based on Giuseppina Gini lectures on
BEHAVIOR BASED ROBOTICS

T. Ryan Fitz-Gibbon
BROOK'S SUBSUMPTIONARCHITECTURE

POLITECNICO
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Cognitive Robotics

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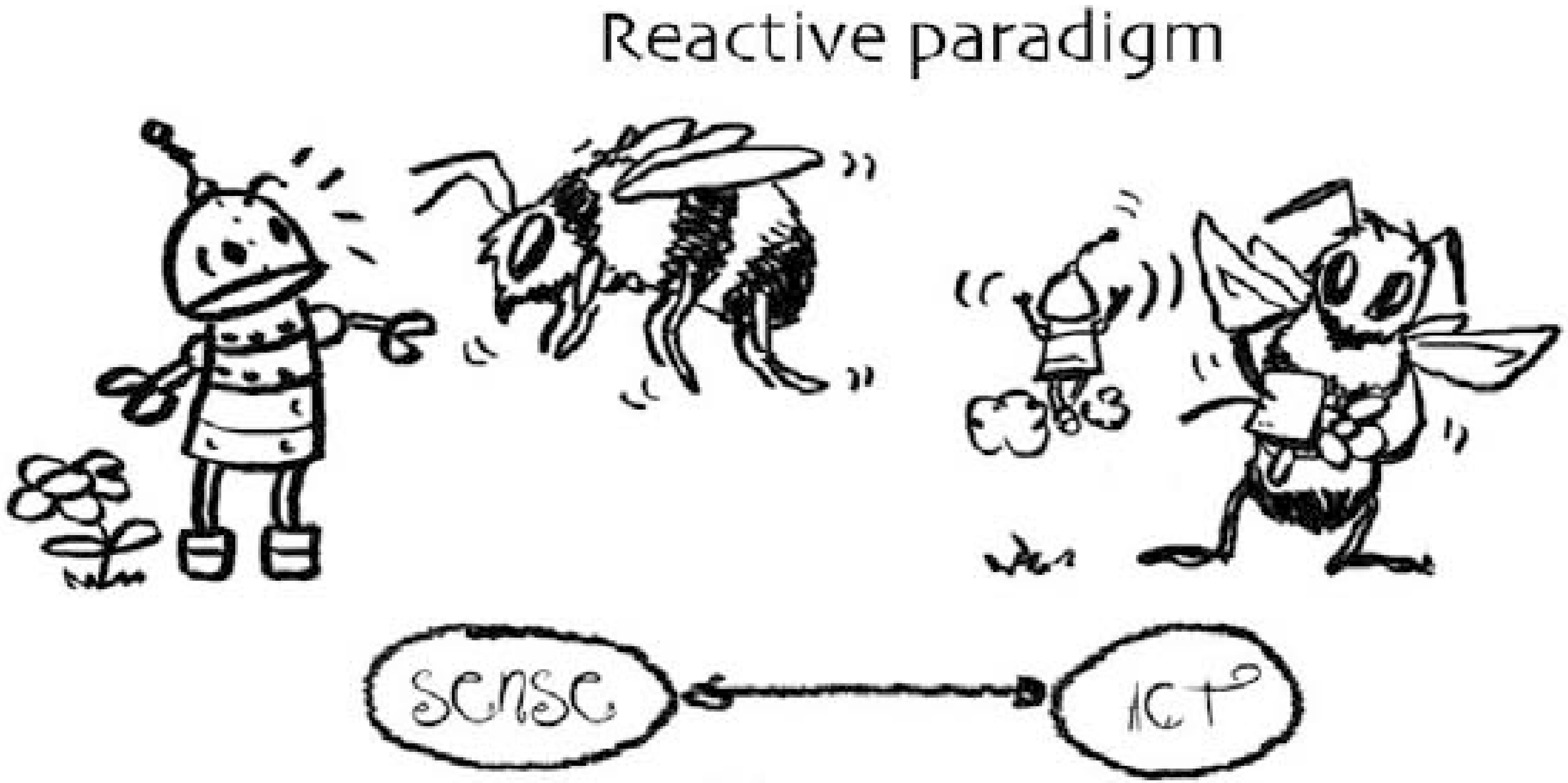
Reactive: Behavior Based Robotics

Matteo Matteucci
matteo.matteucci@polimi.it

Artificial Intelligence and Robotics Lab - Politecnico di Milano

Recall: «Don’t thick, react!»



What is Intelligence?

A housefly is much simpler than most AI attempts, and it is unlikely it:

- Forms 3D surface descriptions of objects
- Reasons about the threat of a human with a fly swatter, in particular about the human's beliefs, goals, or plans
- Makes analogies concerning the suitability for egg laying between dead pigs
- Constructs naïve physics theories of how to land on the ceiling

It is much more likely that a housefly:

- Has close connection of sensors to actuators
- Has pre-wired patterns of behavior
- Has simple navigation techniques
- Functions almost as a deterministic machine

And yet a housefly exhibit a more successful behavior in the real world than many AI attempts …

Other views on Intelligence and Robots

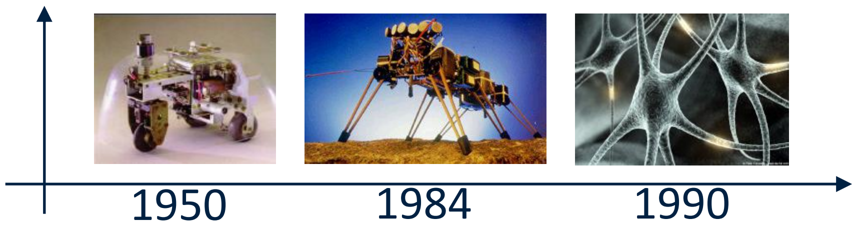
What is the mind – cognitive science answer

