Robotic Agent Architectures

Robótica Móvel e Inteligente

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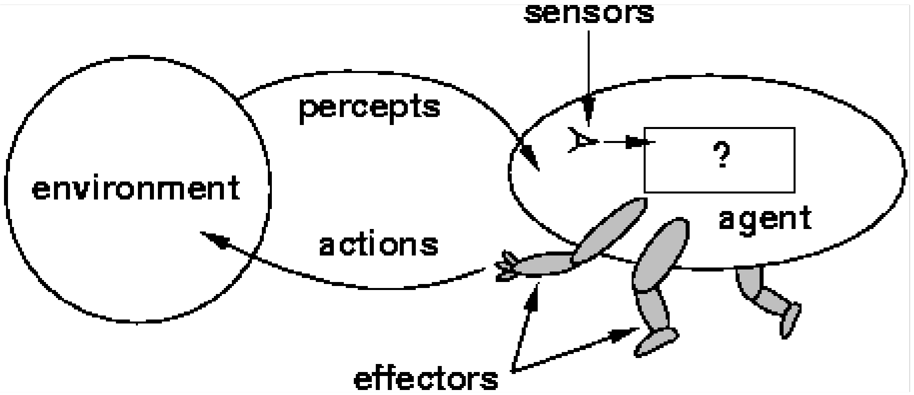
Outline

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

Autonomous Agents

- **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

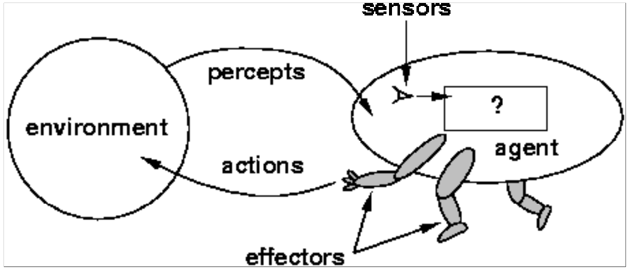
Agent Requisites

- **Traditional definition include to much or leaves “holes”!**
- **Requisites:**
  - Perceive its environment (sensors)
  - Decide actions to execute (“think”)
  - Execute actions in environment using its actuators
  - Communicate?
  - Perform a complex function?
- **Agents vs Objects:**
  - Agents decide what to do
  - Object methods are called externally
  - Agents react to sensors and control actuators

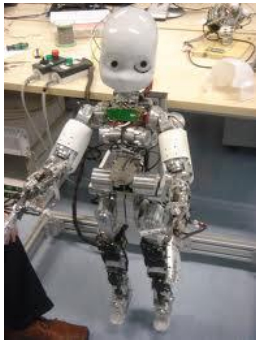
“Objects do it for free; agents do it for money”

Robotic and Human Agents

- **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



Intelligent Robotics

- **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

Best Definitions of Robot

- **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]
- 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]
- 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]

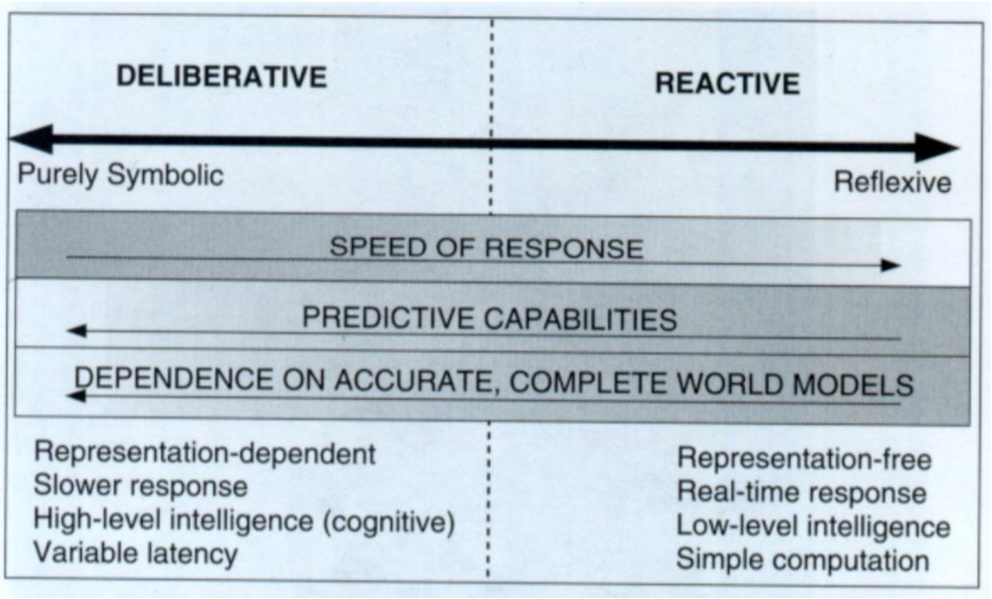
Issues in Robotic Architectures

- **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”

Model-based

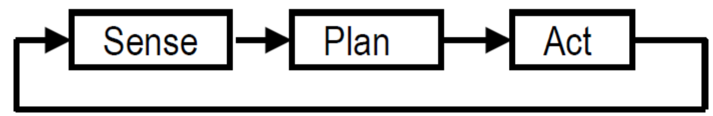


Behavior-based

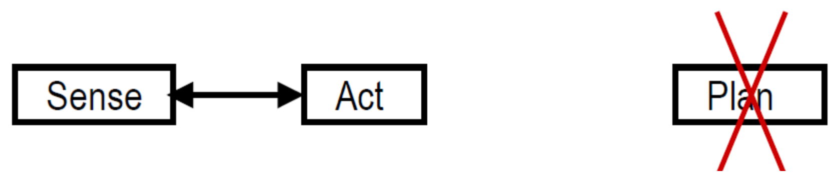
Adapted from Arkin, Behavior-based Robotics (MIT Press, 1998)

Typical Organizations

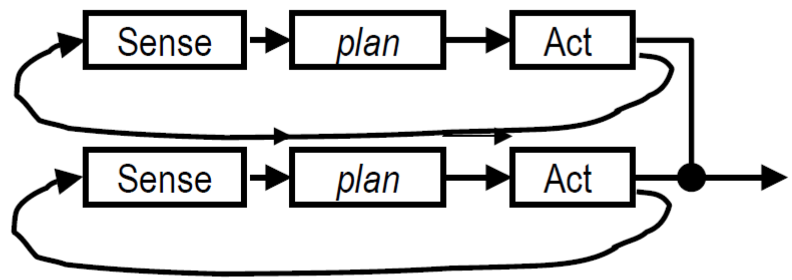
- Typical organizations:
  - Hierarchical / Deliberative



