Robotic Agent Architectures

Robótica Móvel e Inteligente

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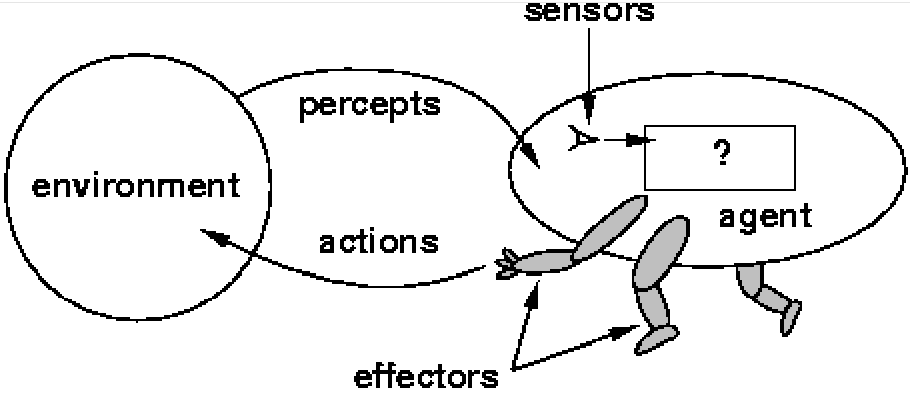
Outline

- 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

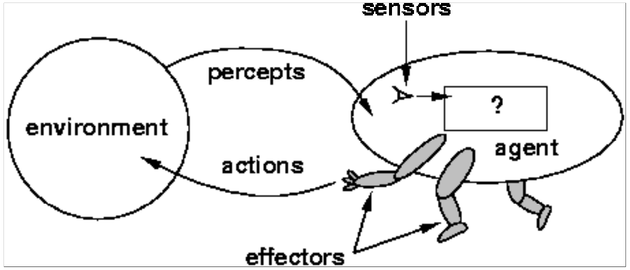
Agent Requisites

- **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

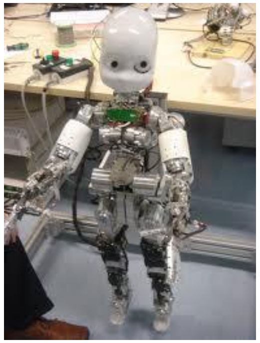
“Objects do it for free; agents do it for money”

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



- **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]

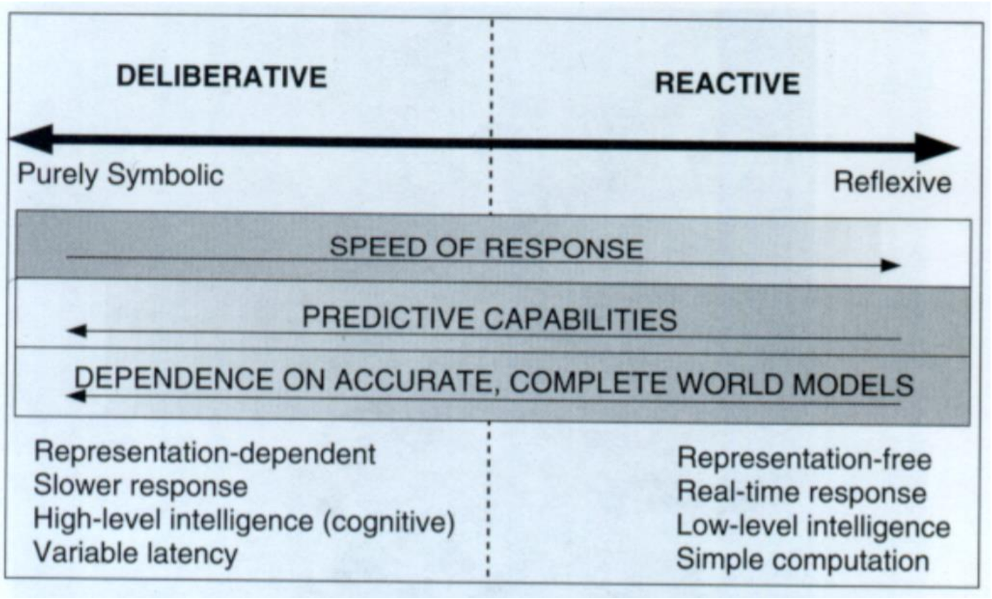
Issues in Robotic Architectures

- **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

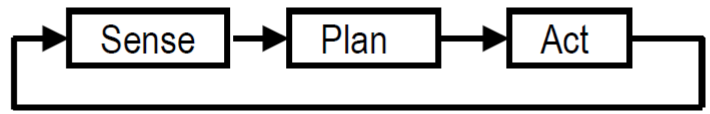


Behavior-based

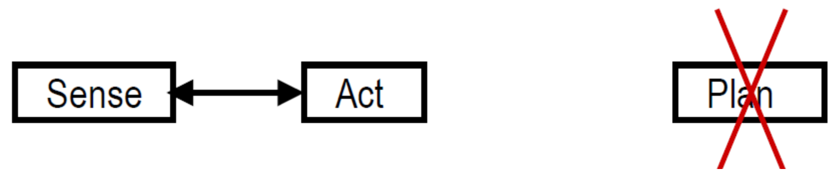
Adapted from Arkin, Behavior-based Robotics (MIT Press, 1998)

Typical Organizations

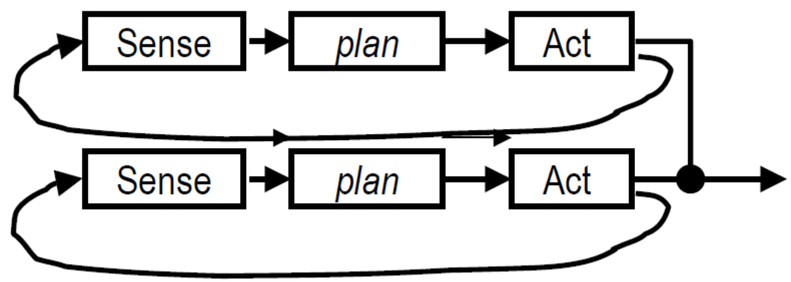
- Typical organizations:
  - Hierarchical / Deliberative



