

Robotic Agent Architectures

Robótica Móvel e Inteligente

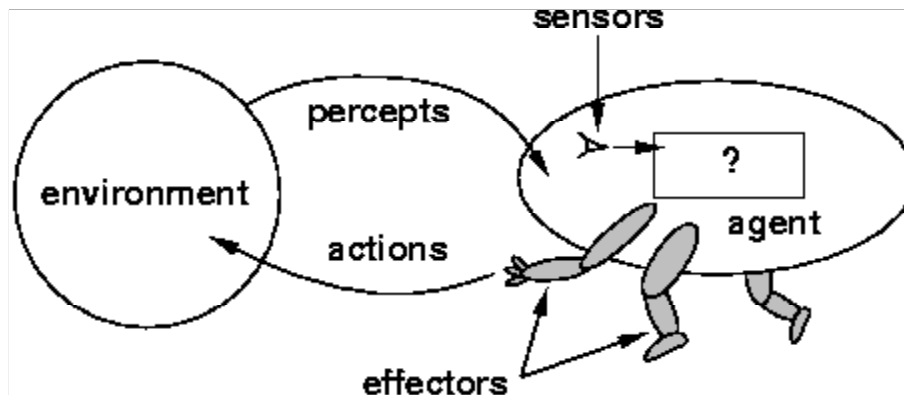
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IEETA – DETI – Universidade de Aveiro

- Introduction to Robotic Agents
- Deliberative Architectures
- Reactive Architectures
- Behavior-Based Architectures
 - Subsumption Architecture
- Hybrid Architectures

- **Traditional Definition:**

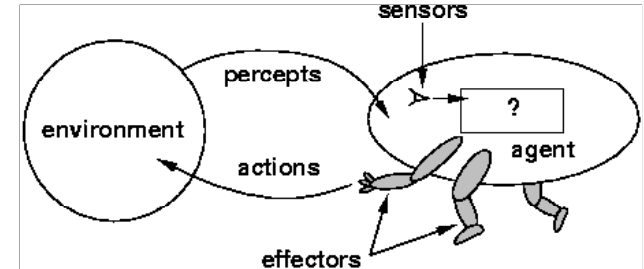
“Computational System, situated in a given **environment**, that has the ability to **perceive** that environment using **sensors** and **act**, in an **autonomous way**, in that environment using its **actuators** to fulfill a given **function**.”



Russel and Norvig, AI: Modern Approach

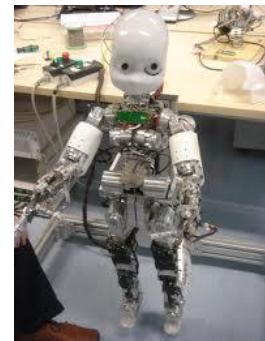
- **Agent:**

- Perceive its environment using sensors and executes actions using its actuators
- Sensors:
 - Eyes, ears, nose, touch, ...
- Actuators:
 - Legs, Arms, hands, vocal cords, ...



- **Robotic Agent:**

- Sensors:
 - Cameras, sonar, infra-red, microphone
- Actuators:
 - Motors, wheels, manipulators, speakers



- **Robotics**

- Science and technology for **projecting, building, programming and using Robots**
- Study of **Robotic Agents (with body)**
- Increased Complexity:
 - **Environments**: Dynamic, Inaccessible, Continuous and Non Deterministic!
 - **Perception**: Vision, Sensor Fusion
 - **Action**: Robot Control
 - **Robot Architecture** (Physical / Control)
 - **Navigation** in unknown environments
 - **Interaction** with other robots/humans
 - **Multi-Robot Systems**



Definition of Robot

- Notion derives from 2 strands of thought:
 - Humanoids: human-like
 - Automata: self-moving things
- “Robot” - derives from Czech word *robota*
 - “*Robota*”: forced work or compulsory service
 - Term coined by Czech playwright Karel Capek (1920)
- Current notion of robot:
 - Programmable
 - Mechanically capable
 - Flexible



- **Electromechanical device which can perform tasks on its own, or with guidance**
- **Physical agent (with body) that generates intelligent/autonomous connection between perception and action**
- **Autonomous system in the physical world which may sense its environment and act on it to achieve a set of goals**

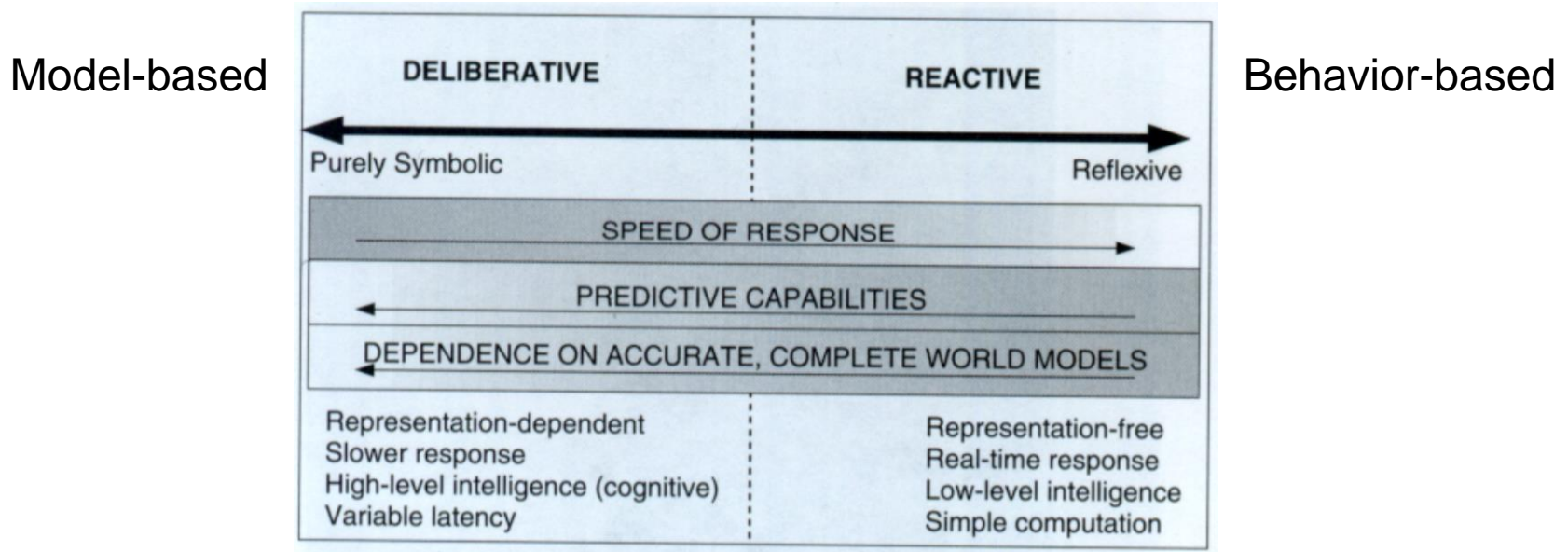
Robotic Architecture - Definition(s)

- An **architecture** provides a **principled way of organizing a control system**. However, in addition to **providing structure**, it **imposes constraints** on the way the control problem can be solved
[Mataric, 1992]
- An architecture is a description of how a **system is constructed from basic components** and how those **components fit together** to form the whole
[Albus, 1995]
- Robotic architecture usually refers to **software**, rather than hardware
[Arkin, 1998]
- How **the job** of generating actions from percepts **is organized**
[Russel and Norvig, 2002]

- **Representation**
 - unified, heterogeneous, multiple or no representation
- **Control and coordination**
 - centralized or distributed control
- **Learning**
 - architecture should organize structures to facilitate learning
- **Timely performance**
 - deal with real-time constraints
- **Biological and psychological inspiration**
 - parallelism, distributed control, reflex loops, etc
- **Evaluation**