Where is the intelligence – behavioral approach

What is in the brain – neurosciences

Alternative perspective in cognitive robotics

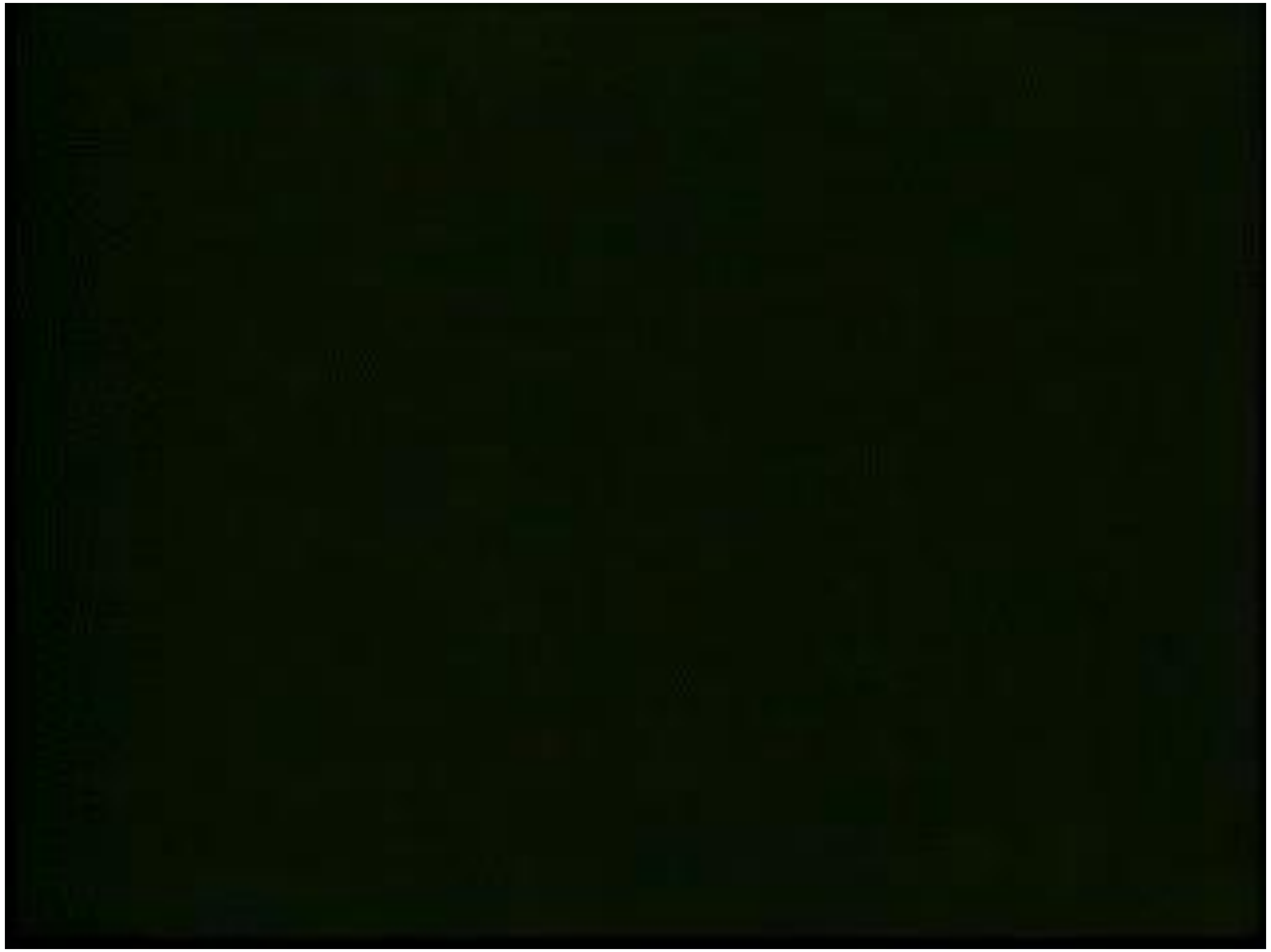
- 1950: Early experiments
- 1984: Behaviorism
- 1990: Subsymbolic



Parallel evolution with studies in Psycology

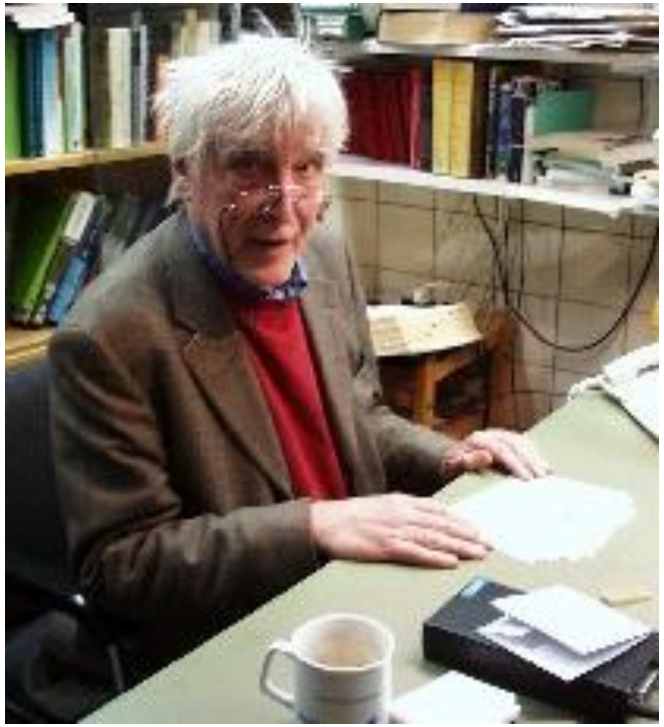
Early «robot» experiments

Grey Walter’s tortoises (’50s): mechanical plausibility of animal tropism. (Tropism/taxis: animal movement directed by stimuli).