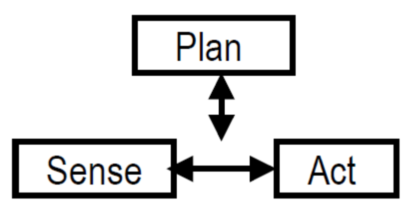
  - Reactive



  - Behavior-based



  - Hybrid

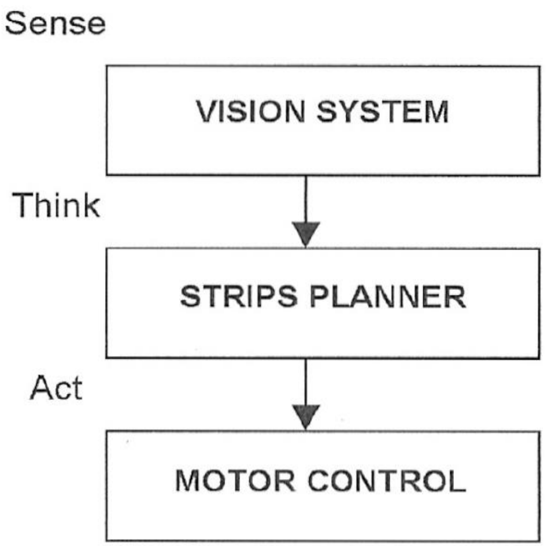


Typical Organizations

- 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

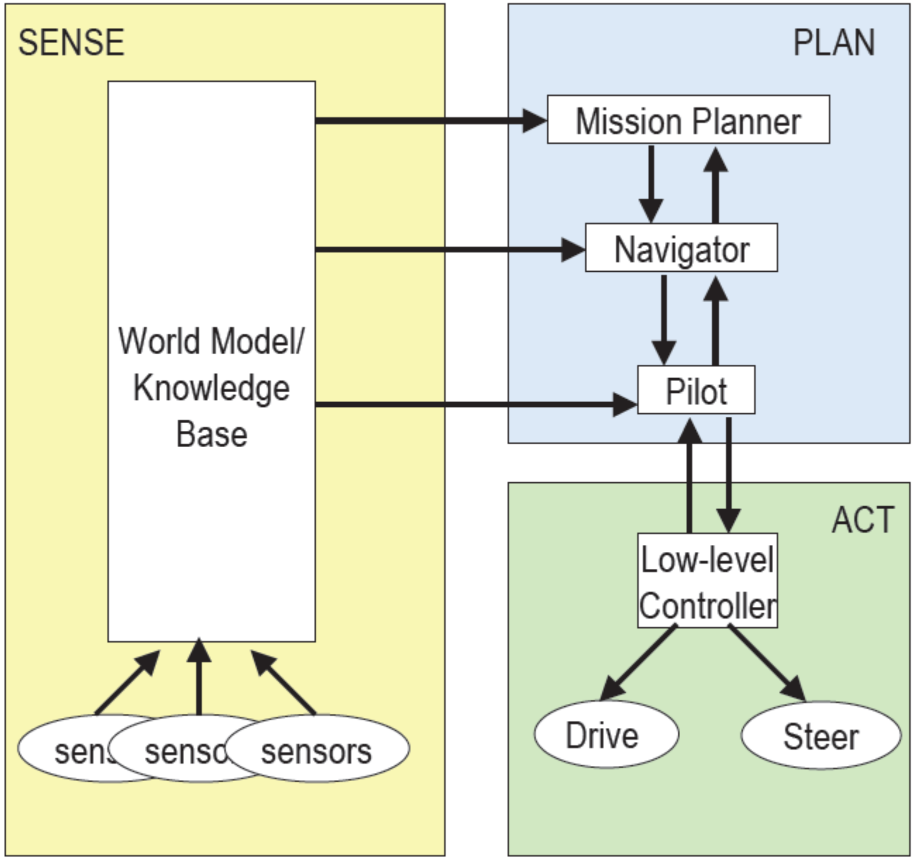
Model-based - Deliberative

- 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



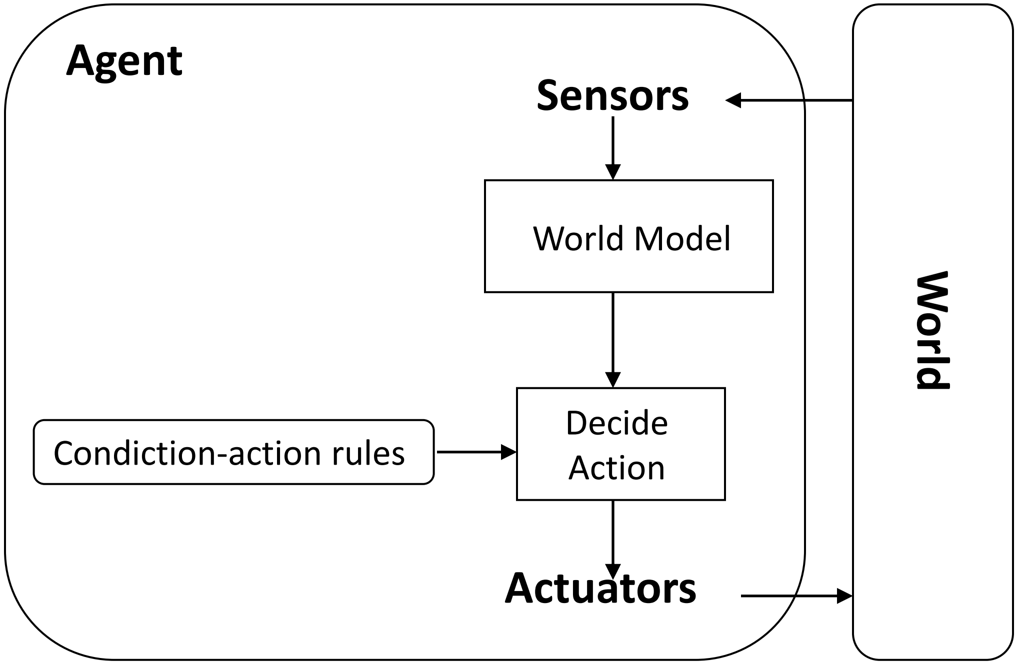
Meystel, A., "*Knowledge Based Nested Hierarchical Control*", 1990