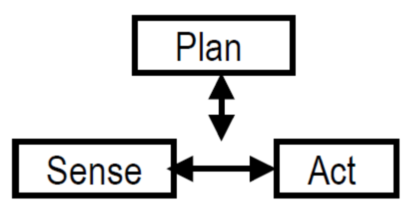
  - Reactive



  - Behavior-based



  - Hybrid

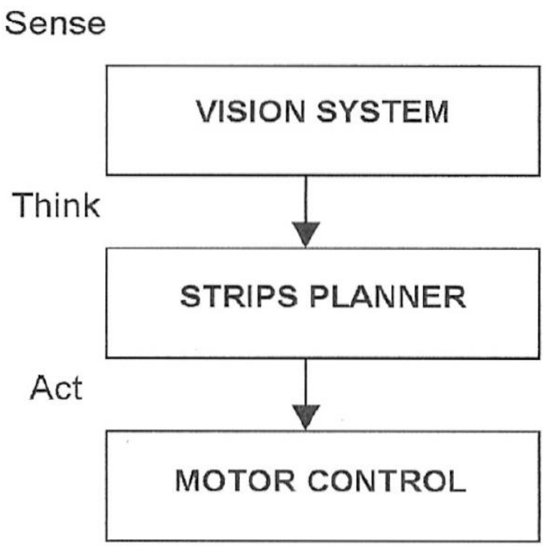


Typical Organizations

- 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

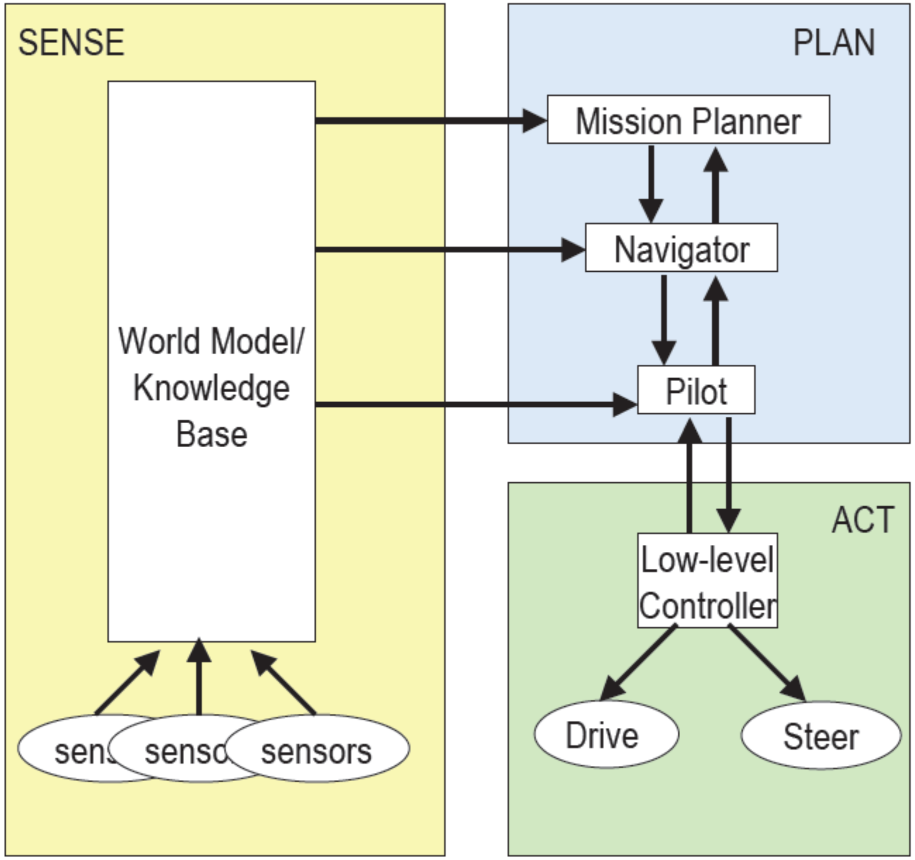
Model-based - Deliberative

- 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 directly tied to action.**



Deliberative Architectures

- Nested Hierarchical Controller



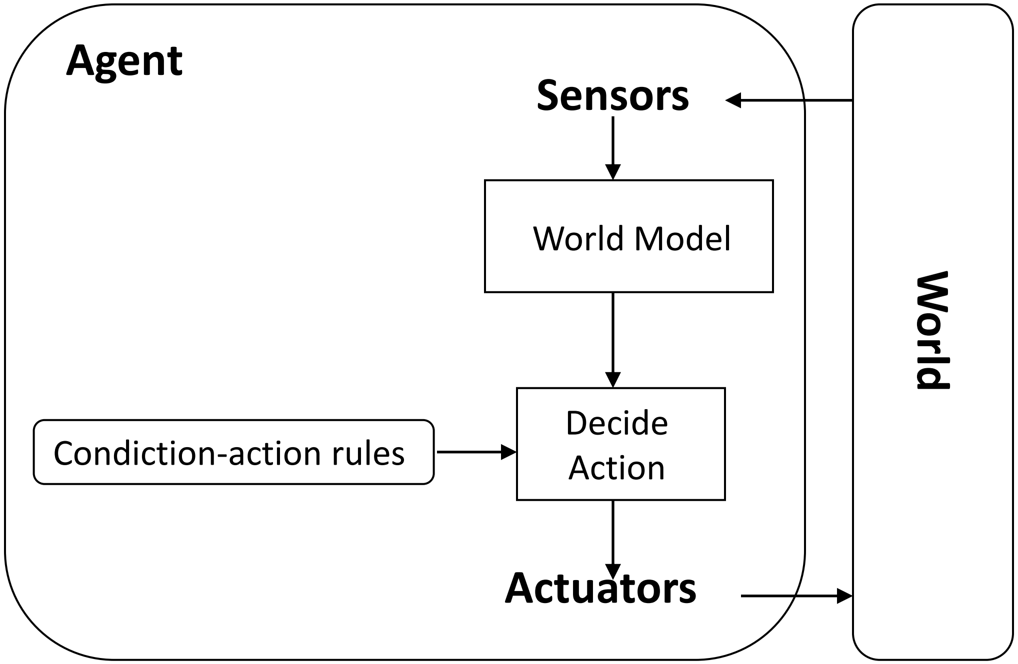
Meystel, A., "*Knowledge Based Nested Hierarchical Control*", 1990