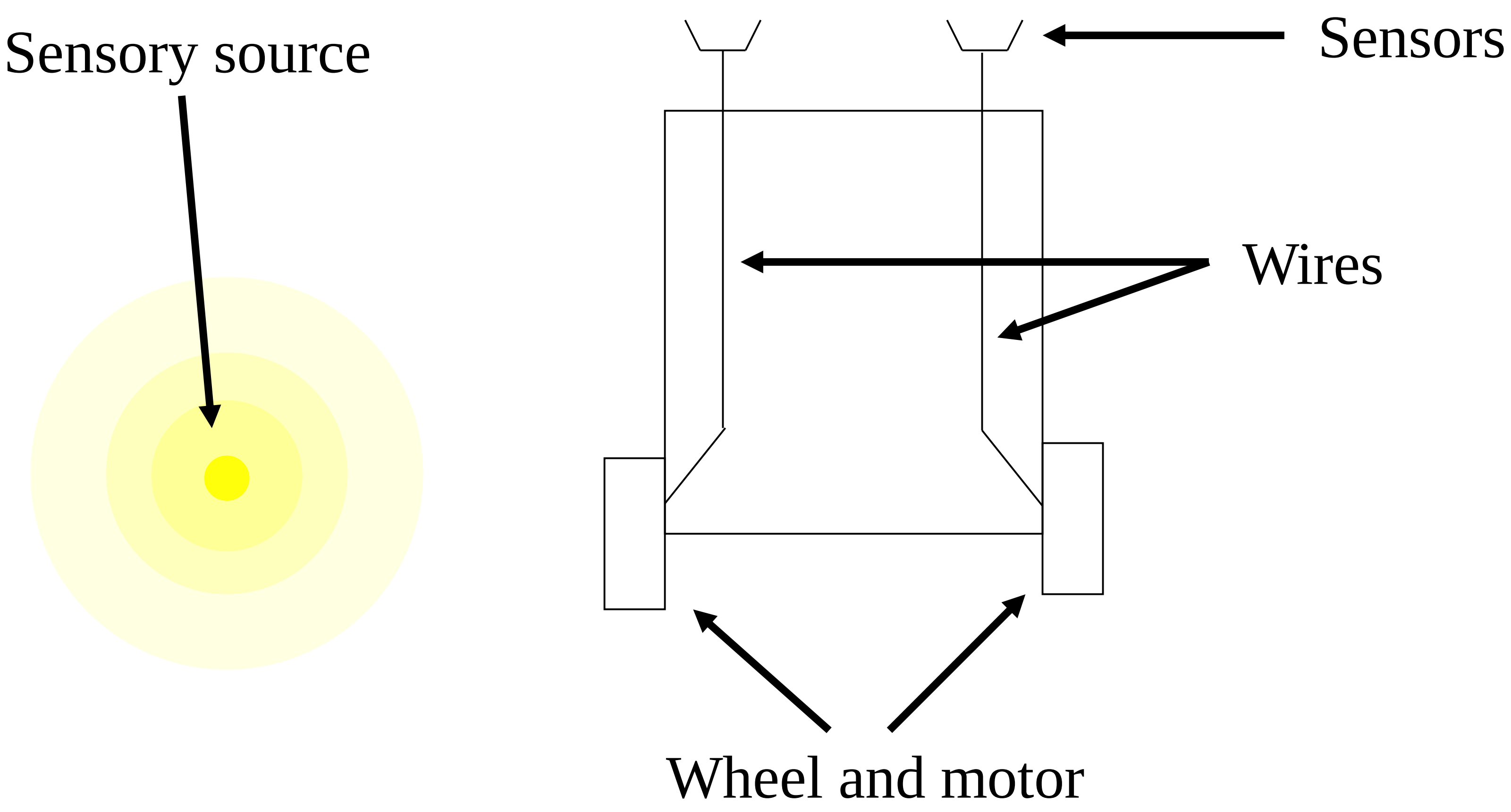
Braitenberg’s Vehicles

- The book *“Vehicles: Experiments in Synthetic Psychology”* was published in 1984 by Valentino Braiteberg
- Neuro-psychologist interested in how primitive neural structures can give rise to complex behavior
- He developed a simple model of robots with sensors and motors to show how complex behavior can arise from simple mechanisms
- “Vehicles” where complex behavior emerges from combination of simple NNs encoding different taxes



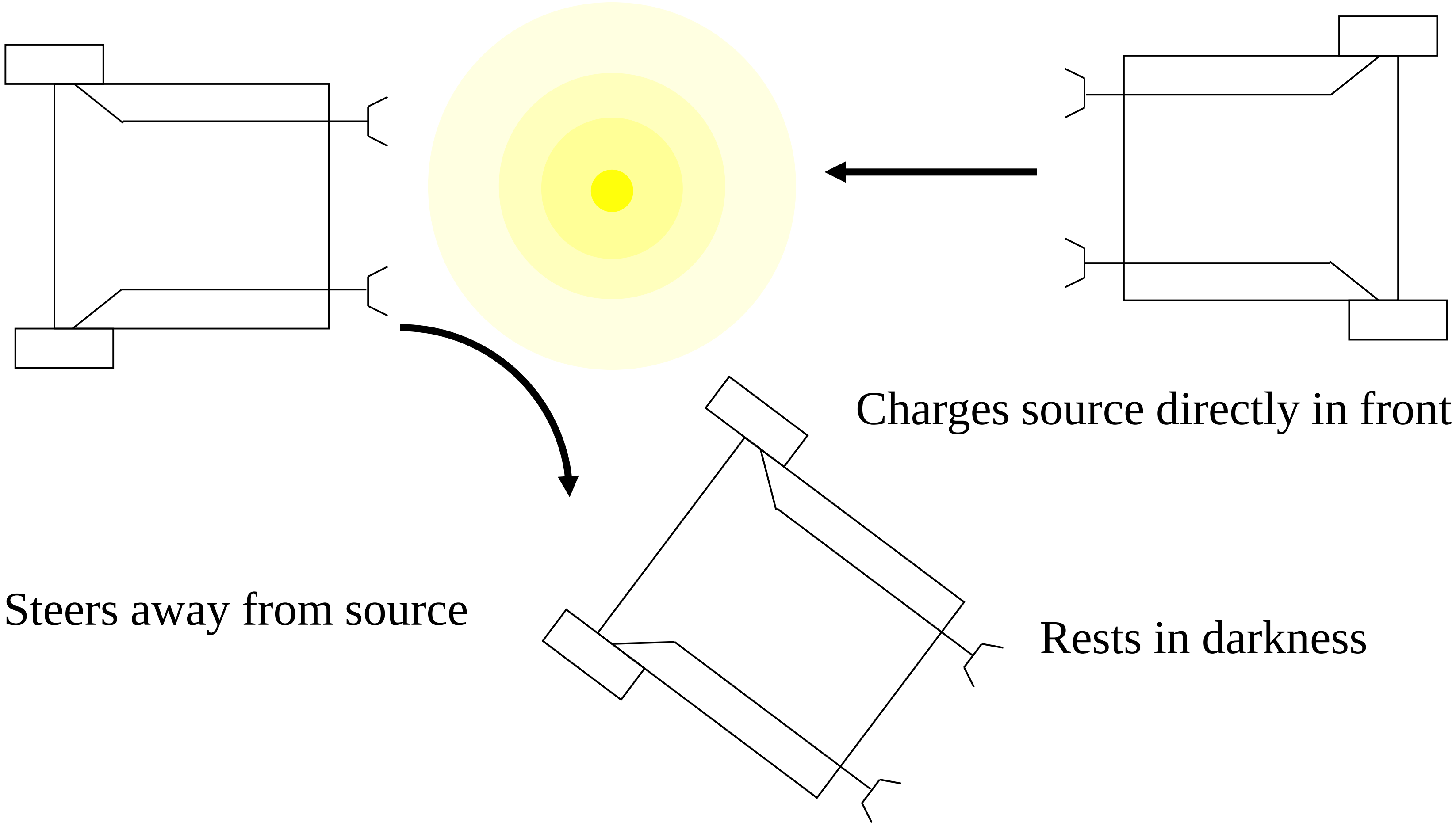
Dr. Braiteberg’s homepage:
http://www.kyb.mpg.de/~braitenb