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

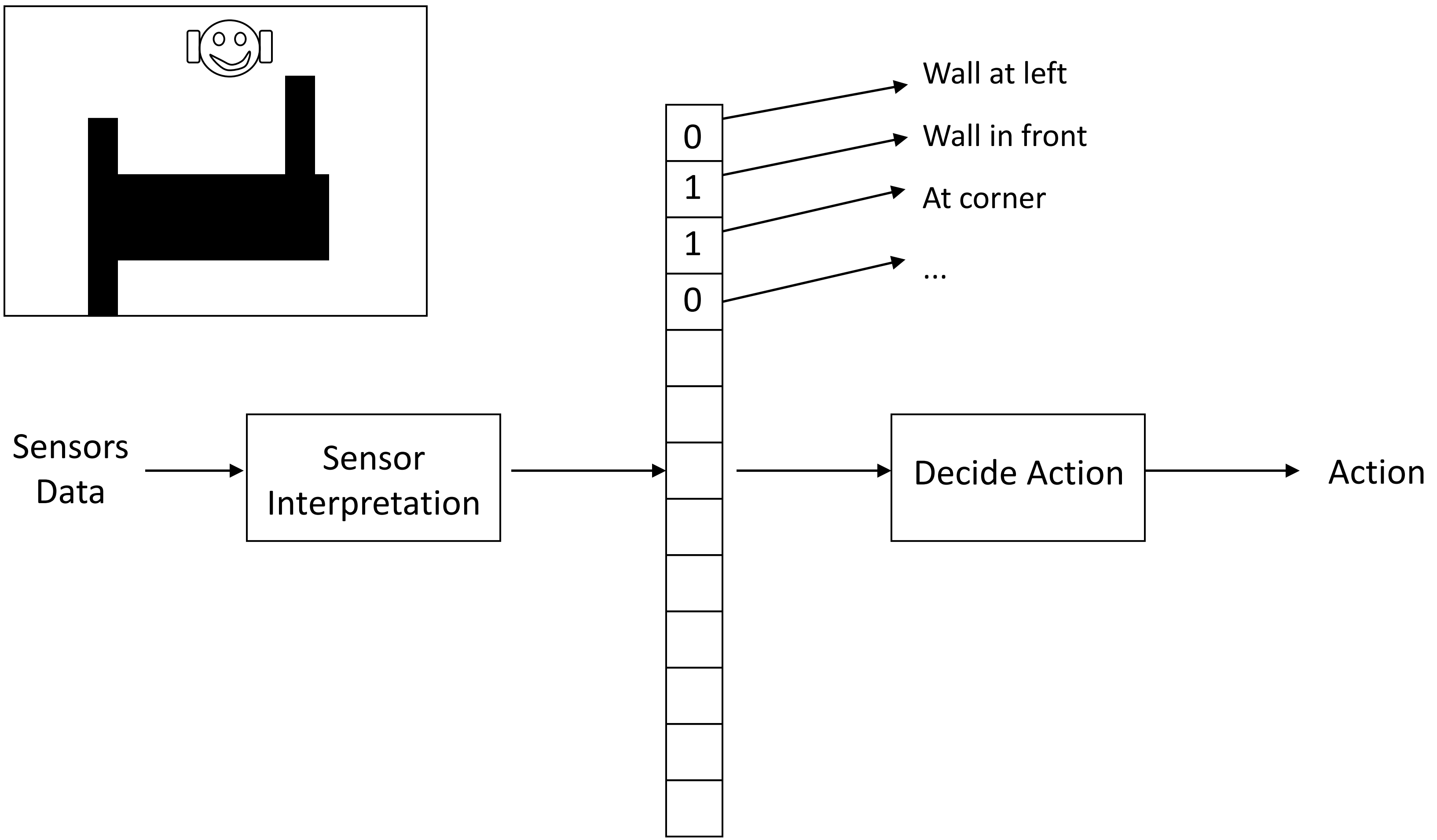
Simple Reactive Agent



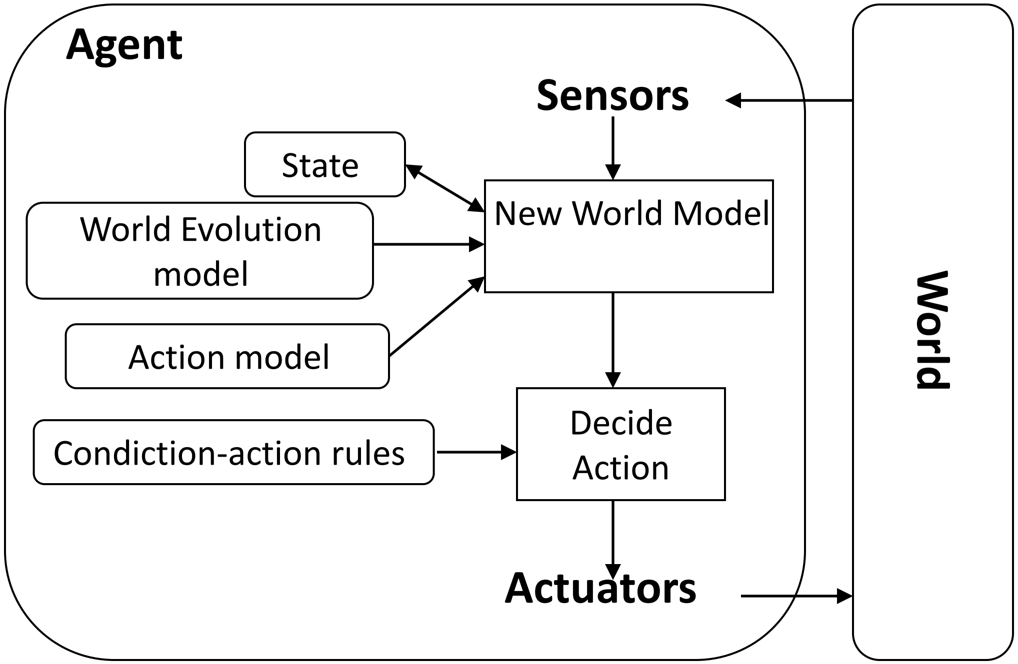
Russel and Norvig, AI: Modern Approach

Simple Reactive Agent

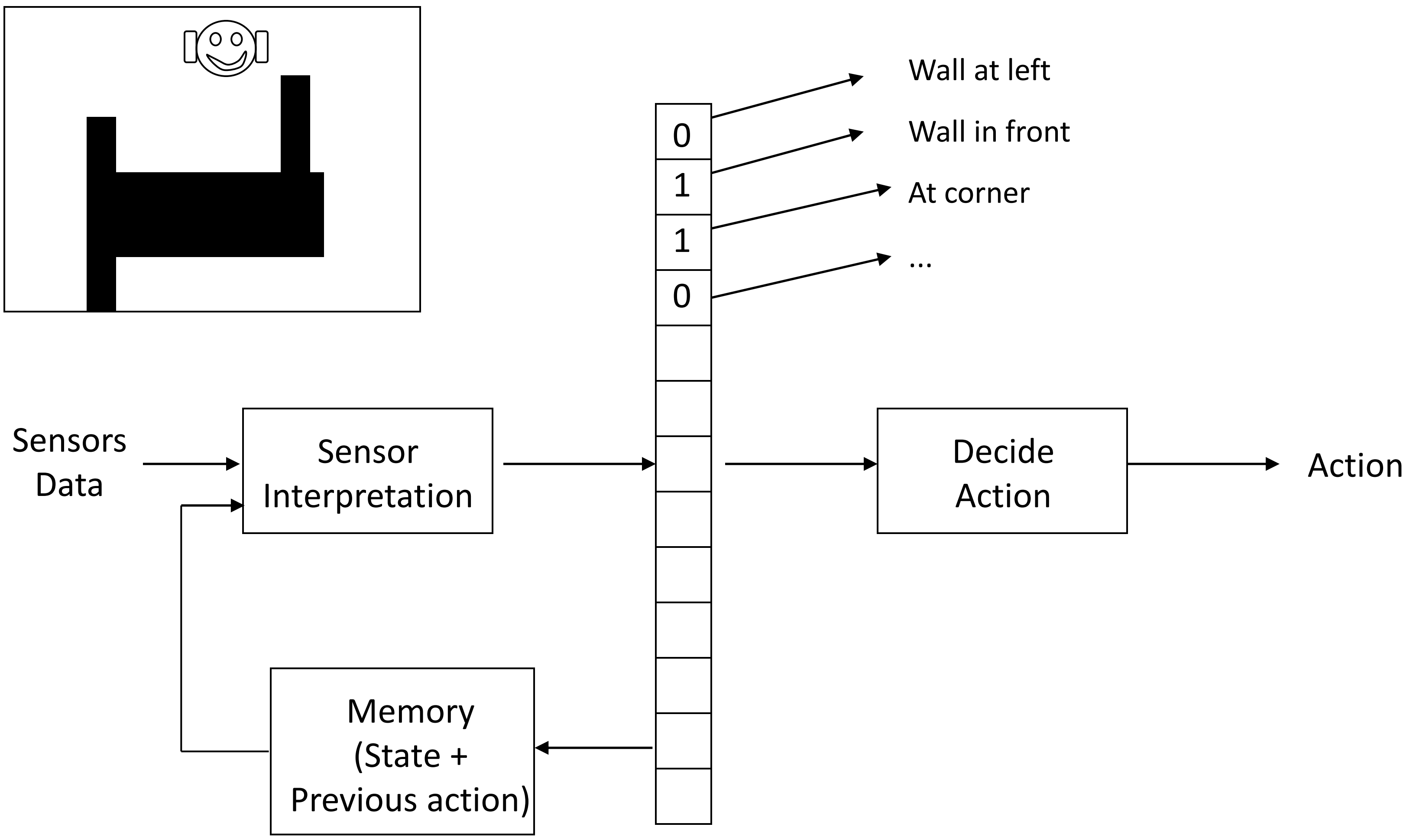
- Perception represented by a feature vector



