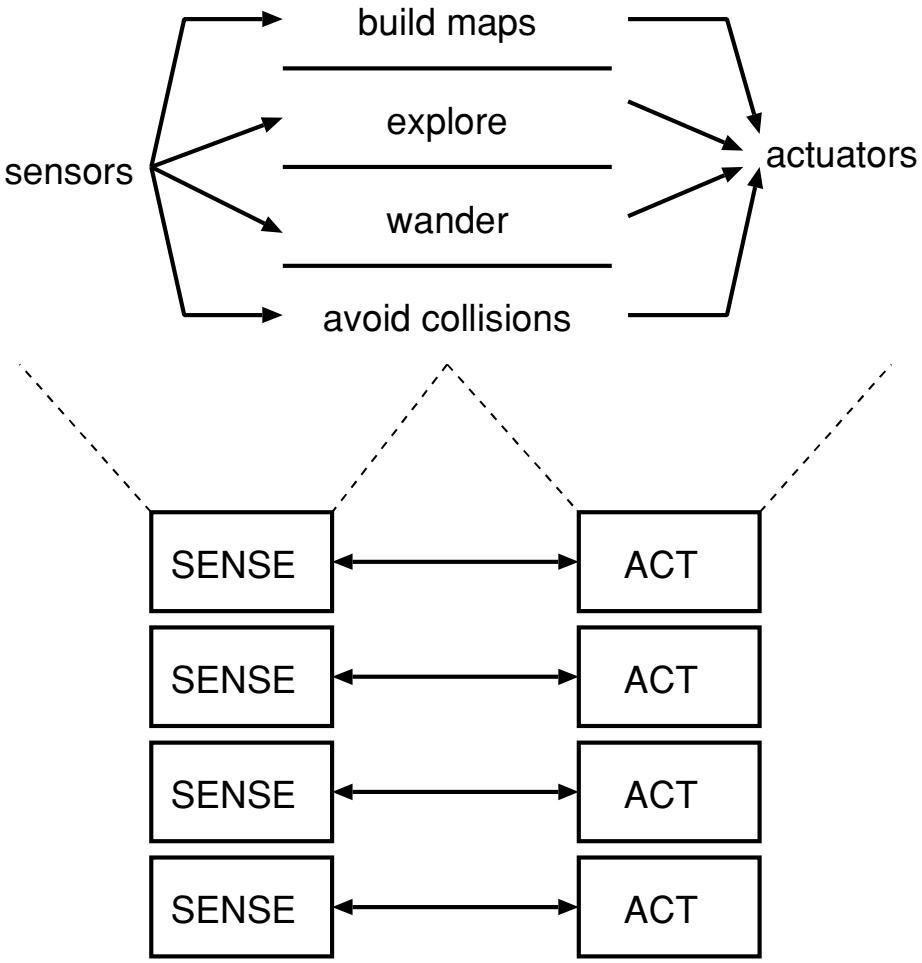

Figure 4.2 Vertical decomposition of tasks into an S-A organization, associated with the Reactive Paradigm.

Arkin and Payton used a potential fields methodology, favoring software implementations. Both approaches are equivalent. The Reactive Paradigm was initially met with stiff resistance from traditional customers of robotics, particularly the military and nuclear regulatory agencies. These users of robotic technologies were uncomfortable with the imprecise way in which discrete behaviors combine to form a rich emergent behavior. In particular, reactive behaviors are not amenable to mathematical proofs showing they are sufficient and correct for a task. In the end, the rapid execution times associated with the reflexive behaviors led to its acceptance among users, just as researchers shifted to the Hybrid paradigm in order to fully explore layering of intelligence.