A Vehicle



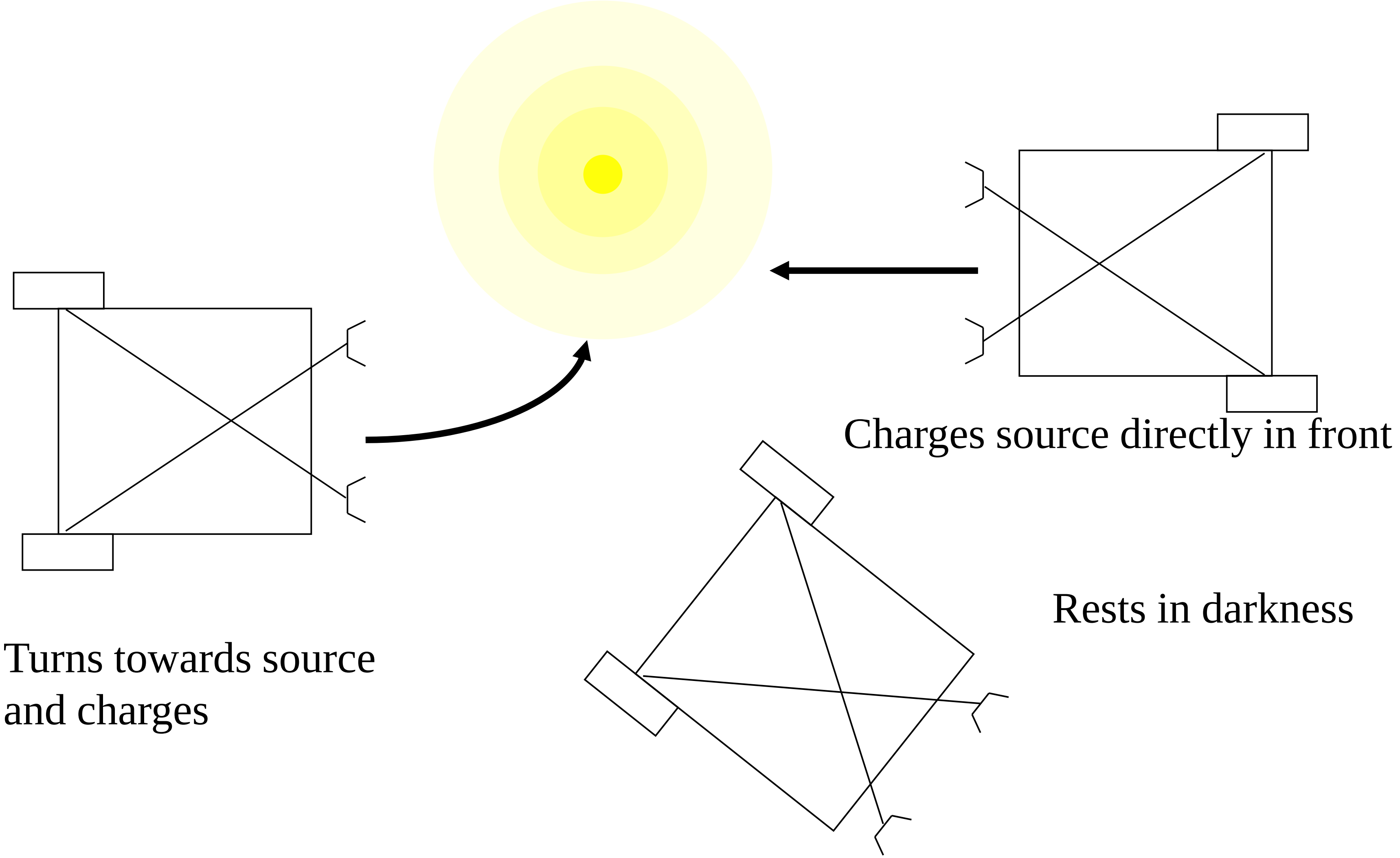
Vehicle 1: Coward

Sensors (light sensors) connected directly to motor on same side



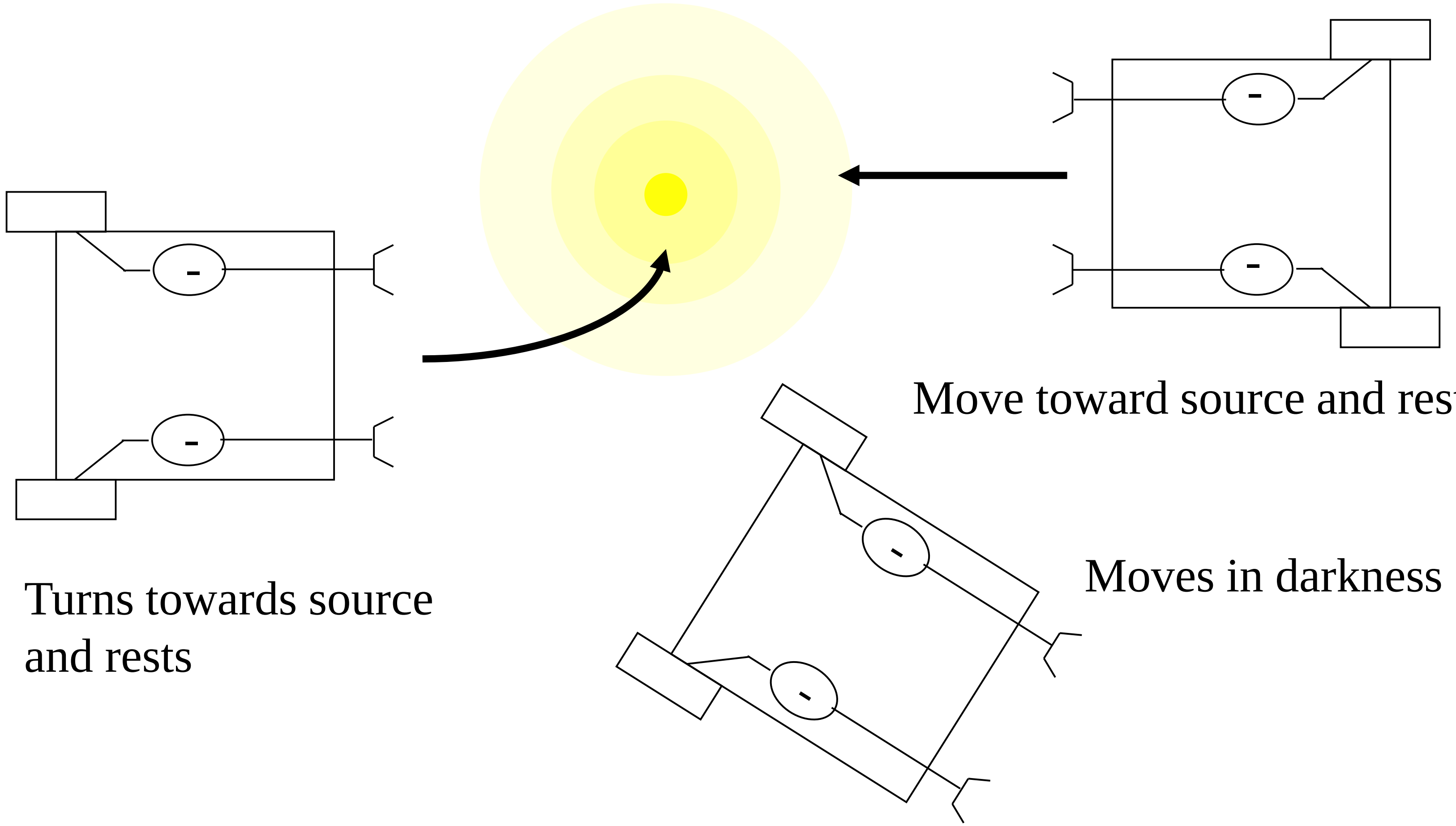
Vehicle 2: Aggressive

Sensors connected directly to motor on opposite side



Vehicle 3: Love

Sensors connected through inverter to same side



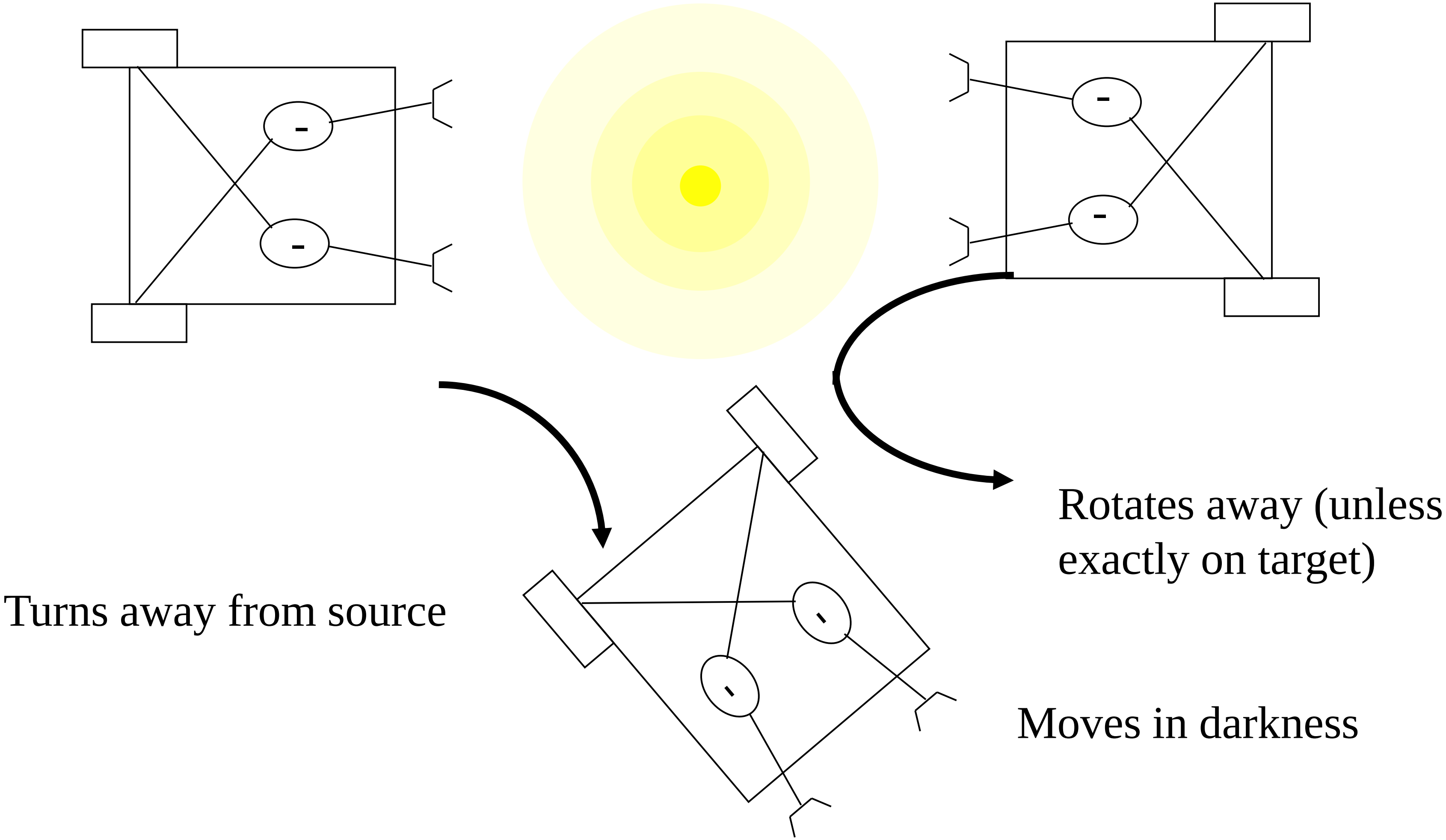
Move toward source and rest

Turns towards source and rests

Moves in darkness

Vehicle 4: Explorer

Sensors connected through inverter to opposite side



Behaviorism

"Psychology should concern itself with
the observable behavior of people and animals,
not with unobservable events that take place
in their minds."

John B. Watson & B. F. Skinner

- Behaviorism emerged in the early twentieth century as a reaction to "mentalistic" psychology
- Nevertheless, in the second half of the 20th century, behaviorism was largely eclipsed as a result of the cognitive revolution

Behaviorism

“Psychology should concern itself with
the <u>observable behavior</u> of people and animals,
not with <u>unobservable events</u> that take place
in their minds.”

John B. Watson & B. F. Skinner

- Psychology is the science of **behavior**, not the science of **mind**.
- Behavior can be described and explained without making ultimate reference to mental events or to internal psychological processes.