Reactive Agent with Internal State



Reactive Agent with Internal State



Deliberative vs Reactive

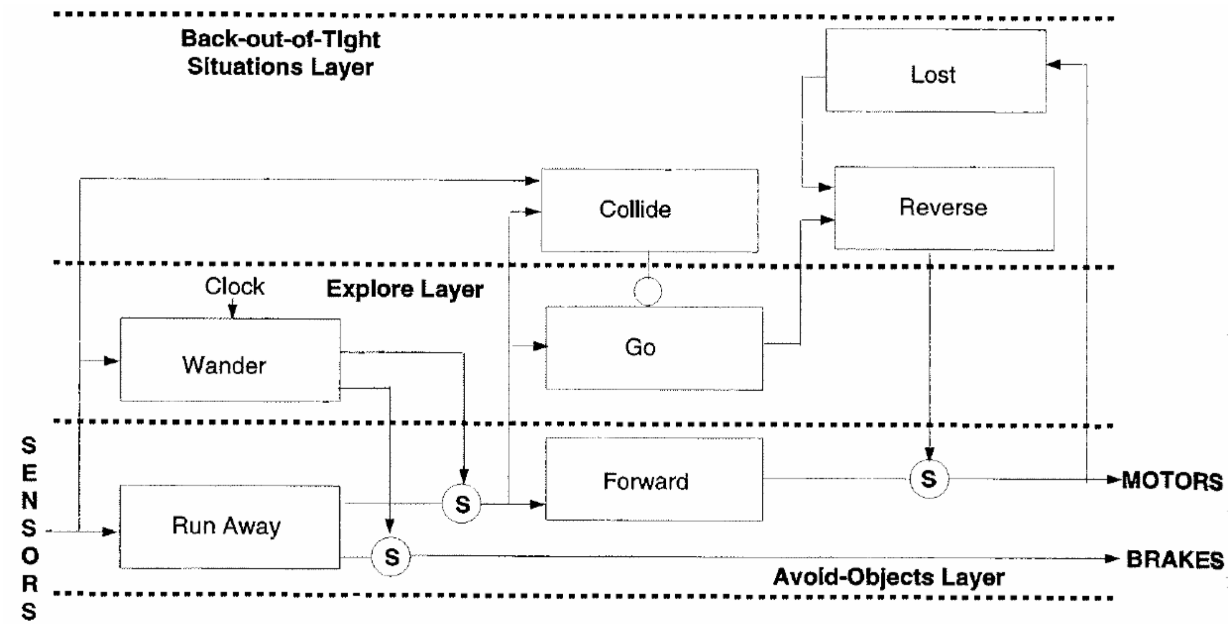
- No single approach is "the best" for all robots; each has its strengths and weaknesses
- Control requires some unavoidable trade-offs because:
  - Thinking is slow
  - Reaction must be fast
  - Thinking allows looking ahead (planning) to avoid bad actions
  - Thinking too long can be dangerous (e.g.,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

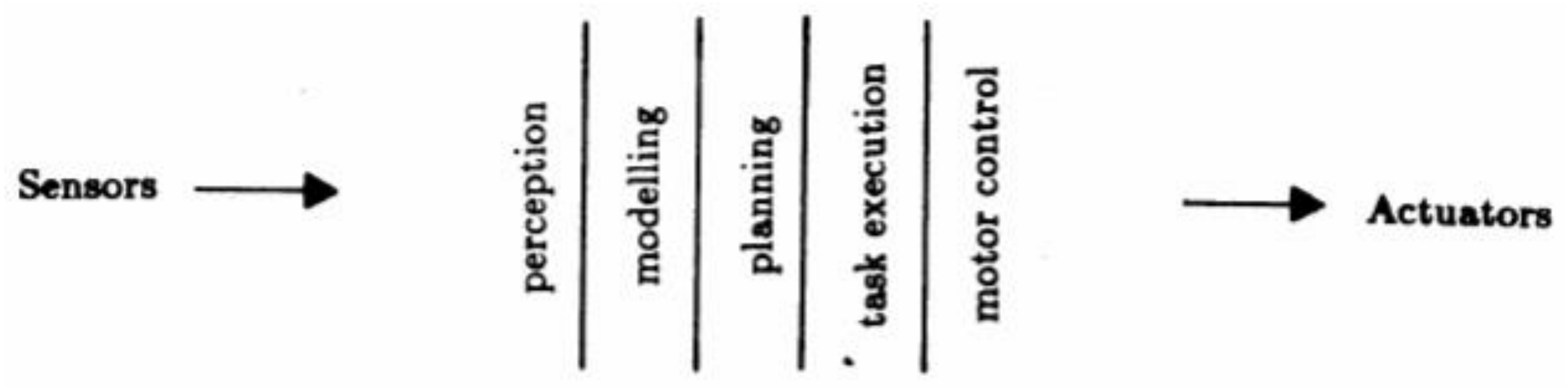


Brooks – Behavior languages

Brooks has put forward three theses:

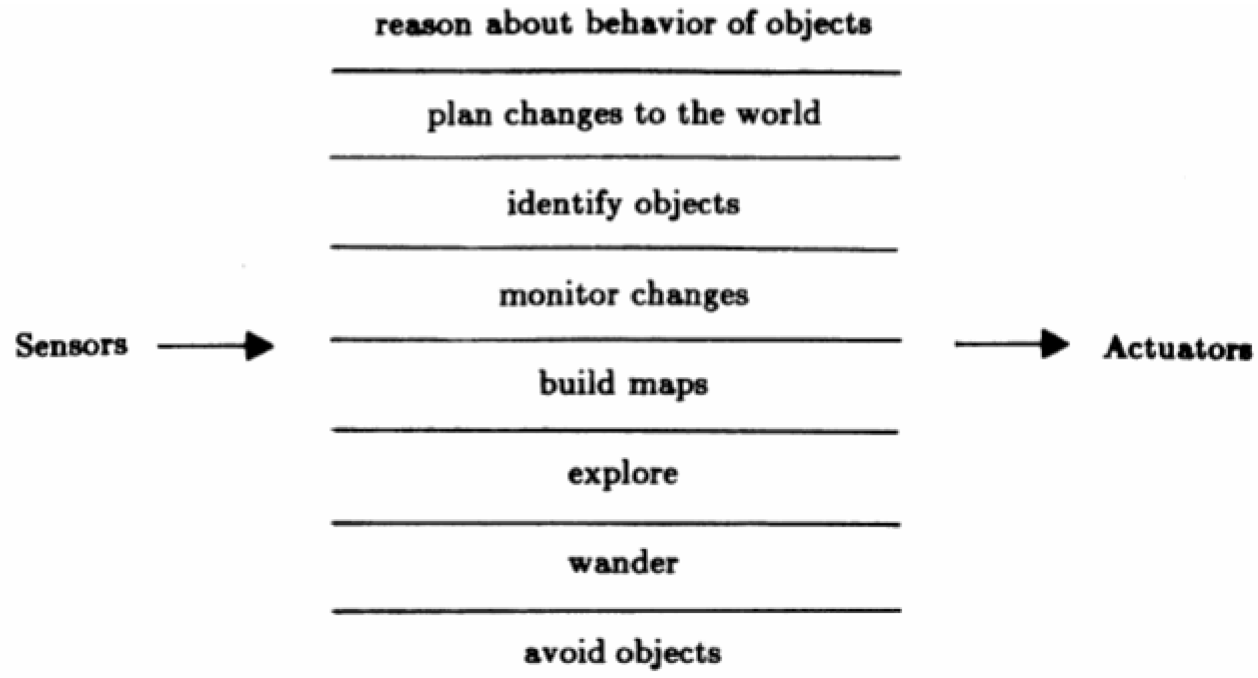
1. **Intelligent behavior** can be generated ***without* explicit representations** of the kind that symbolic AI proposes
2. **Intelligent behavior** can be generated ***without* explicit abstract reasoning** of the kind that symbolic AI proposes
3. **Intelligence is an *emergent property*** *of* certain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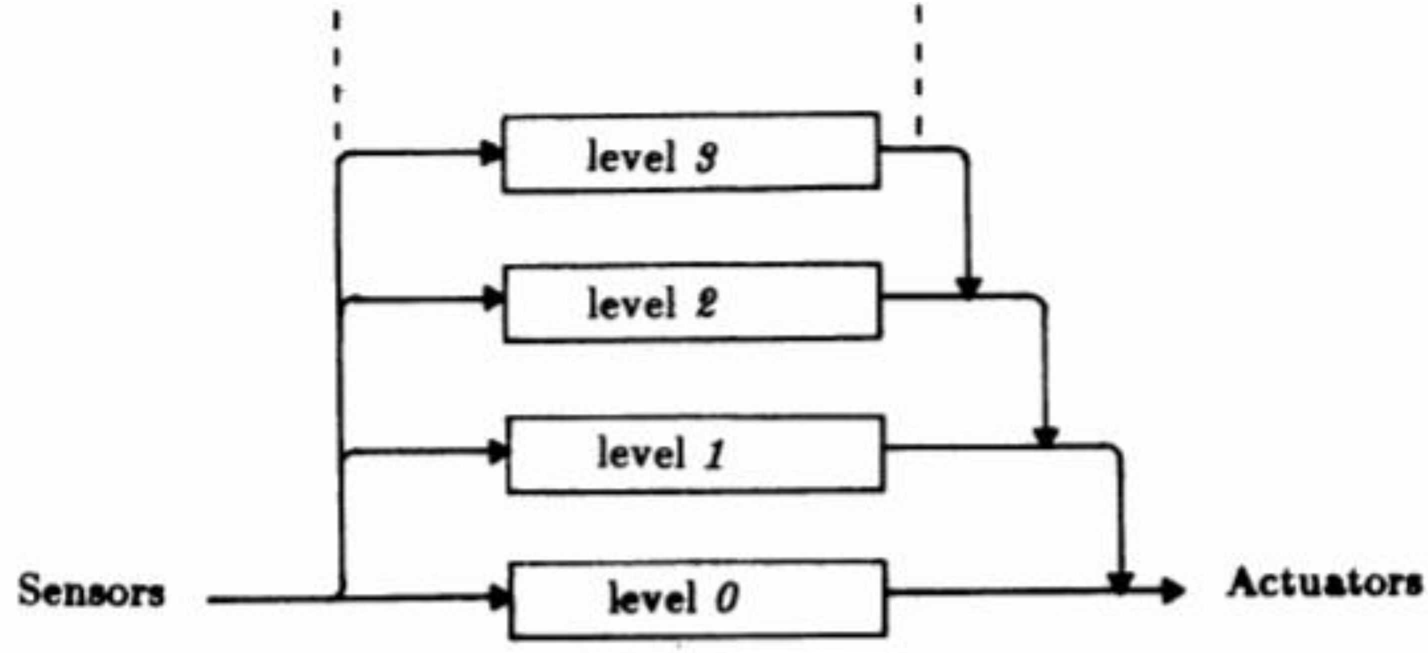
Layered Control in the Subsumption Architecture