Reactive Agents

- 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

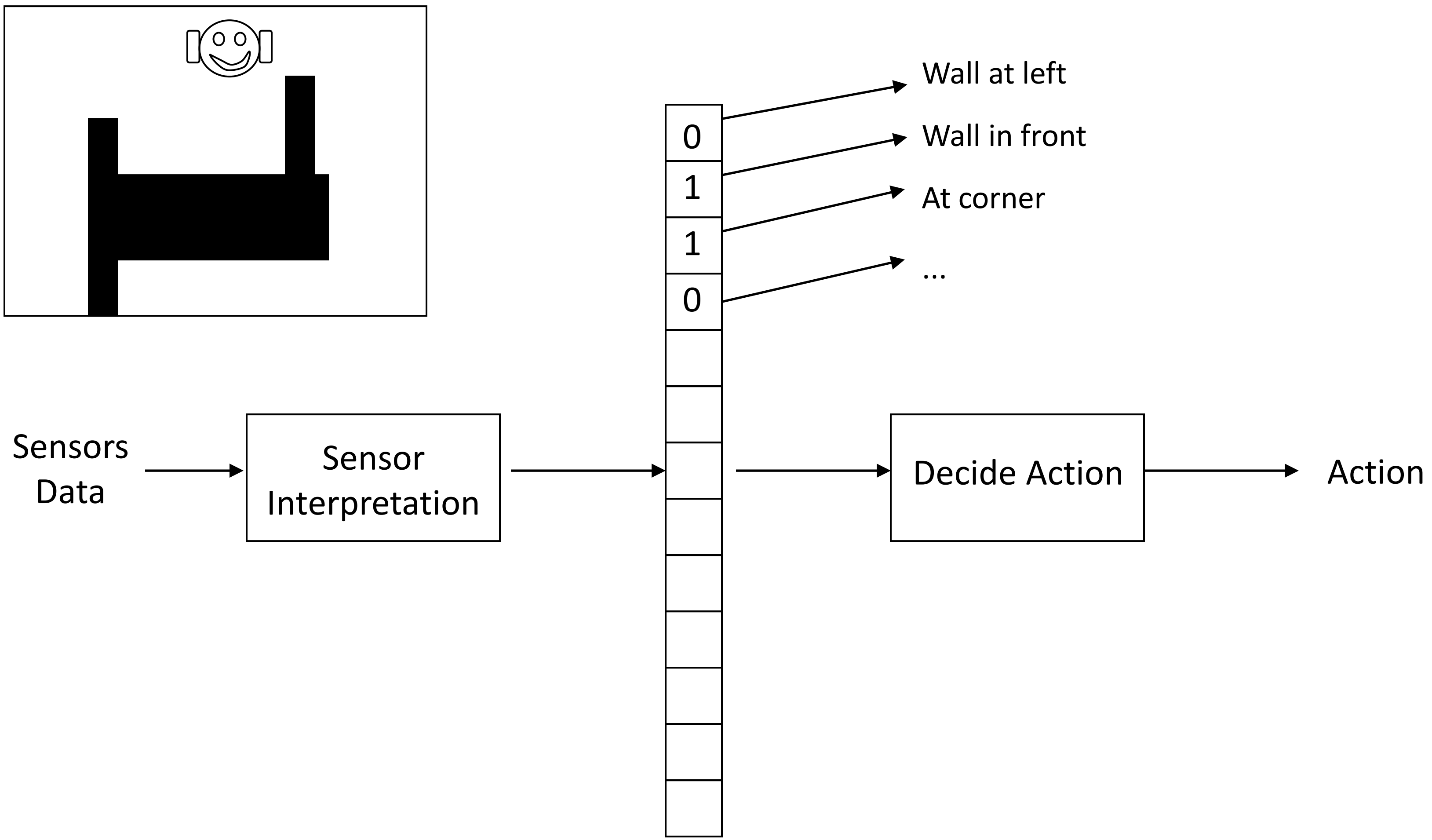
Simple Reactive Agent



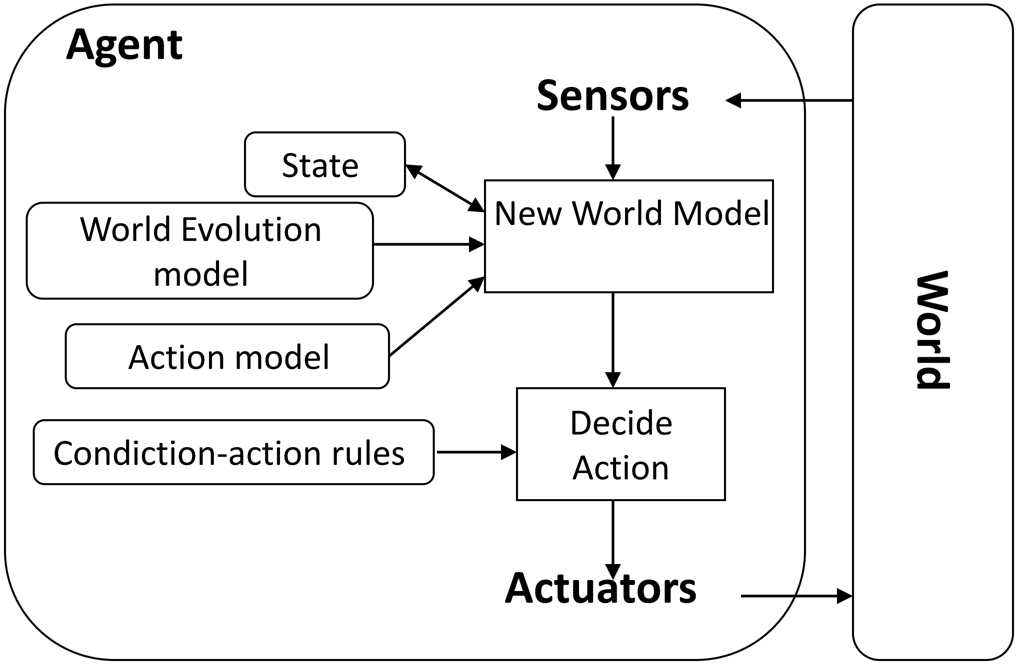
Russel and Norvig, AI: Modern Approach

Simple Reactive Agent

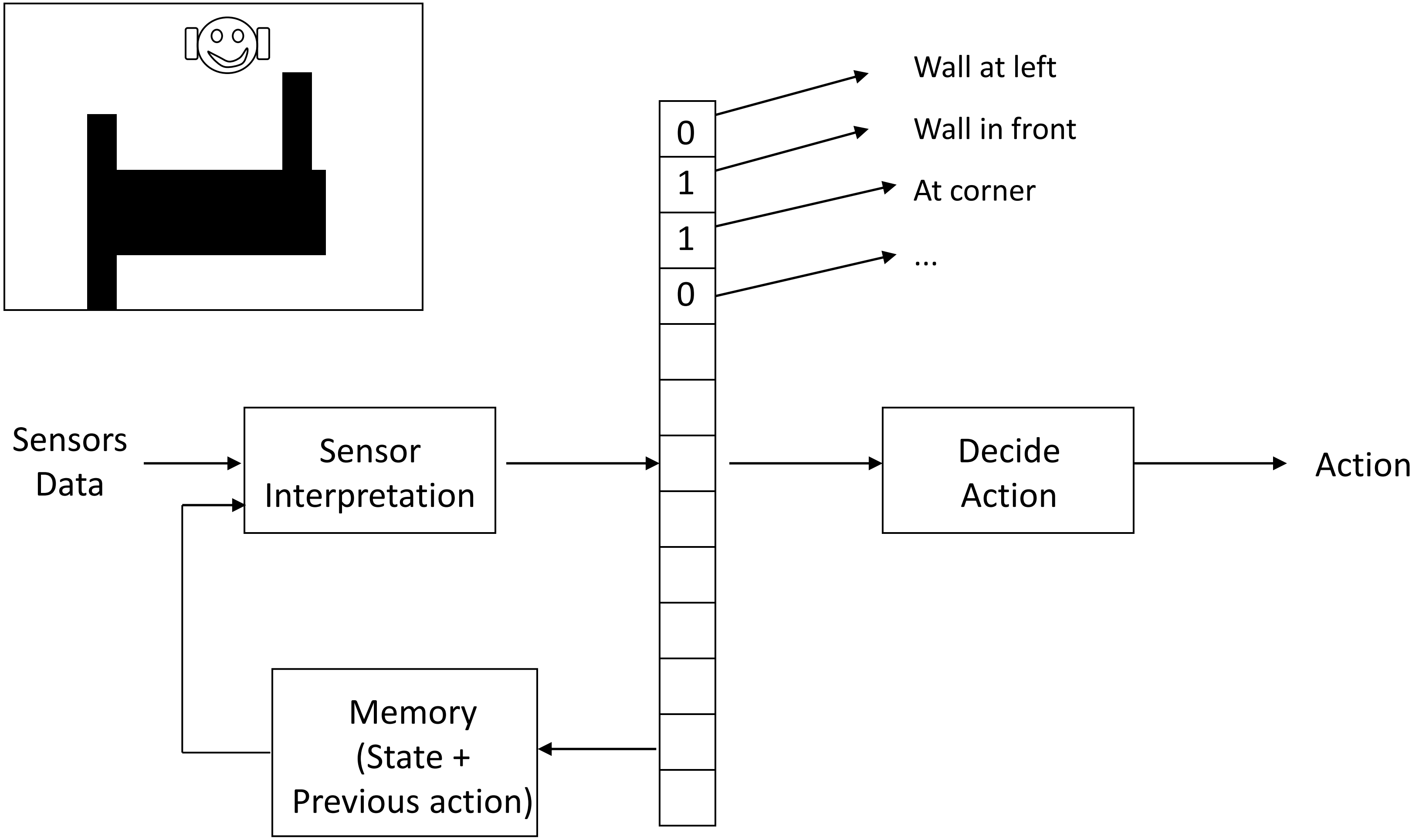
- Perception represented by a feature vector