- The sources of behavior are external (they come from the environment), not internal (they do not come from the mind).

Behavior-based Robotics

An alternative approach to rethink how to organize intelligence born around 1984

- Reactive to dynamic environment
- Operate on human time scales
- Robustness to uncertainty/unpredictability

Implemented simple systems with similar features

- Behavior language at MIT (Rodney Brooks)
- Schema at Georgia Tech (Ron Arkin)
- Fuzzy at SRI (Saffiotti, Ruspini, Konolige)
- Potential fields at Stanford (…)

A Change in Perspective

Reasoning

Where: brain

Artificial Intelligence

Information processing

Absolute coordinates

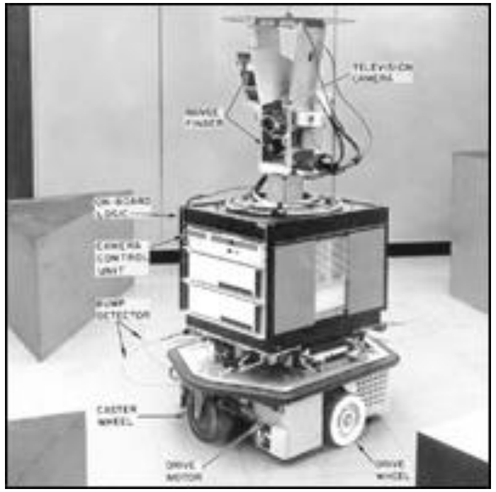
Behave

Where: organism

Artificial Life

Senso-motor integration

Agent-centered



Symbol grounding problem

“The symbol grounding problem is related to the problem of how words (symbols) get their meanings, and hence to the problem of what meaning itself really is. The problem of meaning is in turn related to the problem of consciousness, or how it is that mental states are meaningful.”

Wikipedia

Classic AI, i.e., symbolic approaches. to Cognitive Robots have shown many unsolved (some would say insoluble) problems associated with symbol grounding:

- A purely symbolic system has no embodiment
- Symbol grounding not solved yet which means: no symbols, no symbolic relations, no automatic problem solution, no state space