Spectrum of Robot Control Architectures

- Deliberative control: “think hard, then act”
- Reactive control: “don't think, (re)act”
- Hybrid control: “think and act in parallel”

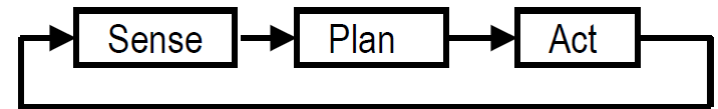


Adapted from Arkin, Behavior-based Robotics (MIT Press, 1998)

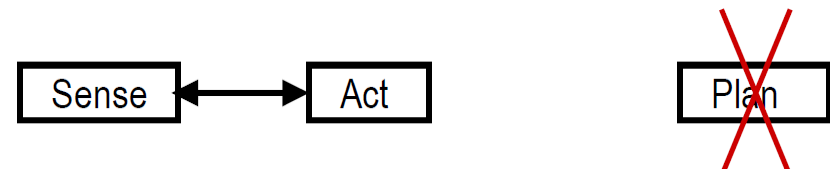
Typical Organizations

- Typical organizations:

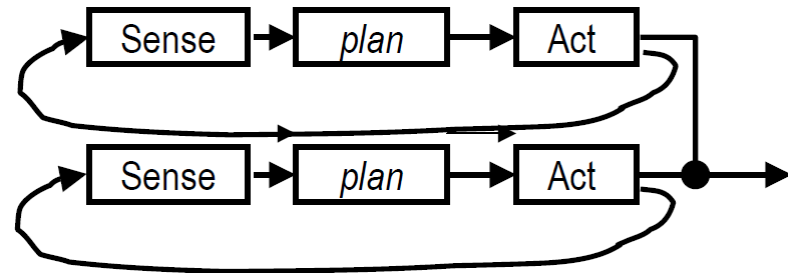
- Hierarchical / Deliberative



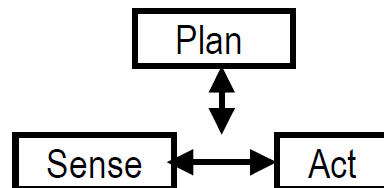
- Reactive



- Behavior-based



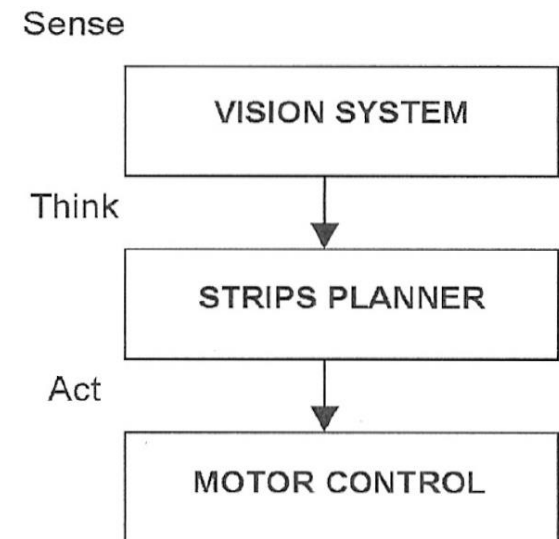
- Hybrid



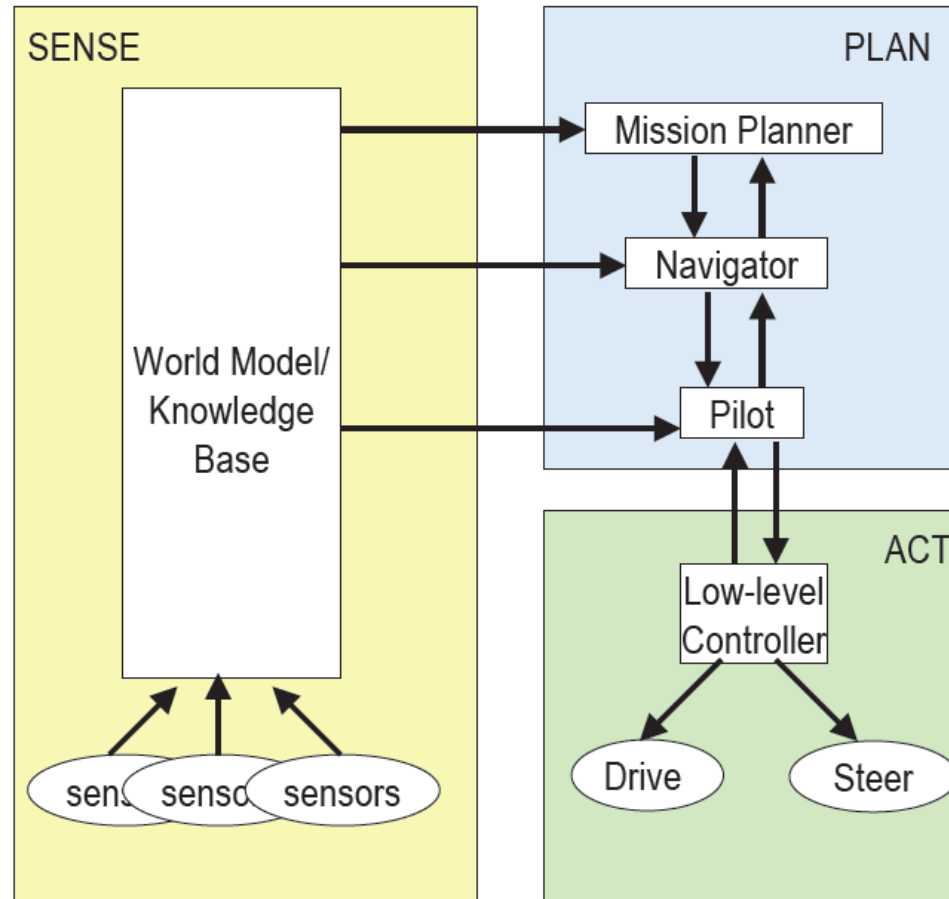
Typical Organizations

- Deliberative
 - Making maps
 - Selecting behaviors
 - Monitor performance
 - Planning
 - Hybrid deliberative/reactive paradigm
- Reactive
 - Cheap low memory processing
 - No world model
- Behavior-Based
 - Combination of simple behaviors
 - No centralized world model
 - Each behavior may store own representation
- Hybrid
 - Combine Reactive and Deliberative approaches

- Sense-plan-act paradigm: dominant view in the AI community was that a control system for an autonomous mobile robot should be decomposed into three functional elements [Nilsson, 1980]:
 - a sensing system (translate raw sensor input into a world model)
 - a planning system (take the world model and a goal and generate a plan to achieve the goal)
 - and an execution system (take the plan and generate the actions it prescribes)
- Perception is the establishment and maintenance of correspondence between the internal world model and the external real world [Albus 1991].
- Action results from reasoning over the world model.
- Perception is not tied directly to action.