Reactive Agent with Internal State



Reactive Agent with Internal State



Deliberative vs Reactive

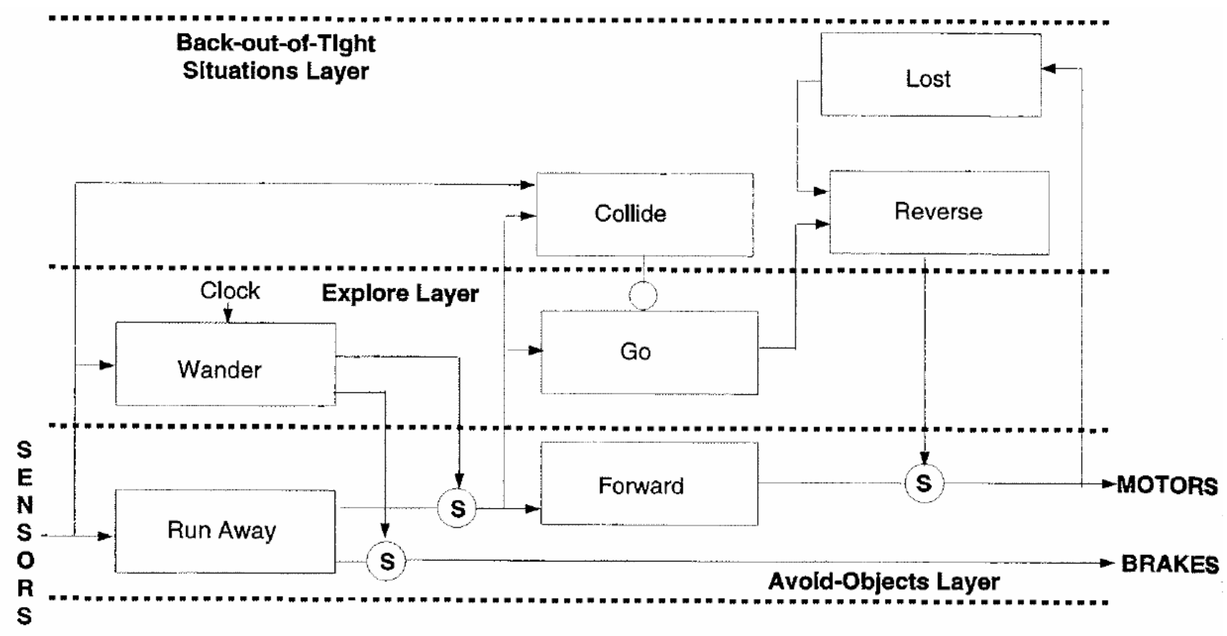
- No single approach is "the best" for all robots; each has its strengths and weaknesses
- Control requires some unavoidable trade-offs because:
  - Thinking is slow
  - Reaction must be fast
  - Thinking allows looking ahead (planning) to avoid bad actions
  - Thinking too long can be dangerous (e.g., 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!**

Behavior-Based Architectures

- 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

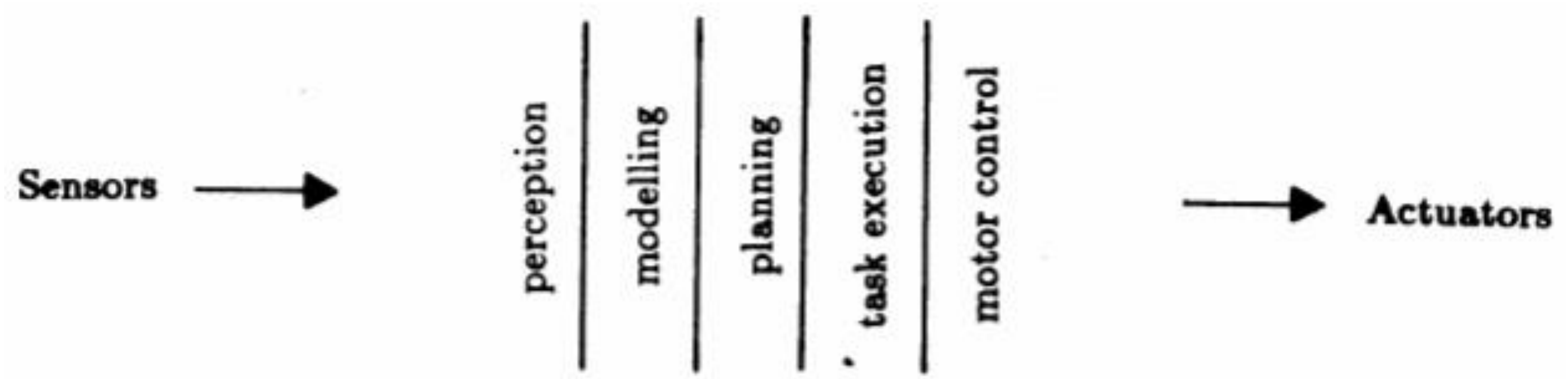


Brooks – Behavior languages

Brooks has put forward three theses:

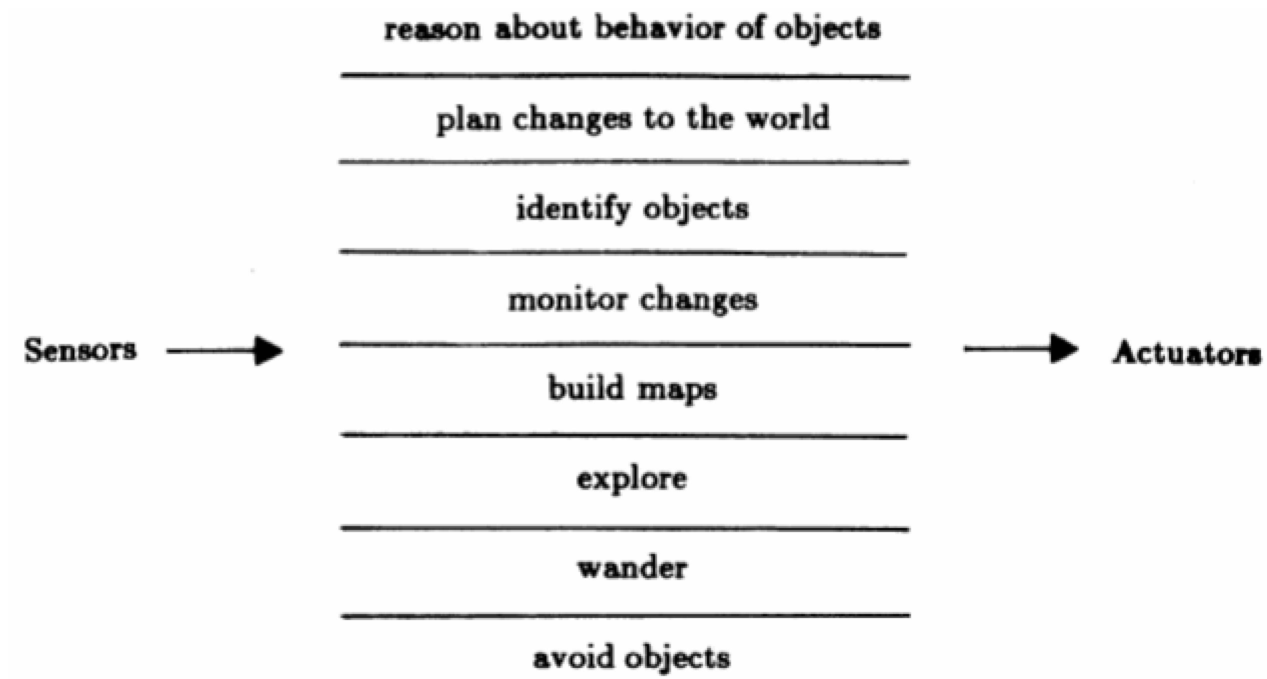
1. **Intelligent behavior** can be generated ***without* explicit representations** of the kind that symbolic AI proposes
2. **Intelligent behavior** can be generated ***without* explicit abstract reasoning** of the kind that symbolic AI proposes
3. **Intelligence is an *emergent property*** *of* certain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