- http://cogprints.org/615/1/The_Symbol_Grounding_Problem.html

Properties of an Autonomous Robot

Situateness: the behavior of a creature depends on the environment in which it is embedded or situated, creatures don't deal with abstract descriptions, but with the "here" and "now" of their environment.

A situated automaton is a finite-state machine
whose inputs are provided by sensors connected to the environment,
and whose outputs are connected to effectors

Embodiment: An *embodied* creature is one which has a physical body and experiences the world, at least in part, directly through the influence of the world on that body.

Only an embodied agent is validated as one that can
deal with real world. Only through a physical grounding can
any internal symbolic system be given meaning.

Properties of an Autonomous Robot

Emergence: The intelligence of the system emerges from the system's interactions with the world and from sometimes indirect interactions between its components-- it is sometimes hard to point to one event or place within the system and say that is why some external action was manifested.

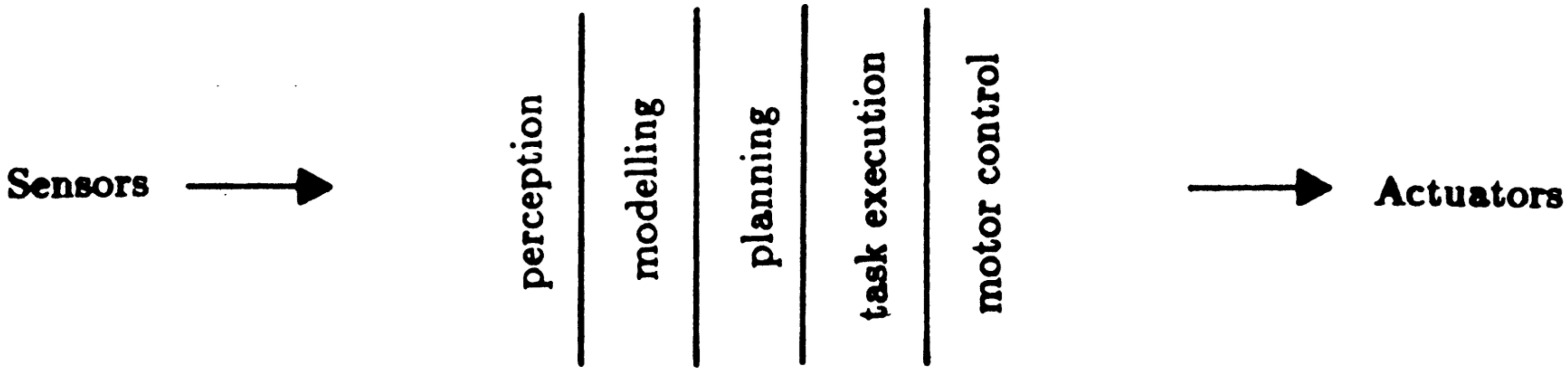
Intelligence: An autonomous (artificial) creature is one that is able to maintain a long term dynamic with its environment without intervention. Once an autonomous artificial creature is switched on, it does what is in its nature to do.