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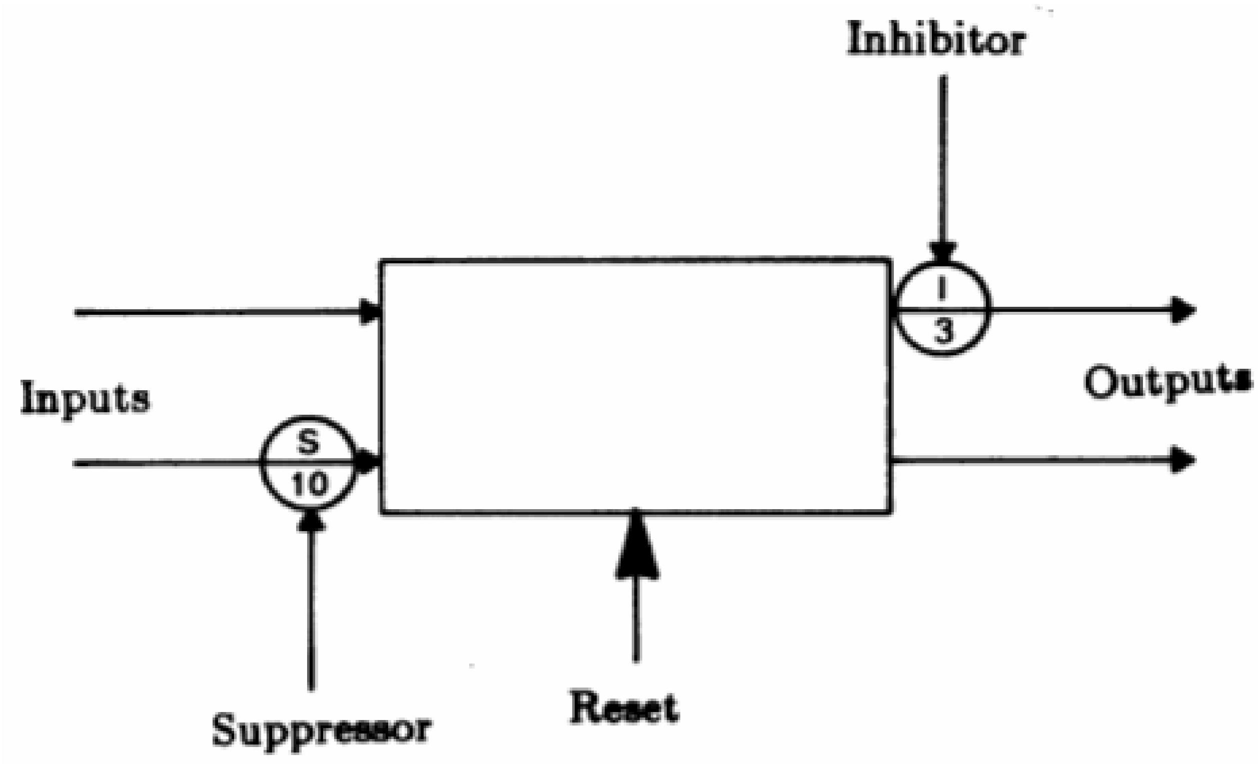
Schematic of a Module



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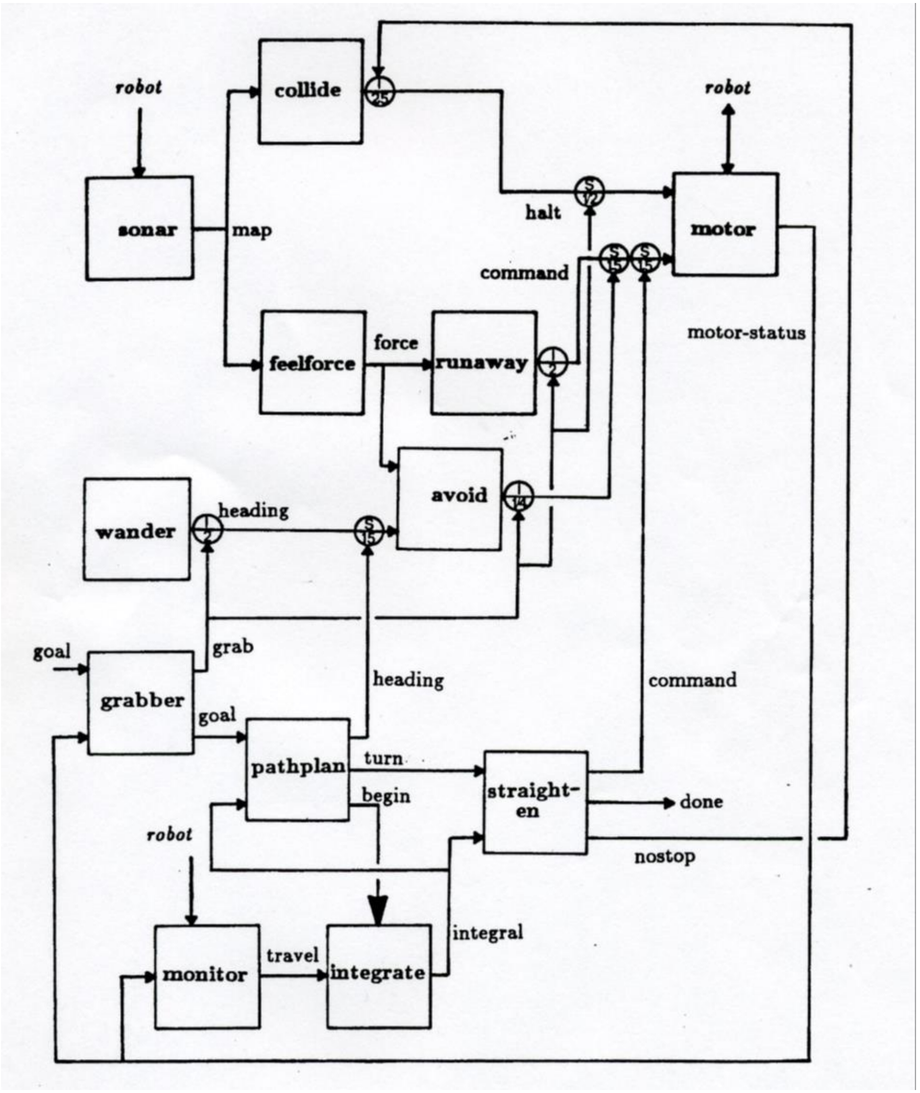
Levels 0, 1, and 2 Control