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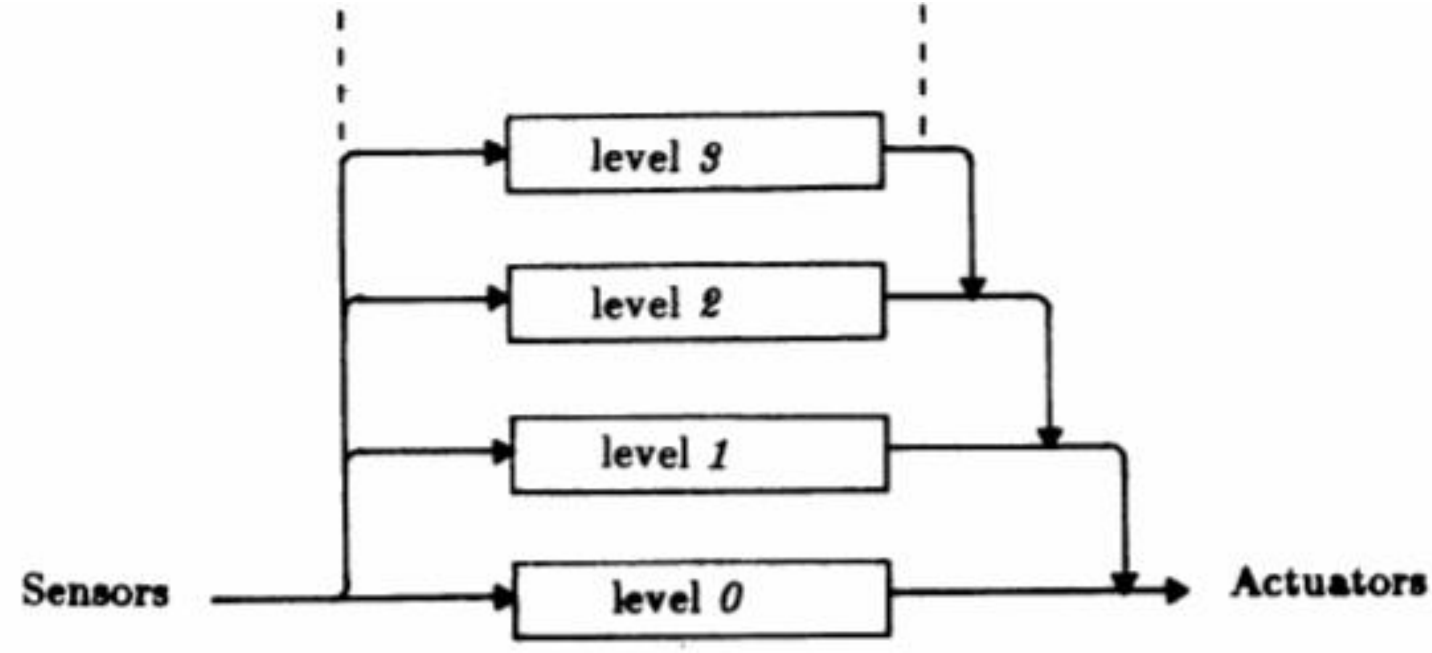
Layered Control in the Subsumption Architecture



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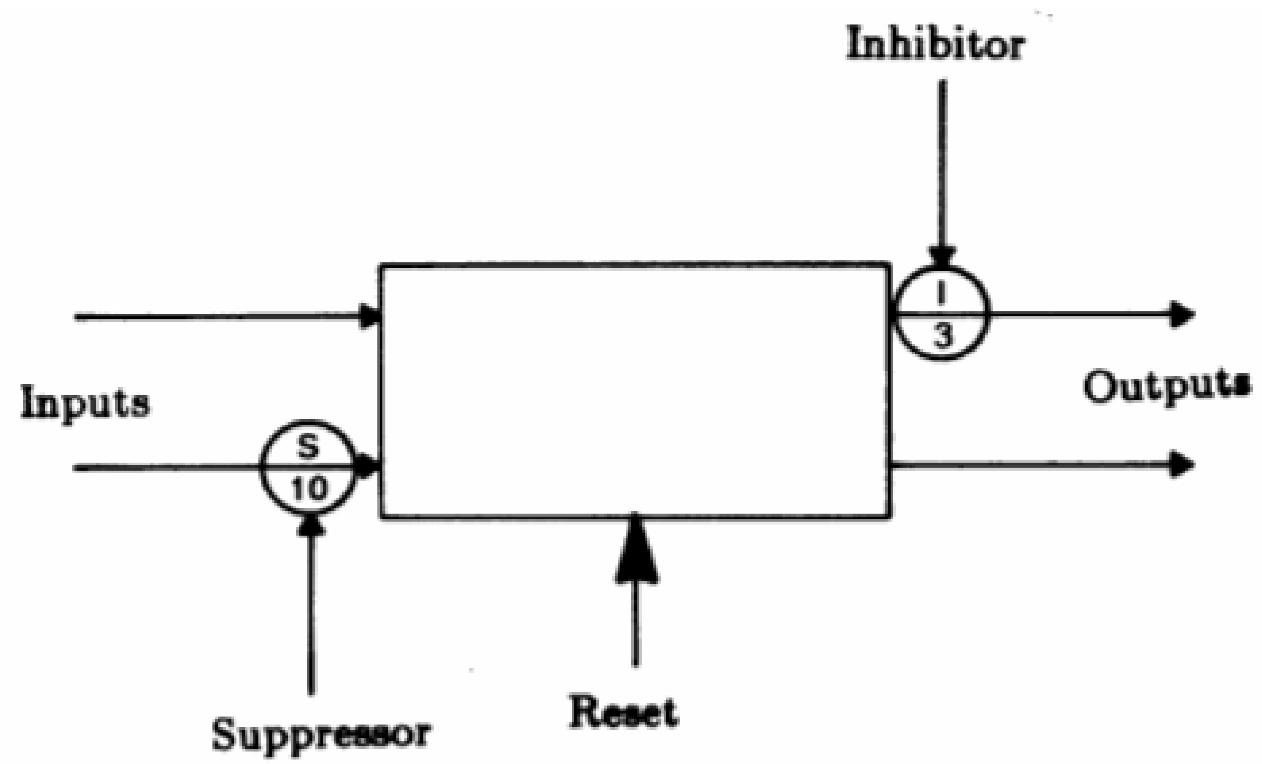
Schematic of a Module