Intelligence is in the eye of the observer.

Hirozontal vs. Vertical Decomposition

Shakey, but …

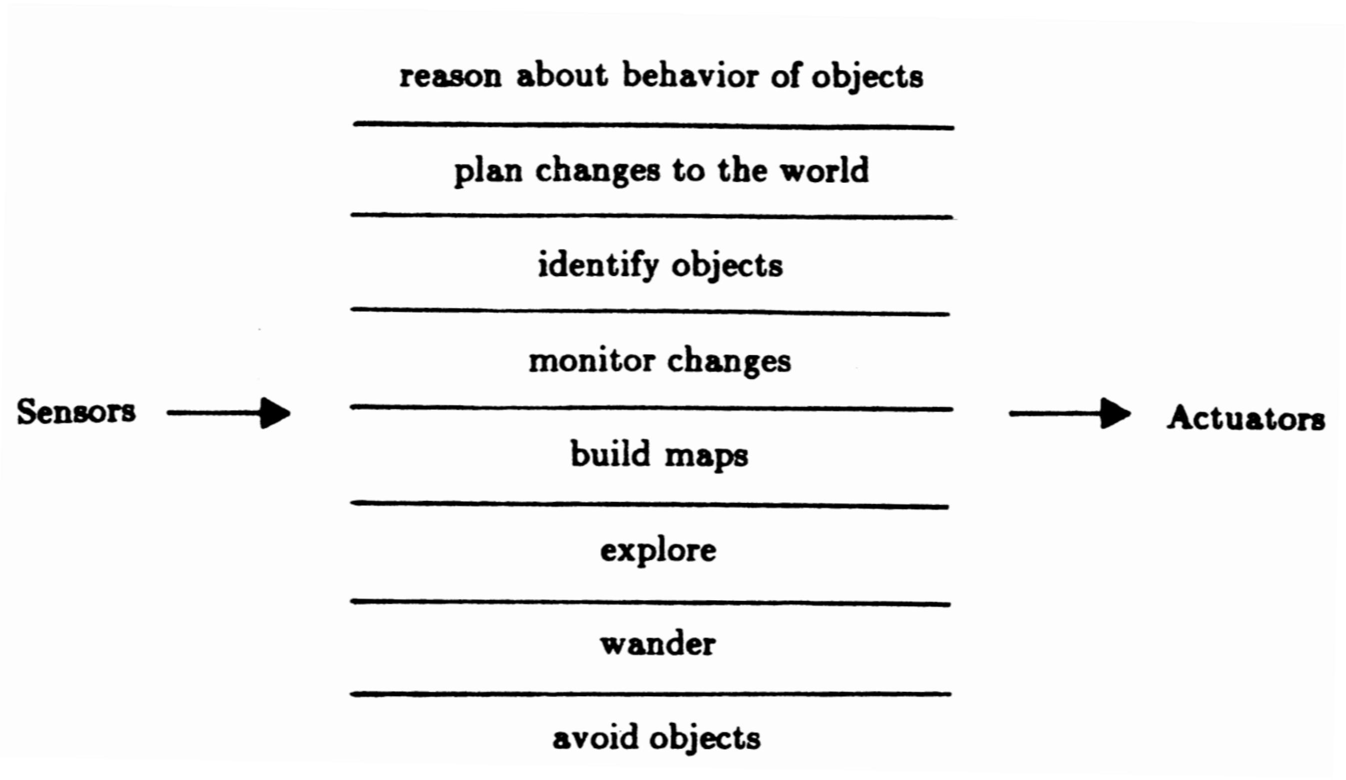
- Perception takes too long
- Perception is still not a solved problem
- Modeling/planning component assumes complete models available
- Overall system cannot respond in real-time
- Most robots built this way have failed



Hirozontal vs. Vertical Decomposition

Decompose overall control system into a layered set of reactive behaviors

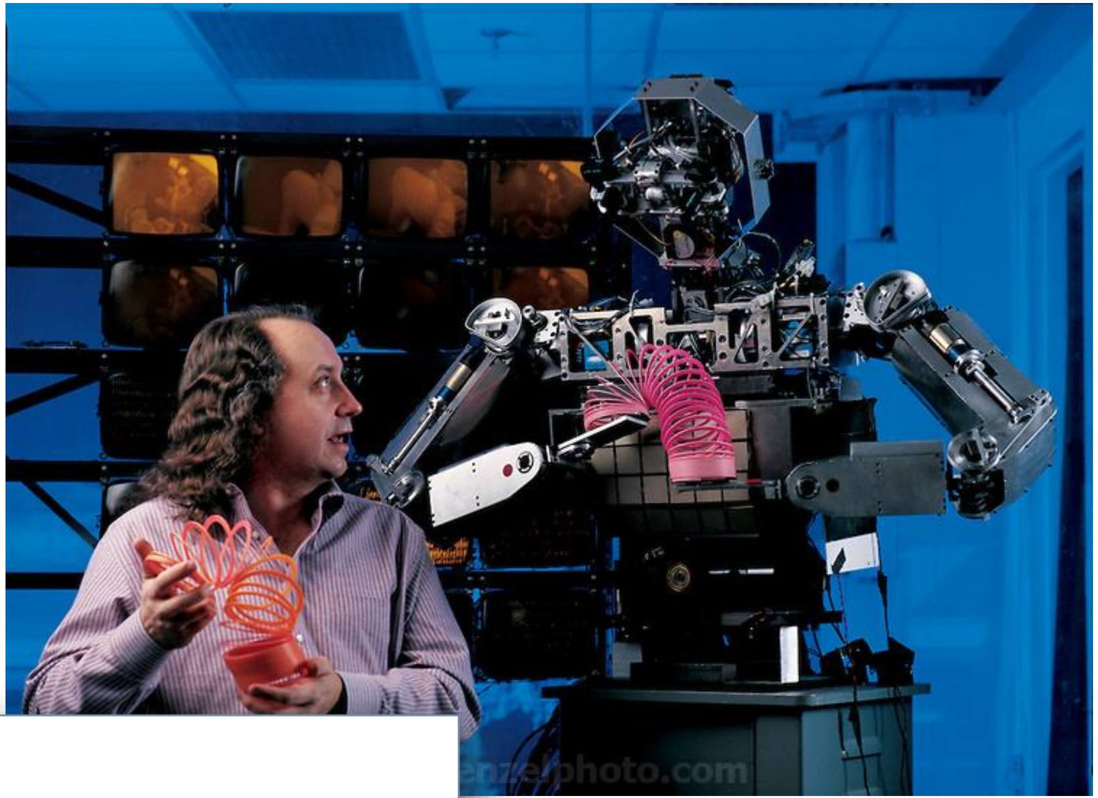
- Each behavior represents a complete mapping from sensors to motor commands
- Low-level behaviors (e.g. avoid) run in real-time since they use little computation
- Requires arbitration strategy to choose among (or combine) conflicting behaviors
- High-level behaviors are invoked only when necessary