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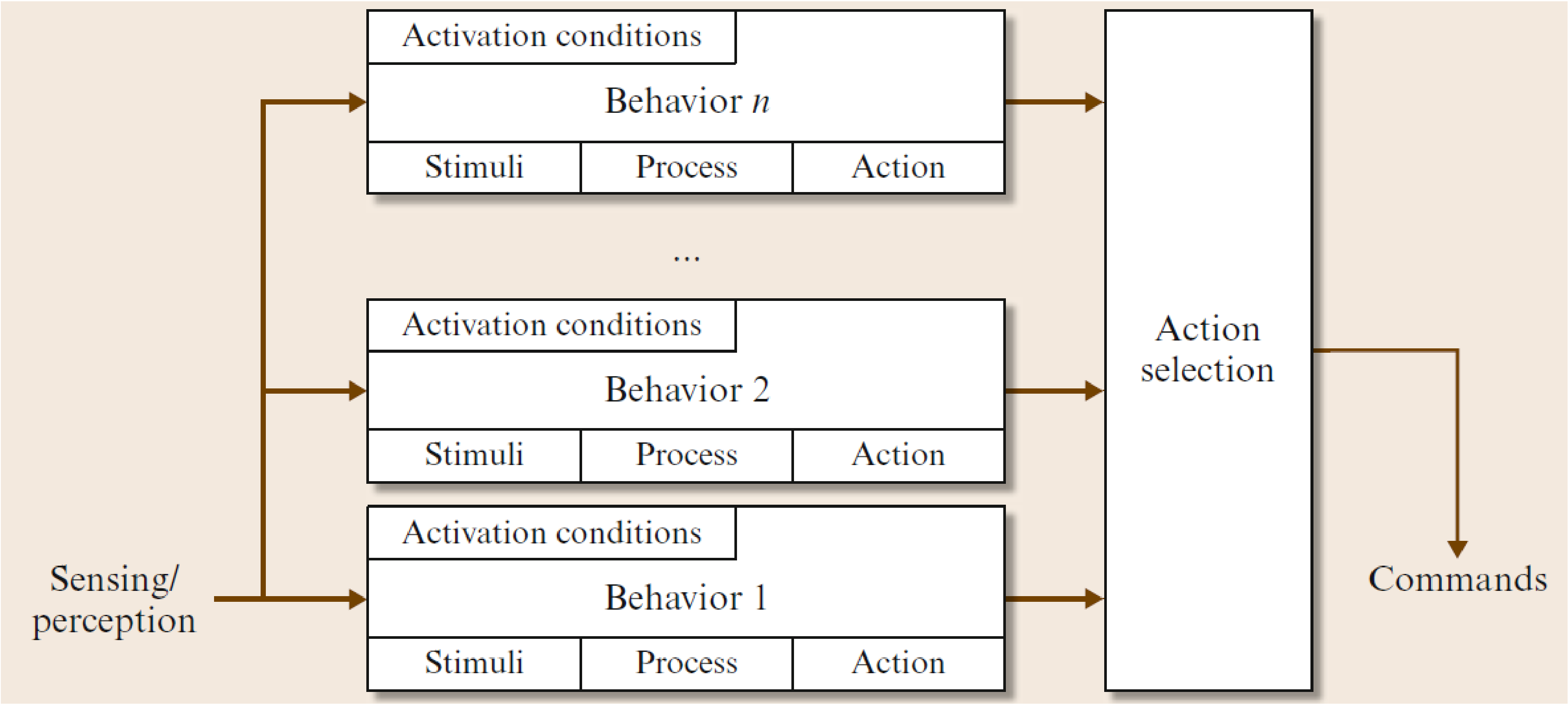
Behavior-Based Architectures