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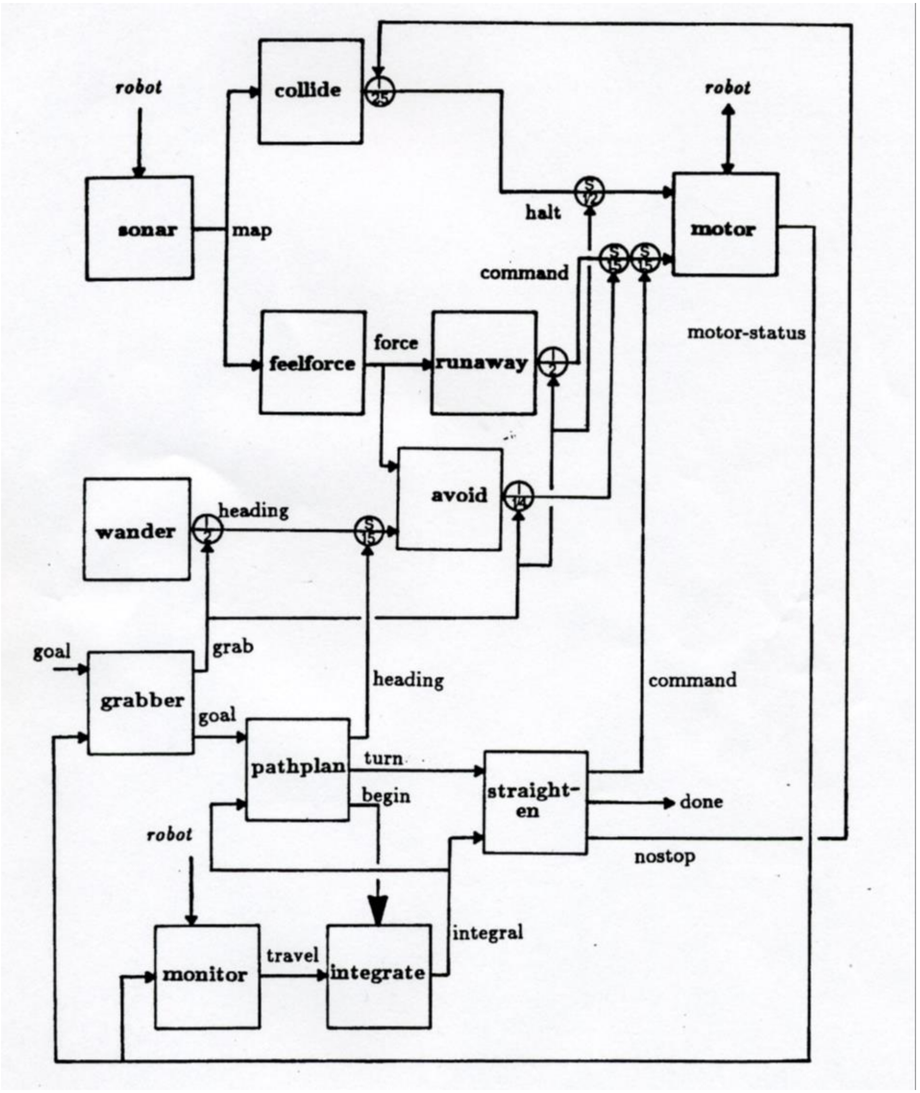
Levels 0, 1, and 2 Control



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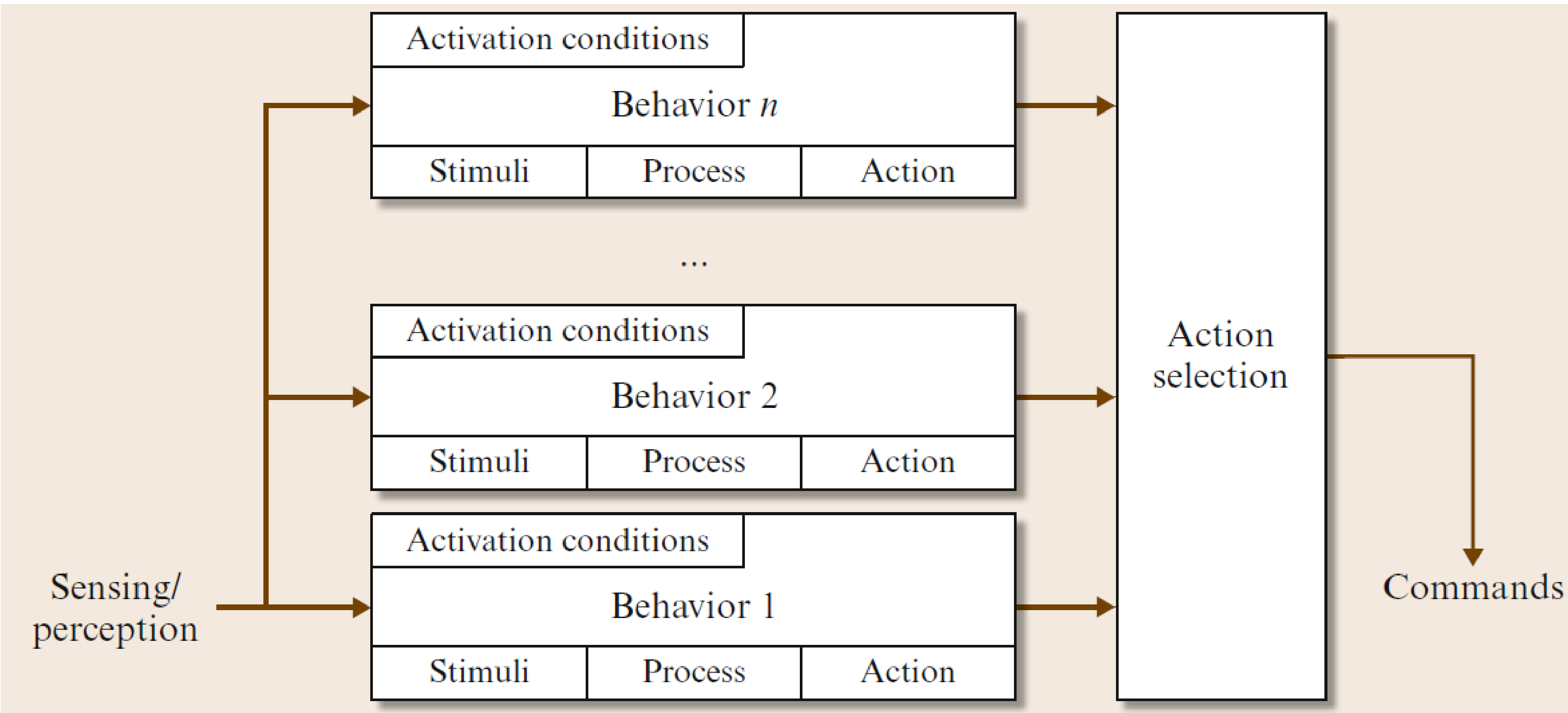
Behavior-Based Architectures