- Nested Hierarchical Controller

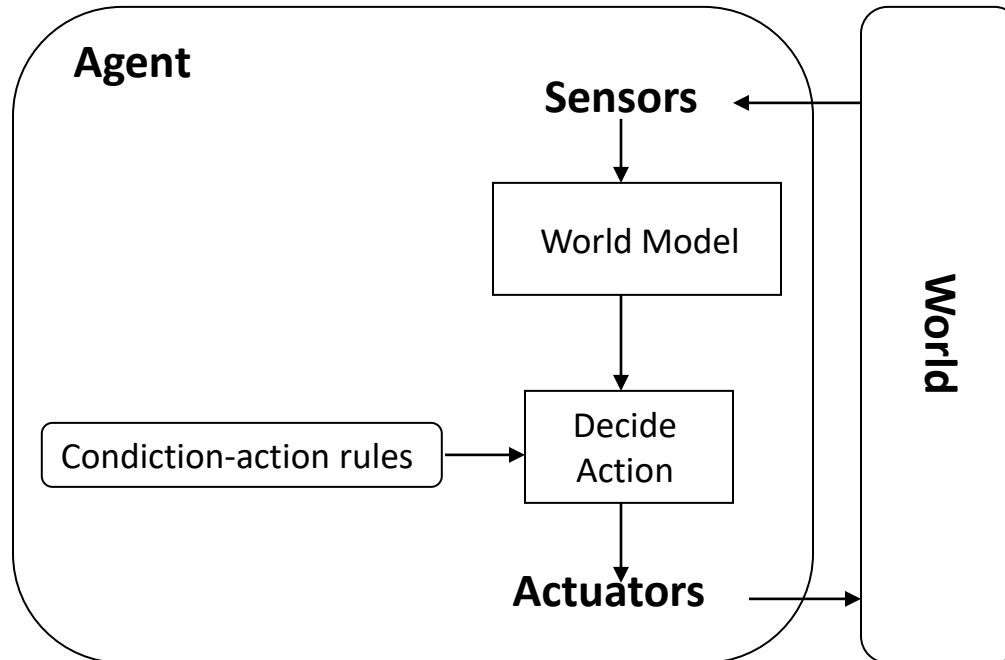


Meystel, A., "Knowledge Based Nested Hierarchical Control", 1990

- General assumptions:
 - The environment lacks temporal consistency and stability
 - The robot's immediate sensing is adequate for the task at hand
 - It is difficult to localize a robot relative to a world model
 - Symbolic representational world knowledge is of little or no value