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

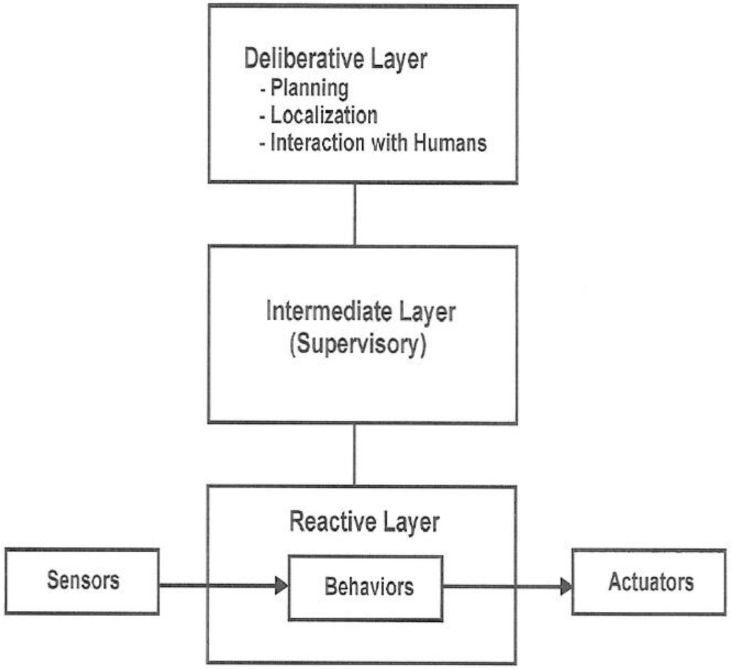
Hybrid Architectures

- 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

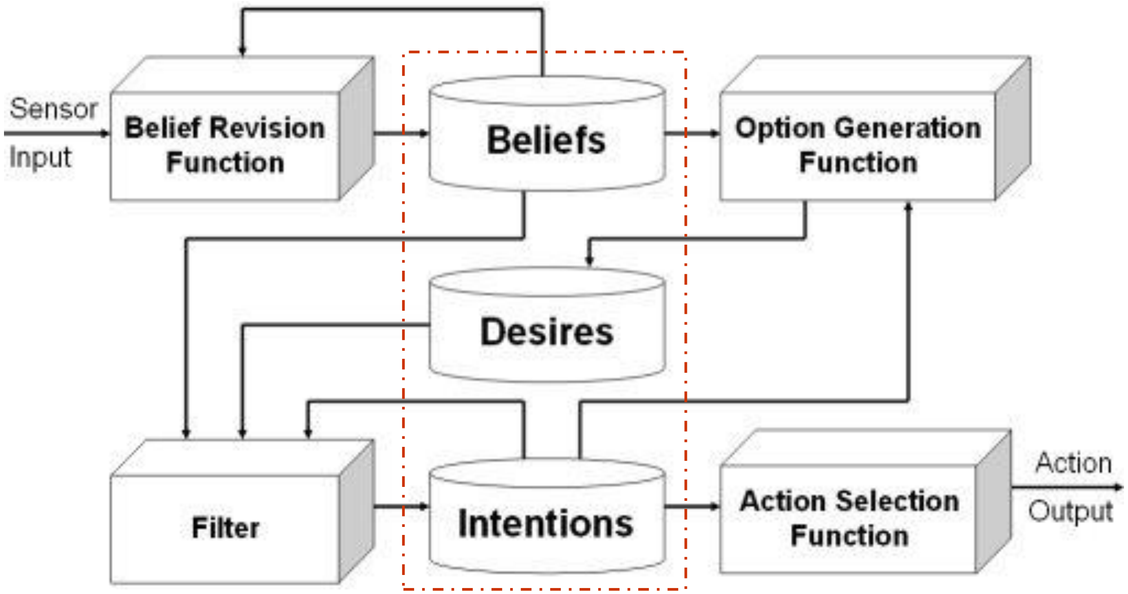
Hybrid Architectures

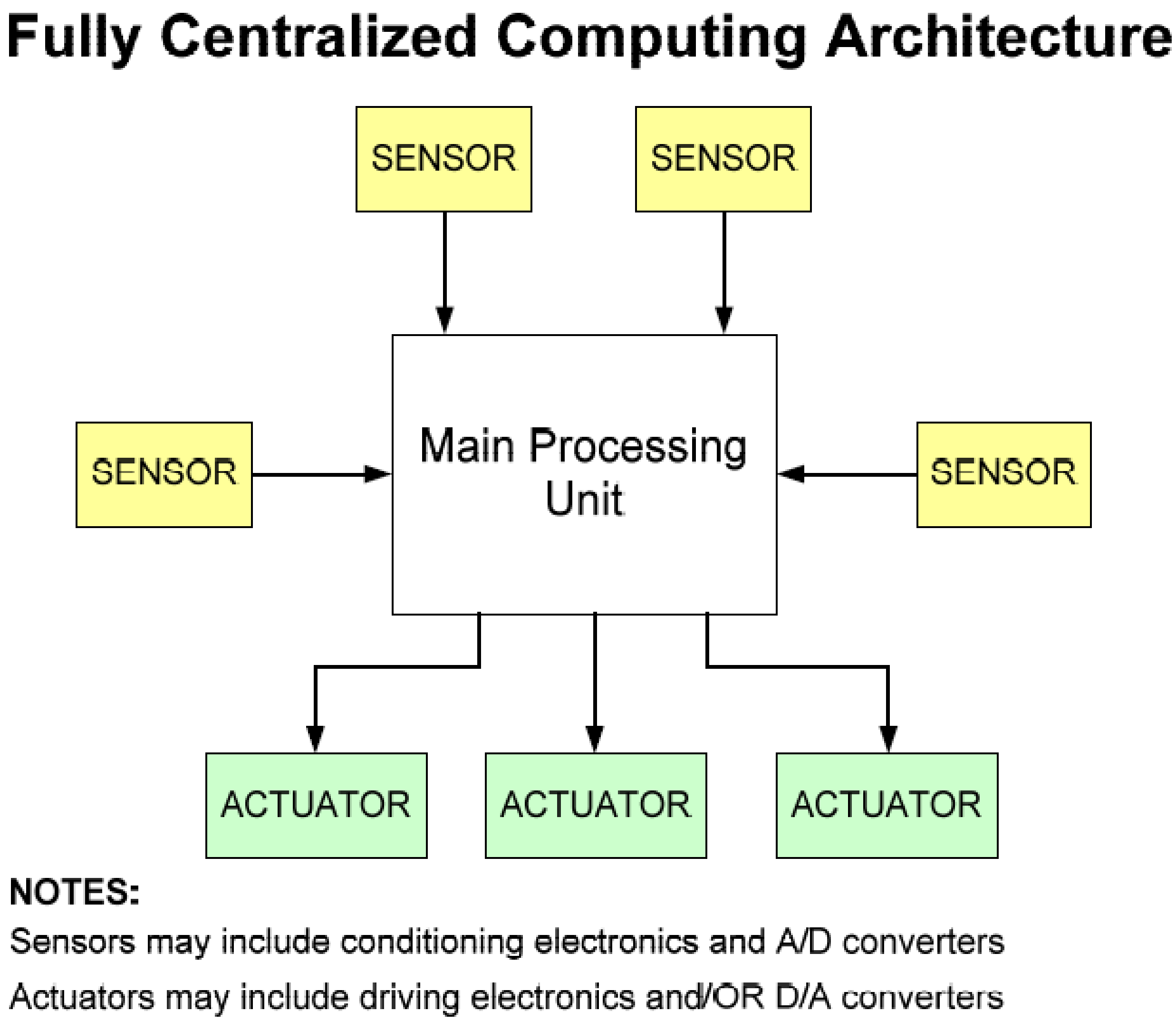
- Combine the responsiveness, robustness, and flexibility of purely reactive systems with more traditional symbolic/deliberative methods
- Reason: purely reactive systems lack the ability to take into account a priori knowledge (e.g. about the world) and to keep track of the history (memory)
- Typical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