From Siciliano et al., “Springer Handbook of Robotics”, Springer, 2008

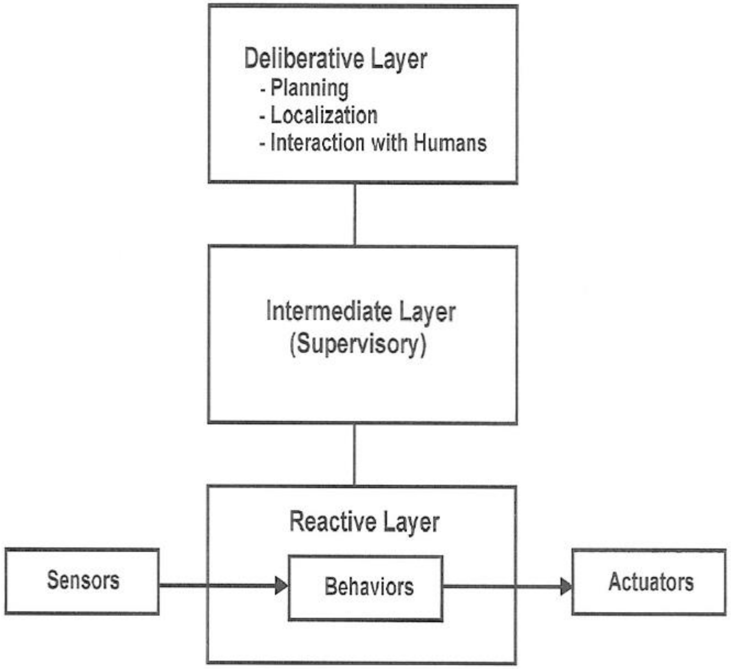
Hybrid Architectures

- 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

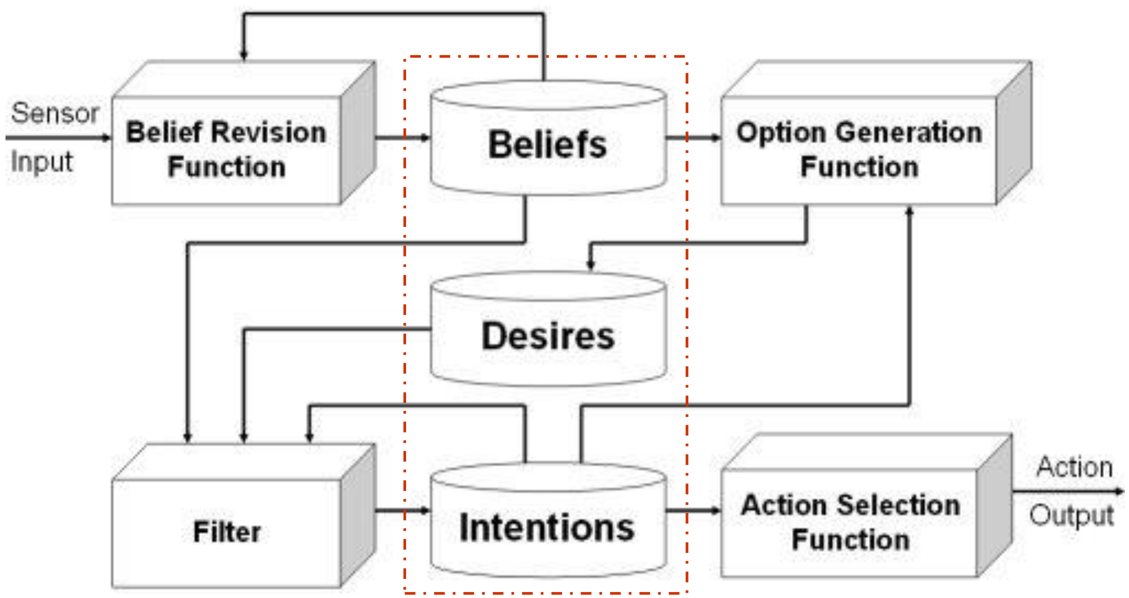
Hybrid Architectures

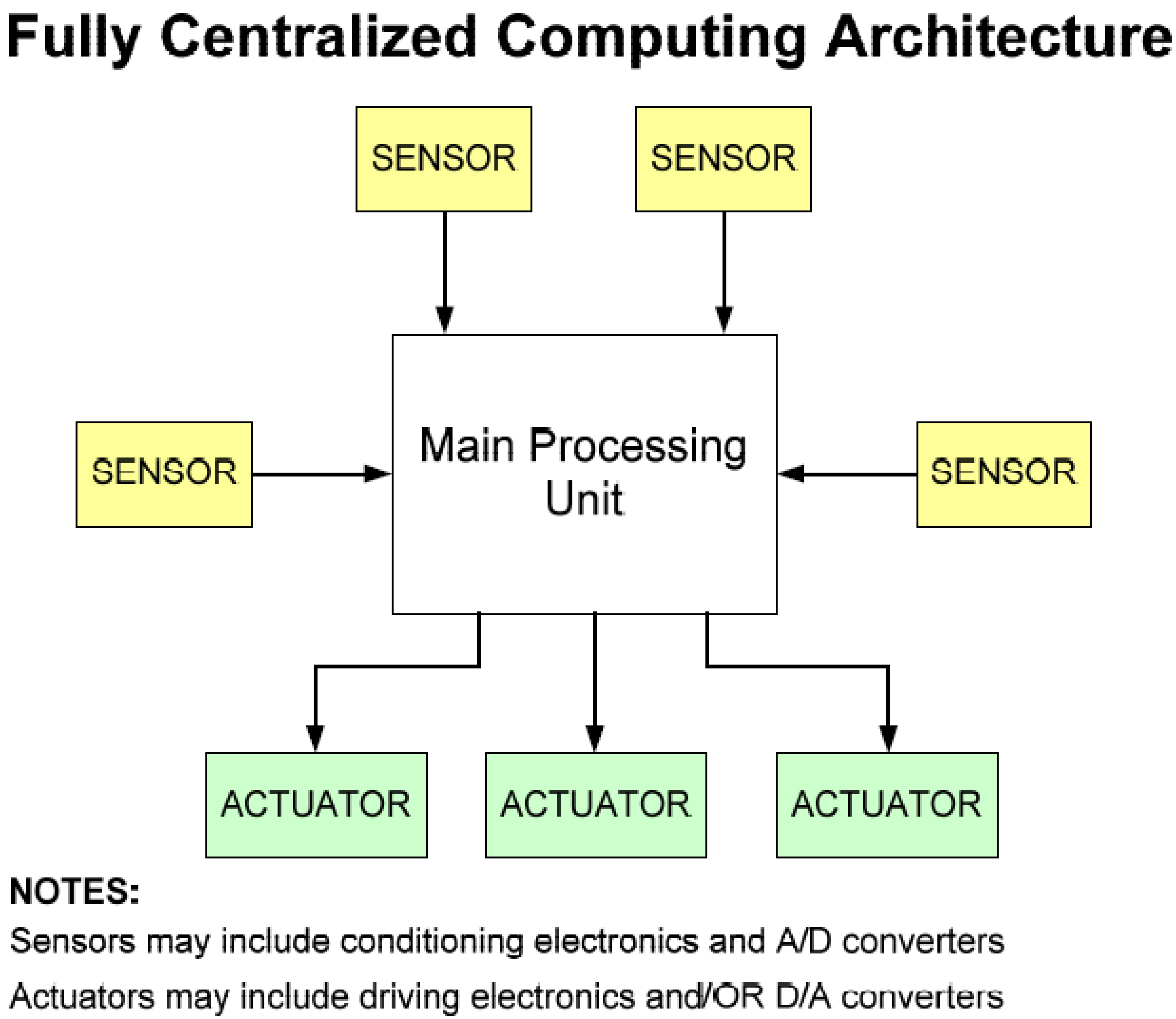
- Combine the responsiveness, robustness, and flexibility of purely reactive systems with more traditional symbolic/deliberative methods
- Reason: purely reactive systems lack the ability to take into account a priori knowledge (e.g. about the world) and to keep track of the history (memory)
- Typical 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