“Planning is Just a Way of Avoiding Figuring Out What To Do Next”, Brooks 1987

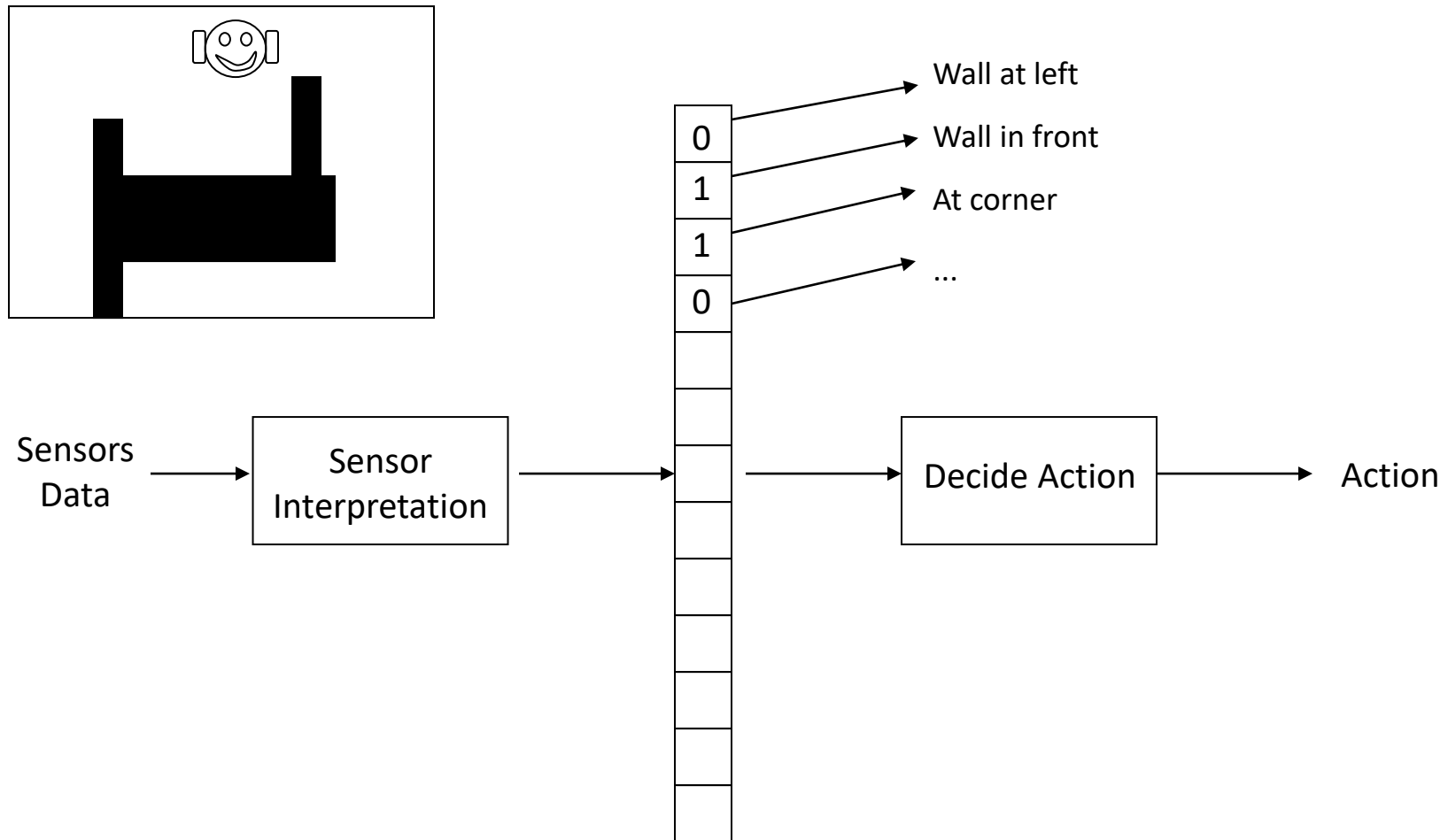
Simple Reactive Agent



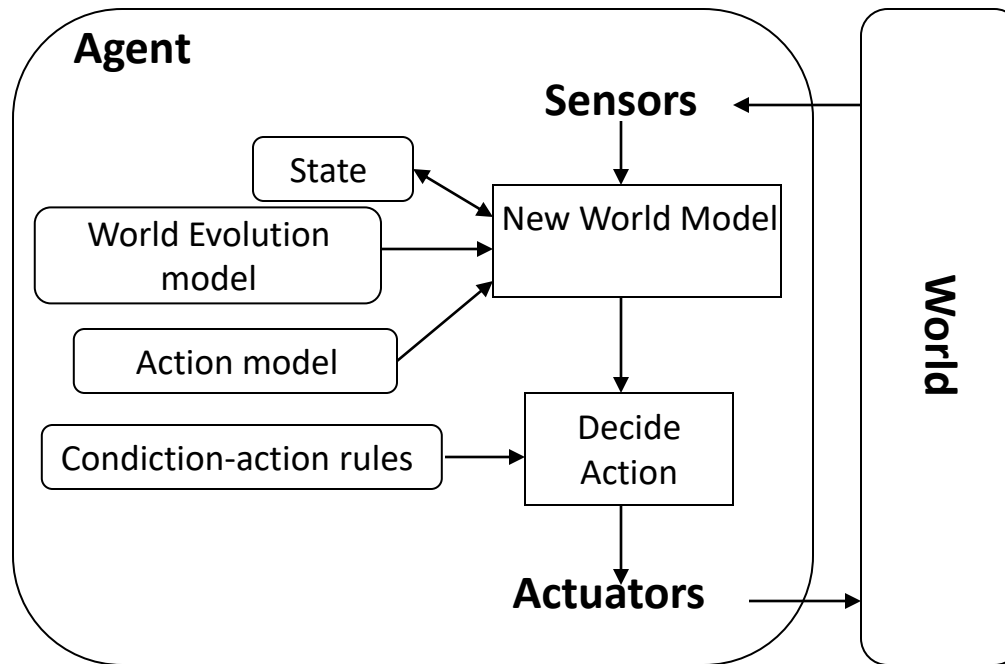
Russel and Norvig, AI: Modern Approach

Simple Reactive Agent

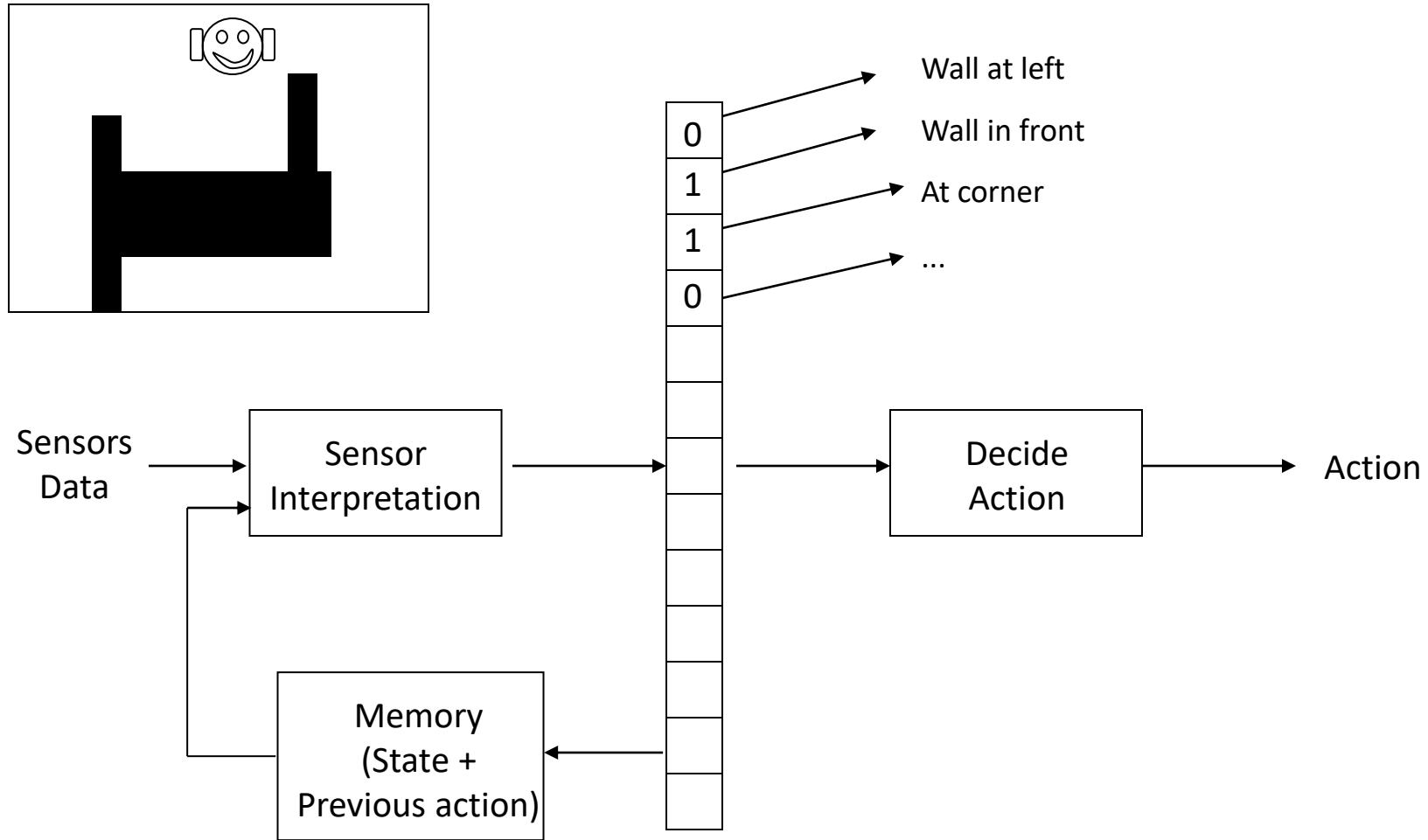
- Perception represented by a feature vector



Reactive Agent with Internal State



Reactive Agent with Internal State

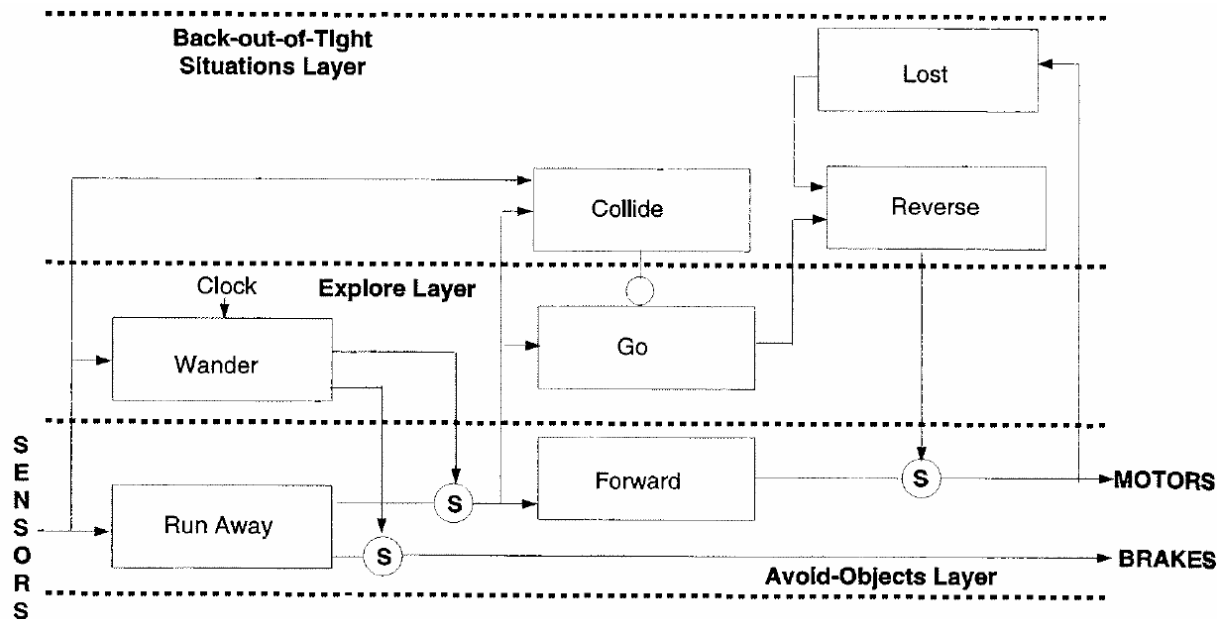


- No single approach is "the best" for all robots; each has its strengths and weaknesses
- Control requires some unavoidable trade-offs because:
 - Thinking is slow
 - Reaction must be fast
 - Thinking allows looking ahead (planning) to avoid bad actions
 - Thinking too long can be dangerous (e.g., falling off a cliff)
 - To think, the robot needs (a lot of) accurate information
 - The world keeps changing as the robot is thinking, so the slower it thinks, the more inaccurate its solutions
- As a result of these trade-offs, some robots don't think at all, while others mostly think and act very little.
 - **It all depends on the robot's task and its environment!**

- Behaviors implemented as control laws (in software or hardware)
- Each behavior receives inputs from the robot's sensors and/or from other modules, and sends outputs to the robot's effectors and/or to other modules.
- Many different behaviors may receive input from the same sensors and output commands to the same actuators.
- Behaviors are encoded to be relatively simple, and are added to the system incrementally.
- Behaviors (or subsets) are executed concurrently

Subsumption Architecture [Brooks 1986]