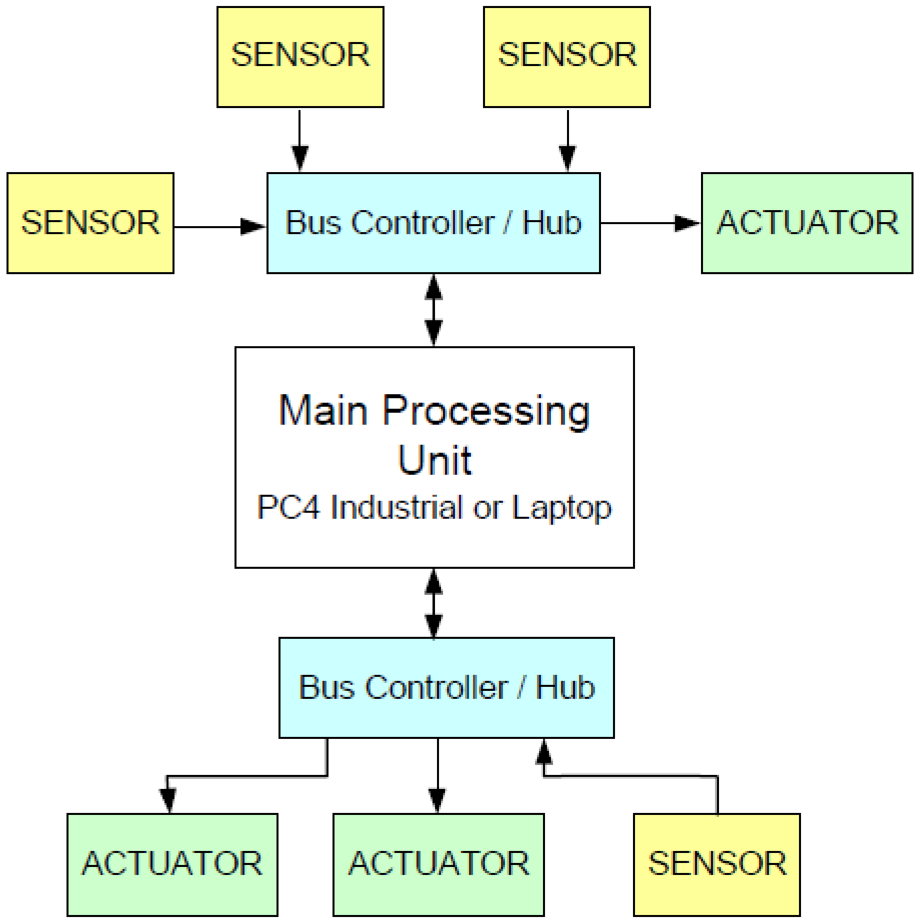
The BDI Model

- 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

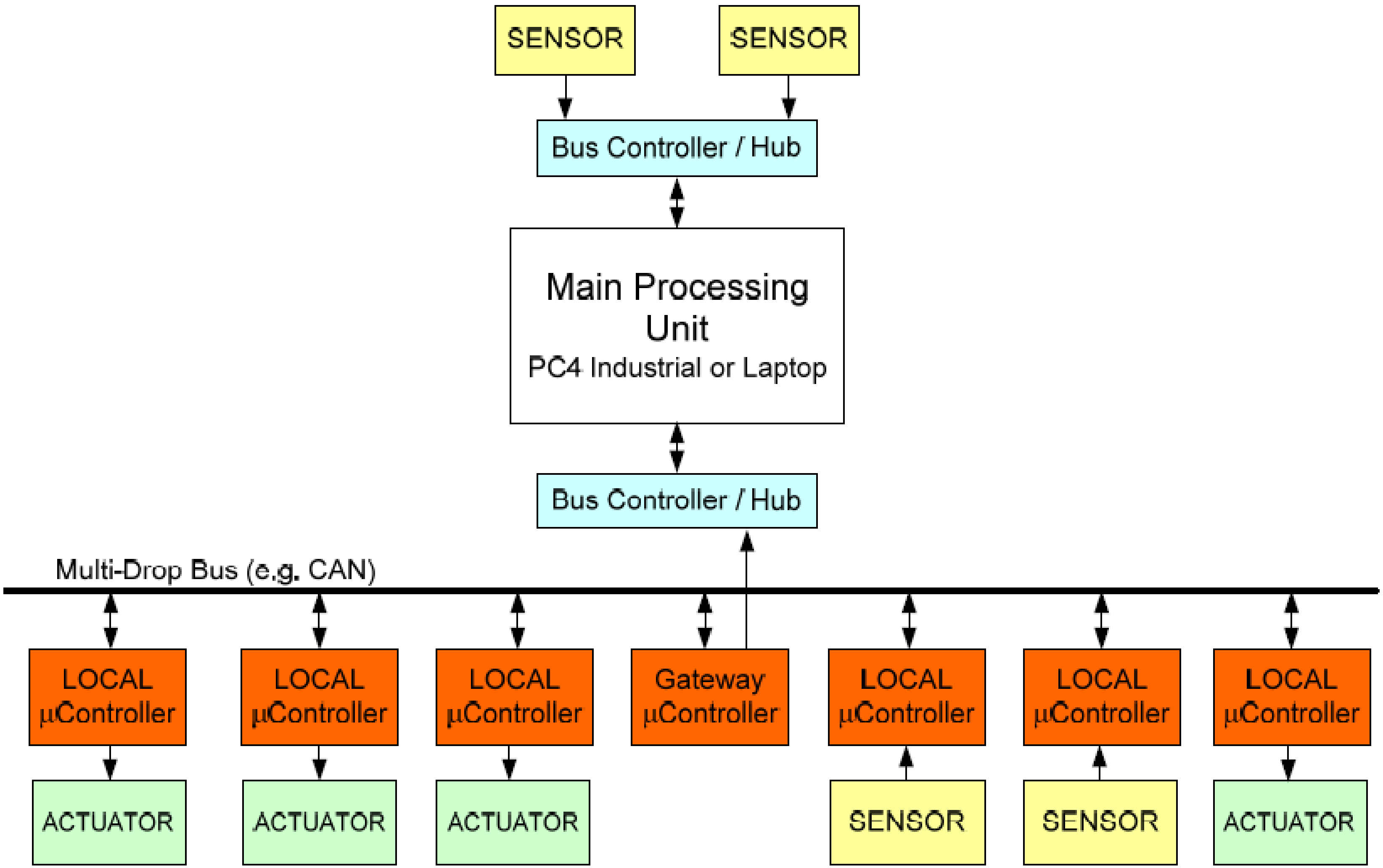


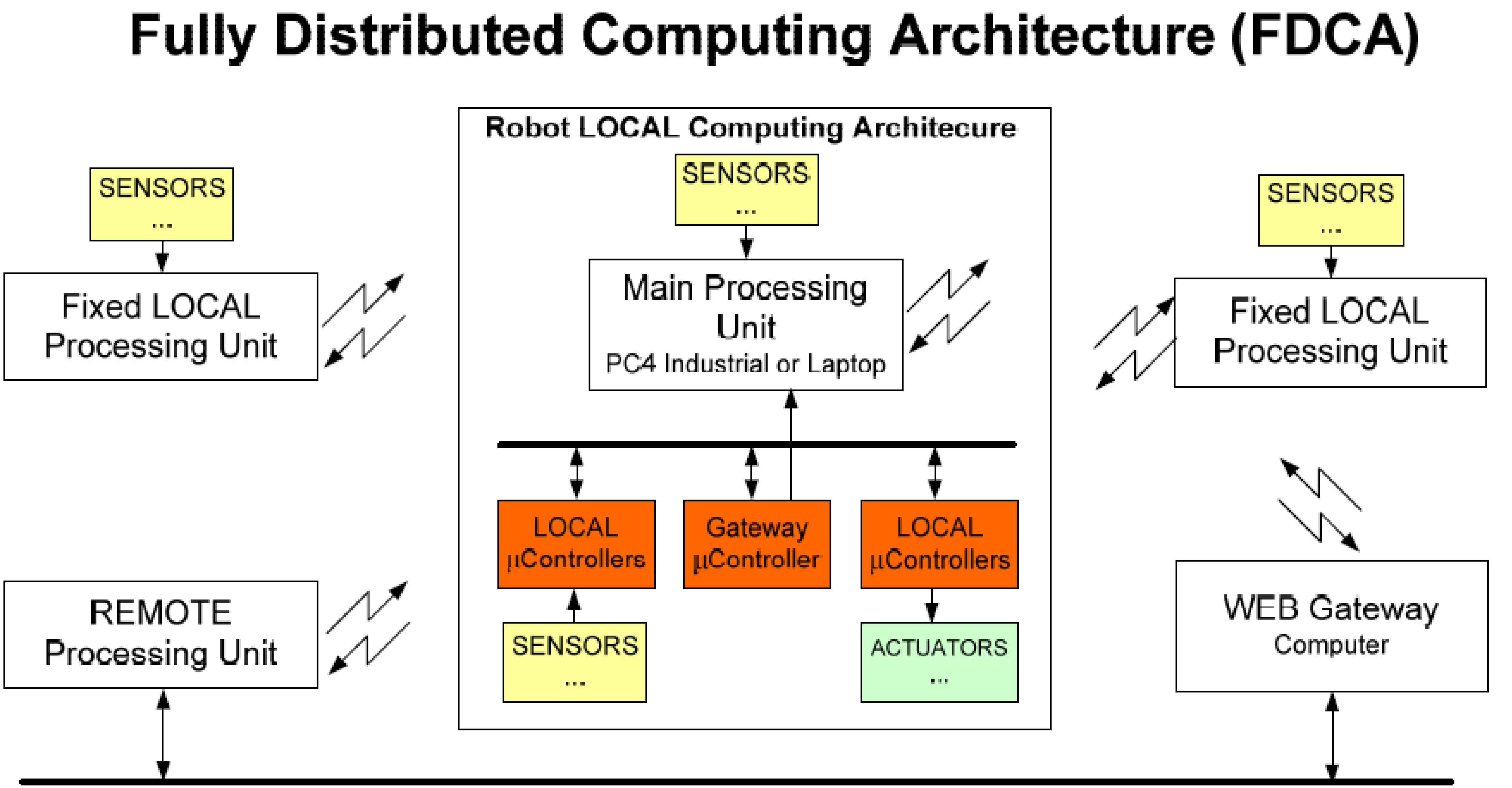

Fully Centralized Computing Architecture
SENSOR
SENSOR
SENSOR
Main Processing Unit
SENSOR
ACTUATOR
ACTUATOR
ACTUATOR
NOTES:
Sensors may include conditioning electronics and A/D converters
Actuators may include driving electronics and/OR D/A converters

Star Network Computing Architecture



Hierarquical Distributed Computing Architecture




Fully Distributed Computing Architecture (FDCA)
Robot LOCAL Computing Architecure
SENSORS
...
Main Processing Unit
PC4 Industrial or Laptop
LOCAL µControllers
Gateway µController
LOCAL µControllers
SENSORS
...
ACTUATORS
...
SENSORS
...
Fixed LOCAL Processing Unit
SENSORS
...
Fixed LOCAL Processing Unit
REMOTE Processing Unit
WEB Gateway
Computer