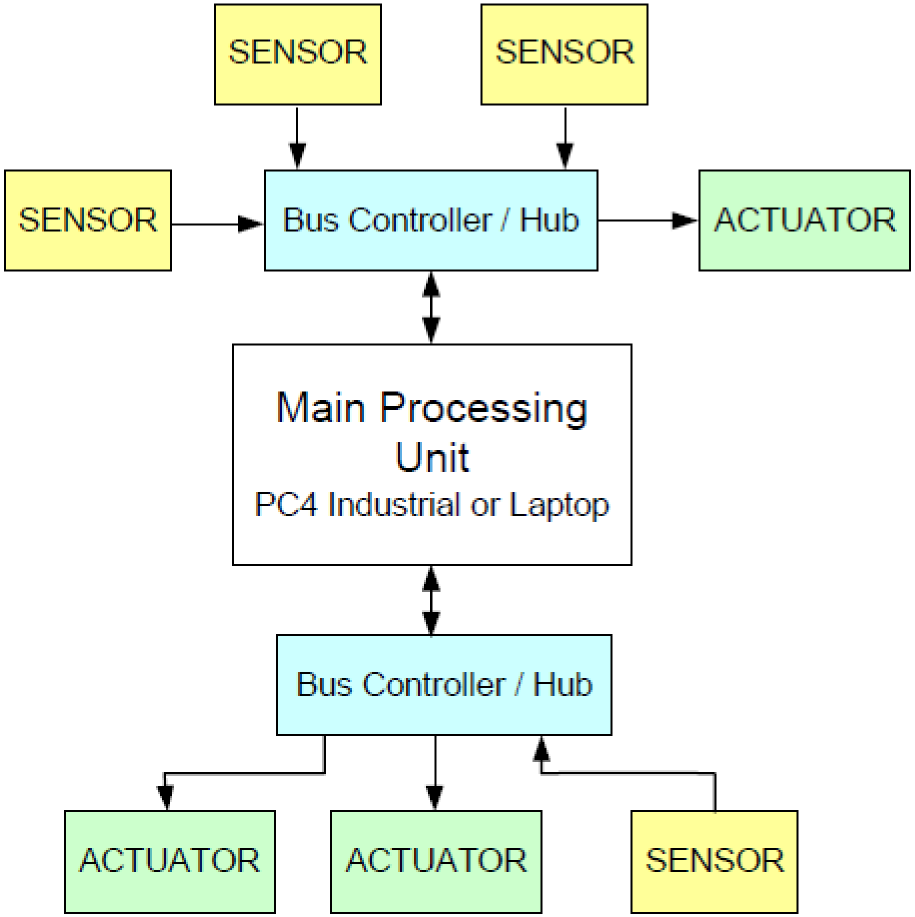
The BDI Model

- Three “mental attitudes”
  - **(B)eliefs** are information the agent has about the world – information
  - **(D)esires** are all the possible states of affairs that the agent might like to accomplish – motivation
  - **(I)ntentions** are the states of affairs that the agent has decided to work towards – deliberation



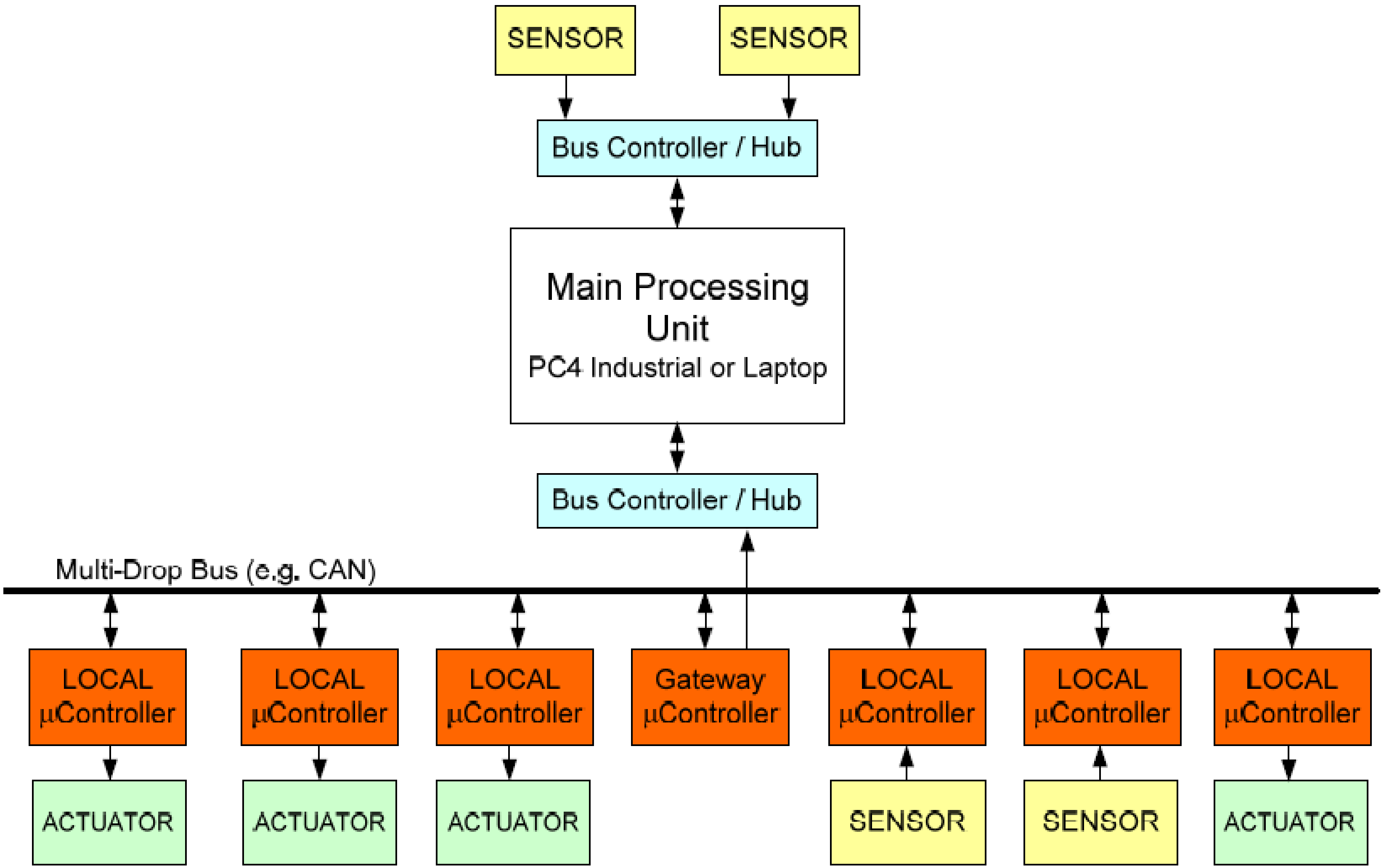

Fully Centralized Computing Architecture
SENSOR
SENSOR
SENSOR
Main Processing Unit
SENSOR
ACTUATOR
ACTUATOR
ACTUATOR
NOTES:
Sensors may include conditioning electronics and A/D converters
Actuators may include driving electronics and/OR D/A converters

Star Network Computing Architecture



Computational models in mobile robotics

Hierarquical Distributed Computing Architecture



Computational models in mobile robotics

Fully Distributed Computing Architecture (FDCA)