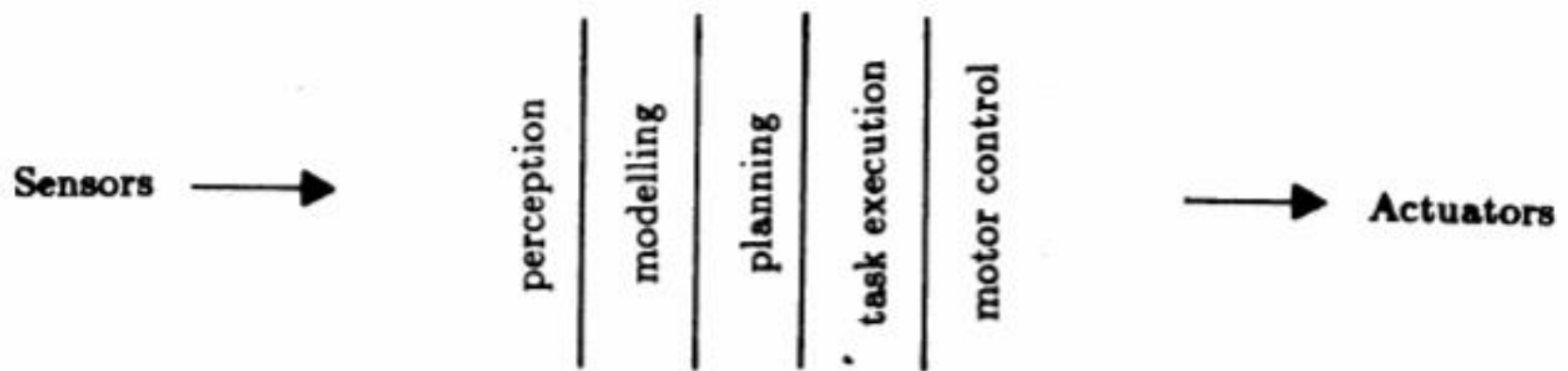
- Behaviors are Augmented Finite State Machines (AFSM)
- Stimulus or response signals can be suppressed or inhibited by other active behaviors; a reset input returns the behavior to its start conditions
- Each behavior is responsible for its own perception of the world
- Arrangement in layers: lower layers have no awareness of higher layers



Brooks has put forward three theses:

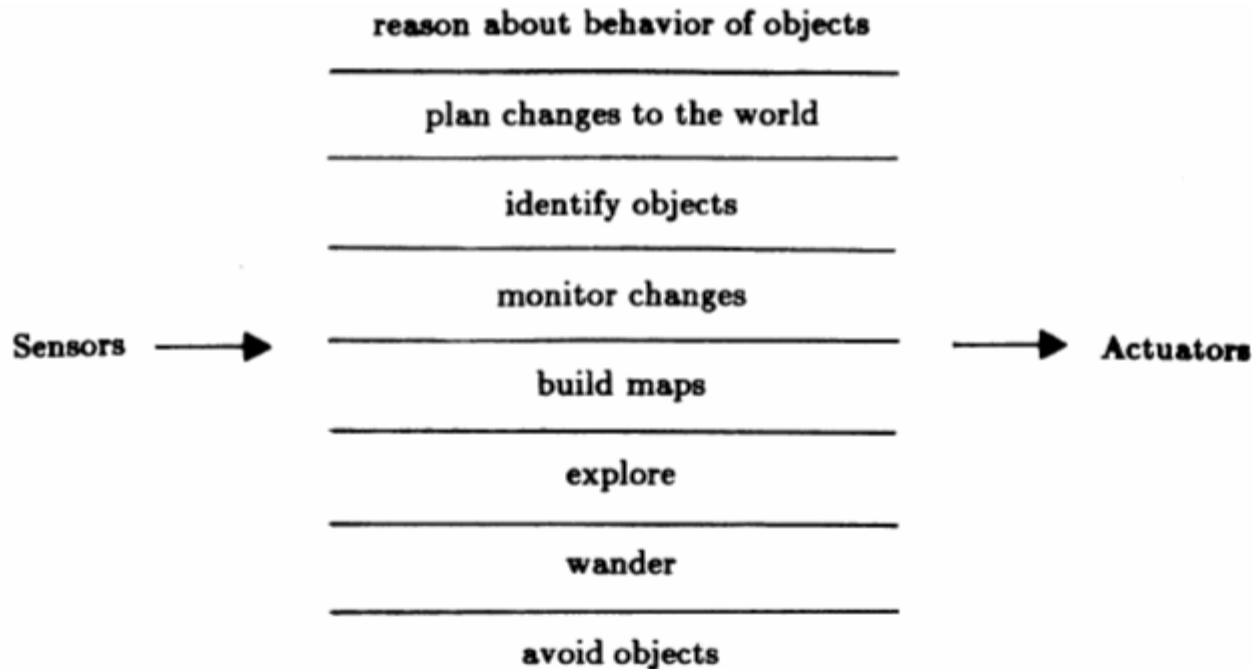
1. **Intelligent behavior** can be generated ***without explicit representations*** of the kind that symbolic AI proposes
2. **Intelligent behavior** can be generated ***without explicit abstract reasoning*** of the kind that symbolic AI proposes
3. **Intelligence is an *emergent property*** of certain complex systems

A Traditional Decomposition of a Mobile Robot Control System into Functional Modules



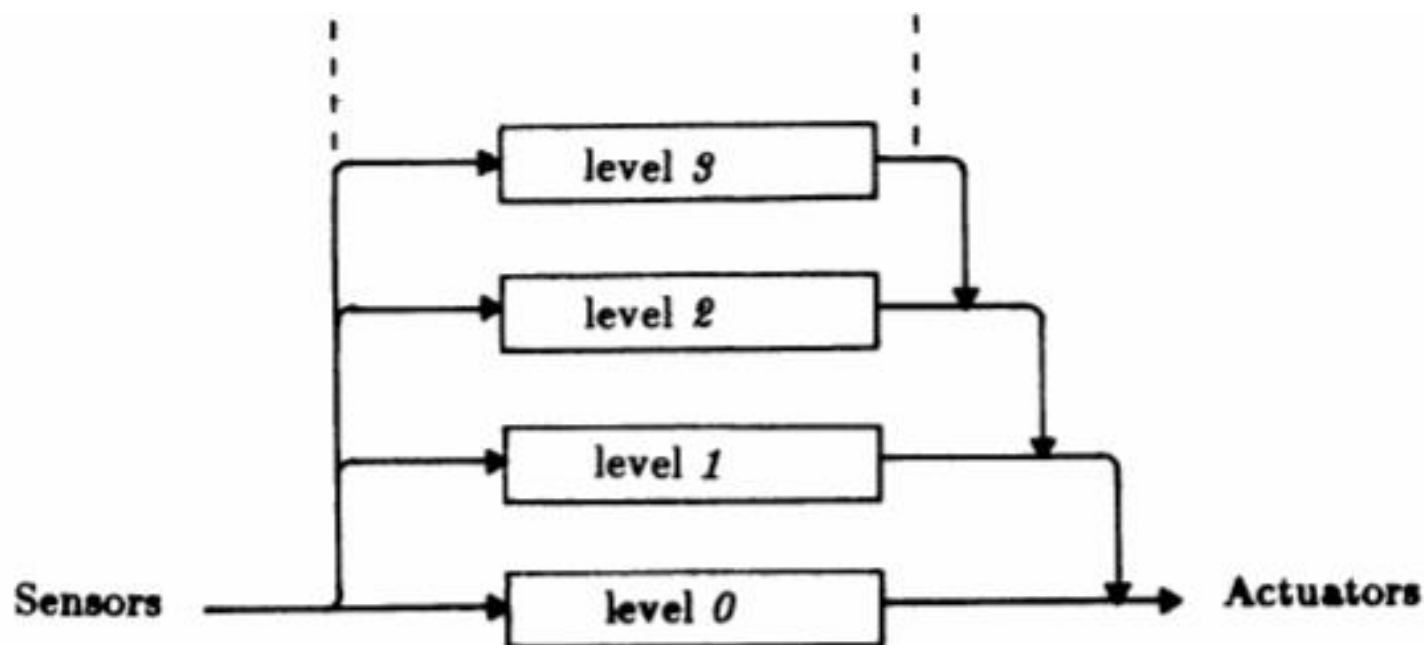
From Brooks, "A Robust Layered Control System for a Mobile Robot", 1985

A Decomposition of a Mobile Robot Control System Based on Task Achieving Behaviors



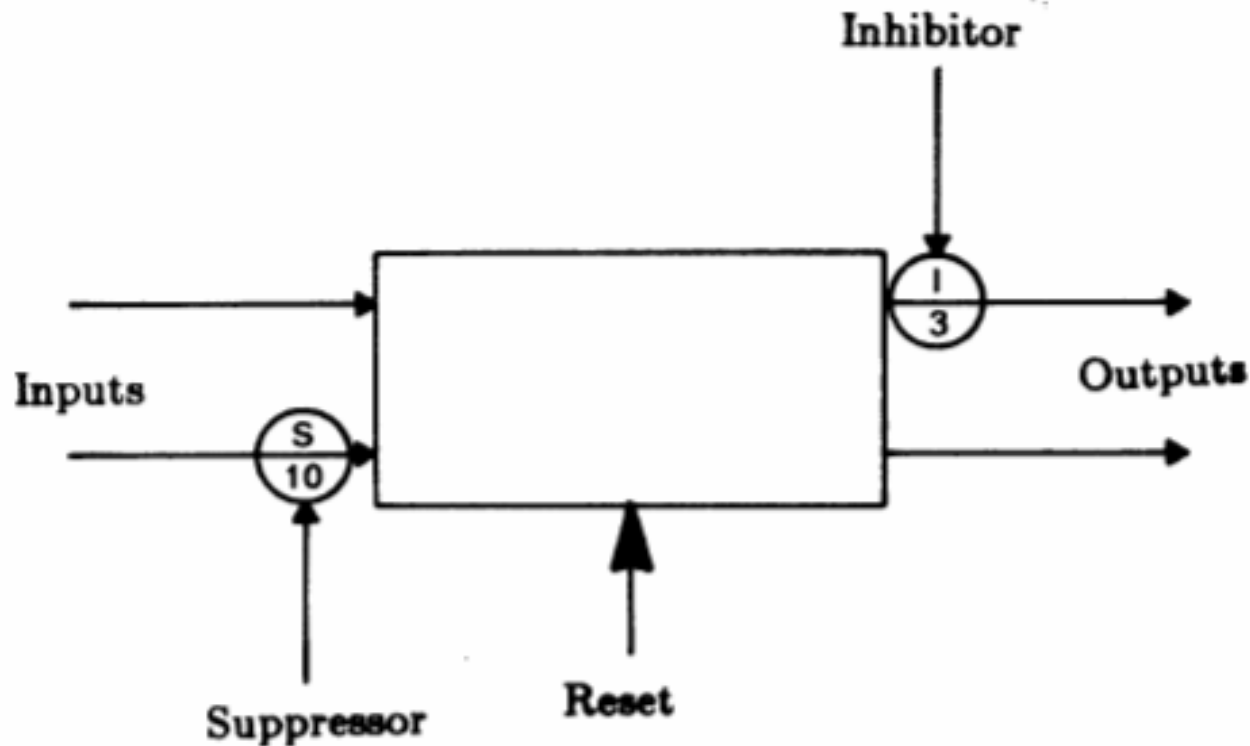
From Brooks, "A Robust Layered Control System for a Mobile Robot", 1985

Layered Control in the Subsumption Architecture



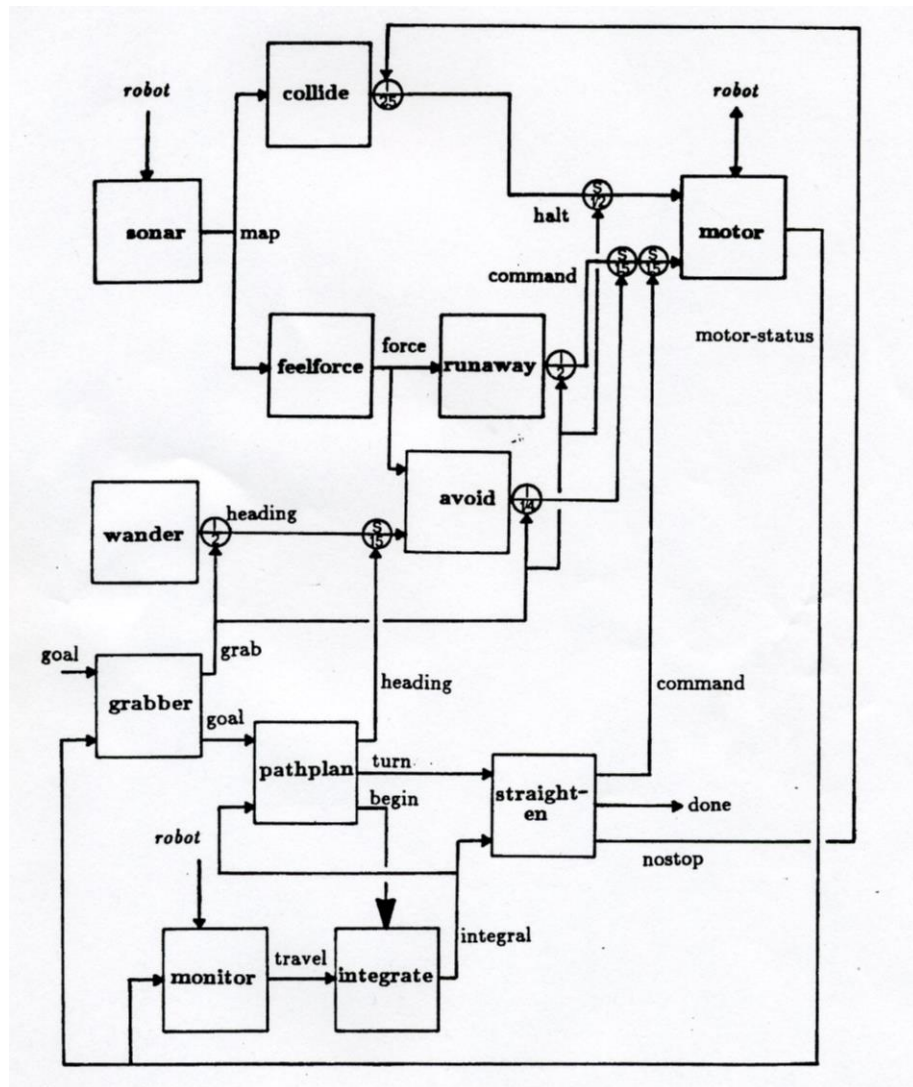
From Brooks, "A Robust Layered Control System for a Mobile Robot", 1985

Schematic of a Module



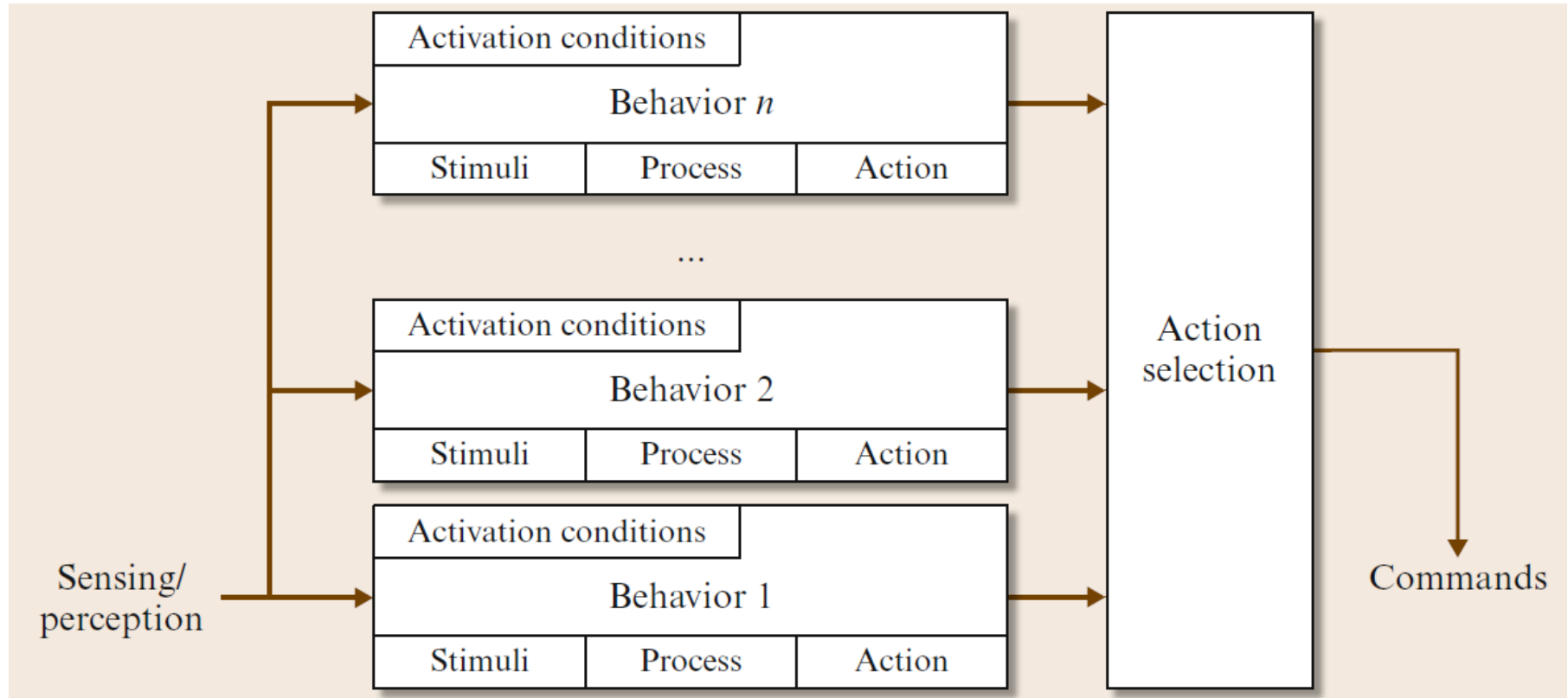
From Brooks, "A Robust Layered Control System for a Mobile Robot", 1985

Levels 0, 1, and 2 Control



From Brooks, "A Robust Layered Control System for a Mobile Robot", 1985
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Behavior-Based Architectures

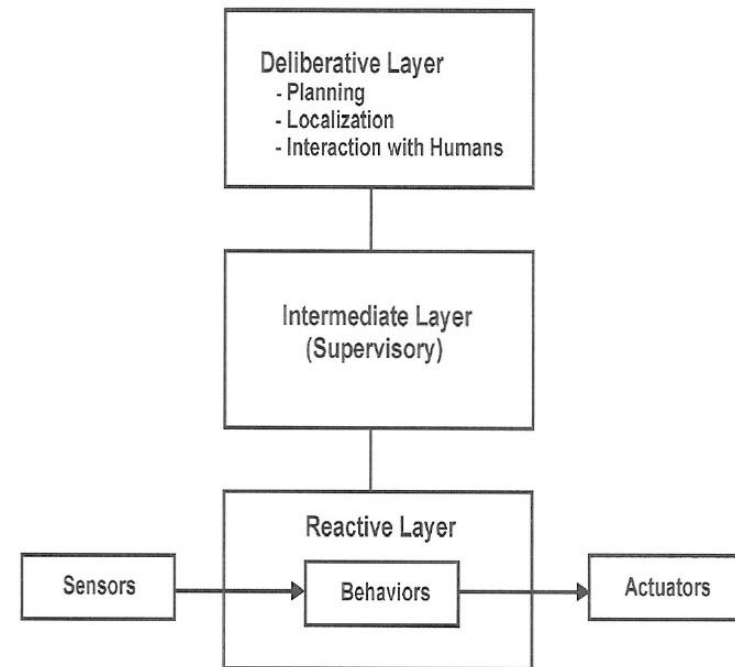


From Siciliano et al., "Springer Handbook of Robotics", Springer, 2008

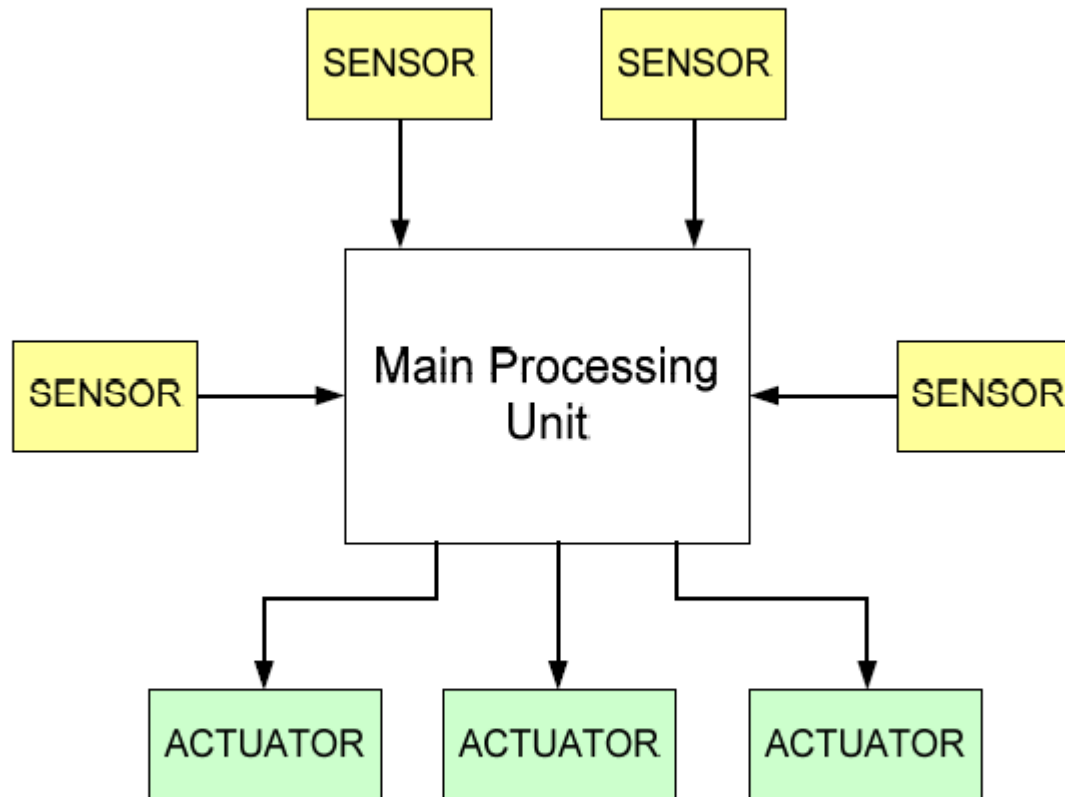
- In **Hybrid Control**, the goal is to **combine the best of both Reactive and Deliberative** control. In it, one part of the robot's "brain" plans, while another deals with immediate reaction, such as avoiding obstacles and staying on the road.
- The **challenge** of this approach is bringing the **two parts** of the brain **together**, and allowing them to **talk** to each other, and **resolve conflicts** between the two.
- This requires a "third" part of the robot brain, and as a result these systems are often called "three-layer systems"

Adapted from <http://www-robotics.usc.edu/~maja/robot-control.html>

- Combine the responsiveness, robustness, and flexibility of purely reactive systems with more traditional symbolic/deliberative methods
- Reason: purely reactive systems lack the ability to take into account a priori knowledge (e.g. about the world) and to keep track of the history (memory)
- Typical three-layer (3T) hybrid architecture
 - Bottom layer is the reactive/behavior-based layer, in which sensors/actuators are closely coupled
 - Upper layer provides the deliberative component (e.g., planning, localization)
 - The intermediate between the two is sometimes called supervisory layer
- Examples of coupling between planning and reactive layers:
 - Planning to guide reaction: planning sets reactive system parameters.
 - Coupled: planning and reacting are concurrent activities, each guiding the other



Fully Centralized Computing Architecture

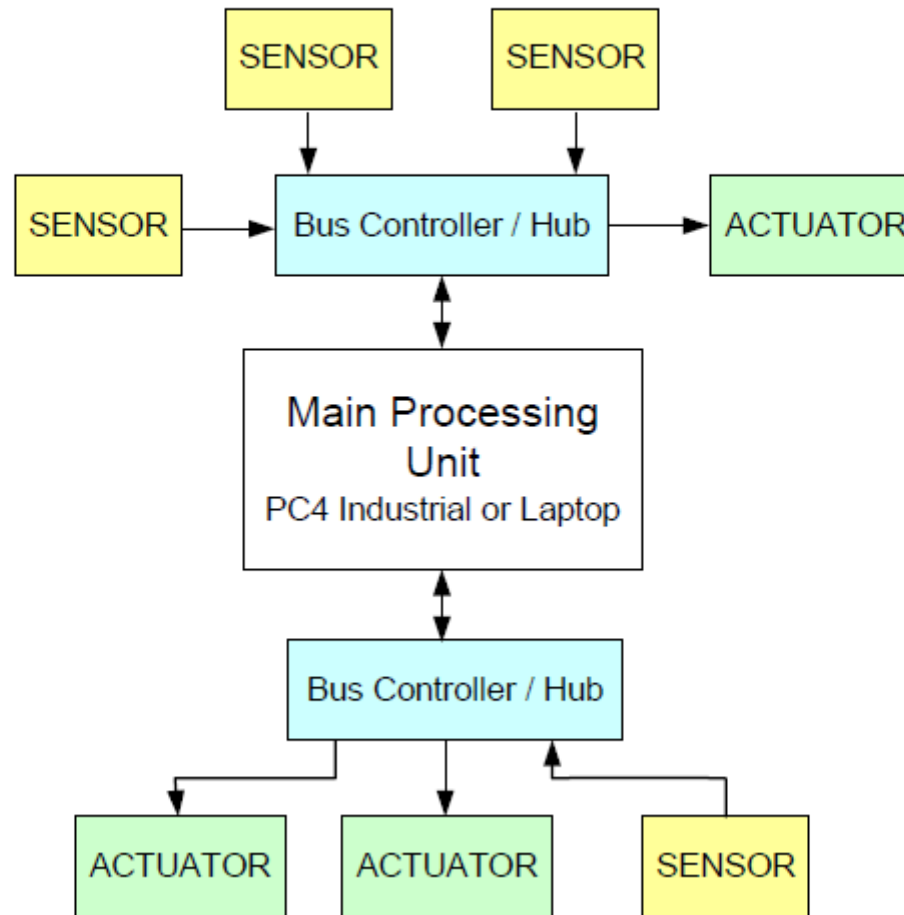


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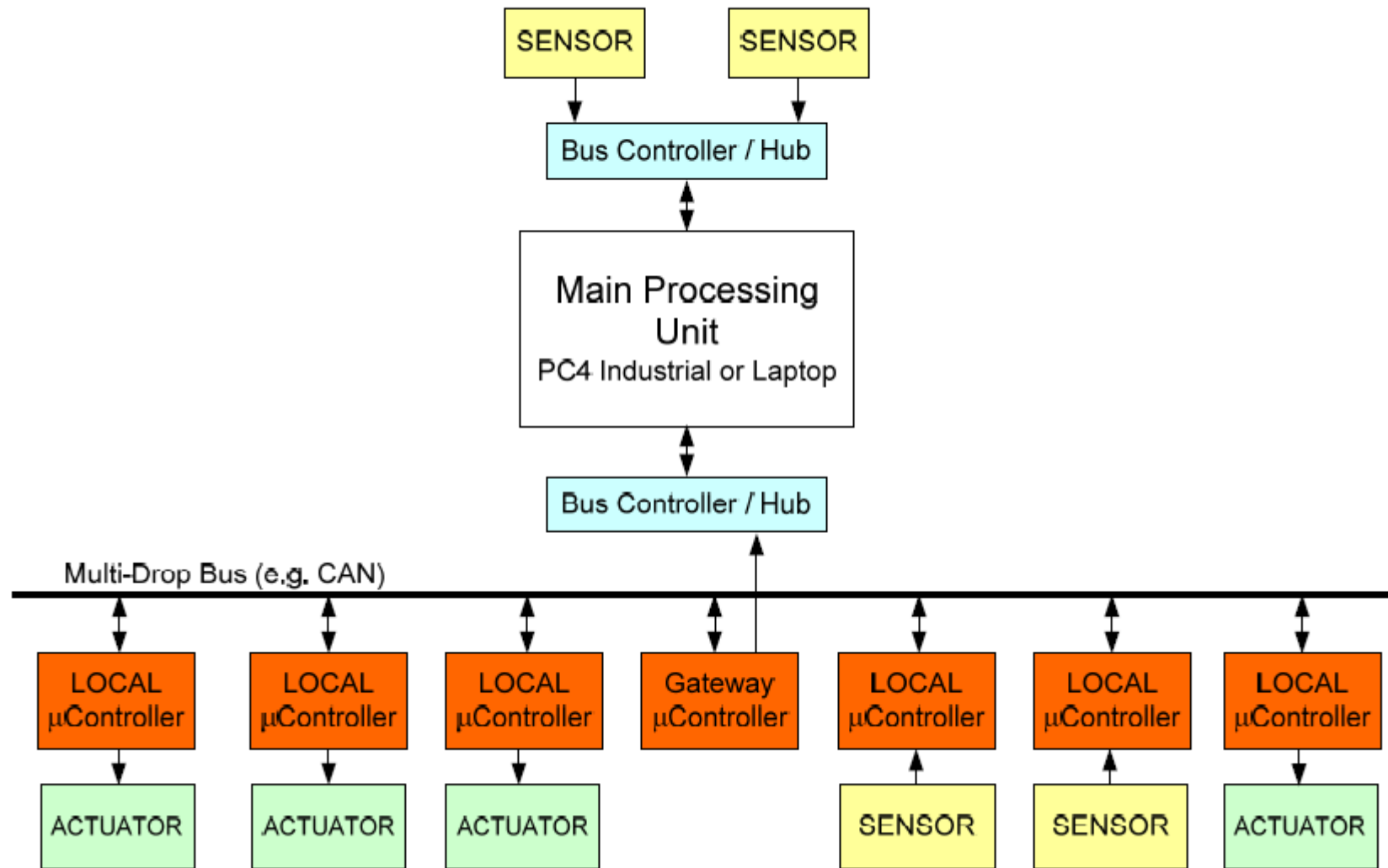
Sensors may include conditioning electronics and A/D converters

Actuators may include driving electronics and/OR D/A converters

Star Network Computing Architecture



Hierarquical Distributed Computing Architecture



Fully Distributed Computing Architecture (FDCA)