Hirozontal vs. Vertical Decomposition

Rodney Brooks has put forward three theses:

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



Intelligence without representation*

Rodney A. Brooks

MIT Artificial Intelligence Laboratory, 545 Technology Square, Rm. 836, Cambridge, MA 02139, USA

Received September 1987

Brooks, R.A., Intelligence without representation, Artificial Intelligence 47 (1991), 139–159.

The Subsumption Architecture

Complex behavior needs not necessarily be a product of a complex control system

- Absolute coordinate systems are a source of error
- Relational maps are more useful to a mobile robot
- Able to function when one or more of its sensors fails recovery should be quick
- Robots should be autonomous and self-sustaining

To illustrate his ideas, Brooks built some based on his subsumption architecture:

- A subsumption architecture is a hierarchy of task-accomplishing behaviors
- Each behavior is a rather simple rule-like structure
- Each behavior ‘competes’ with others to exercise control over the agent
- Lower layers represent more primitive kinds of behavior (such as avoiding obstacles), and have precedence over layers further up the hierarchy

Subsumption Architecture Principles

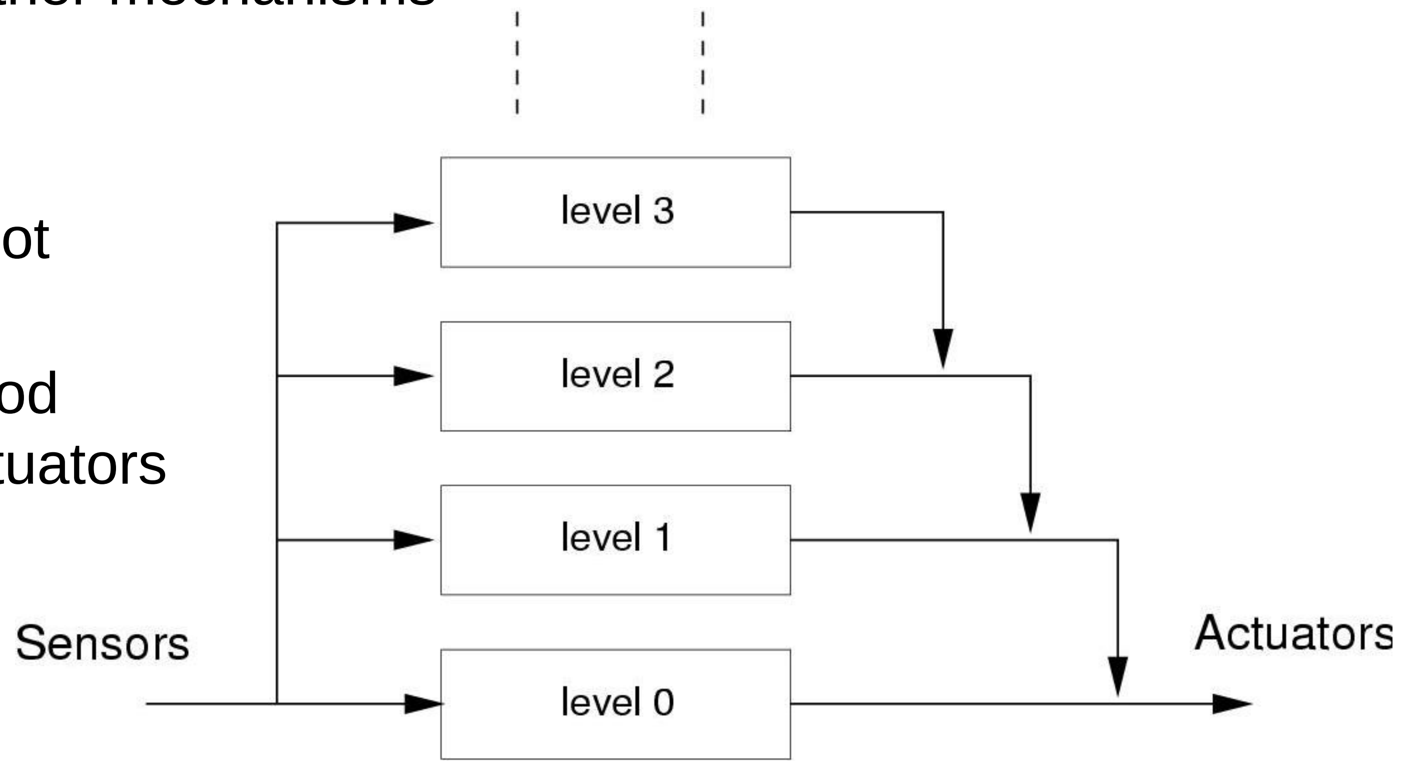
A complex system has precursor in a simpler one

- The offspring contains the same mechanisms of the father with something more
- The offspring sussumes the father mechanisms

The Subsumption Architecture is:

- A layering methodology for robot control systems
- A parallel and distributed method for connecting sensors and actuators

Each level sussumes as a subsystem the previous level



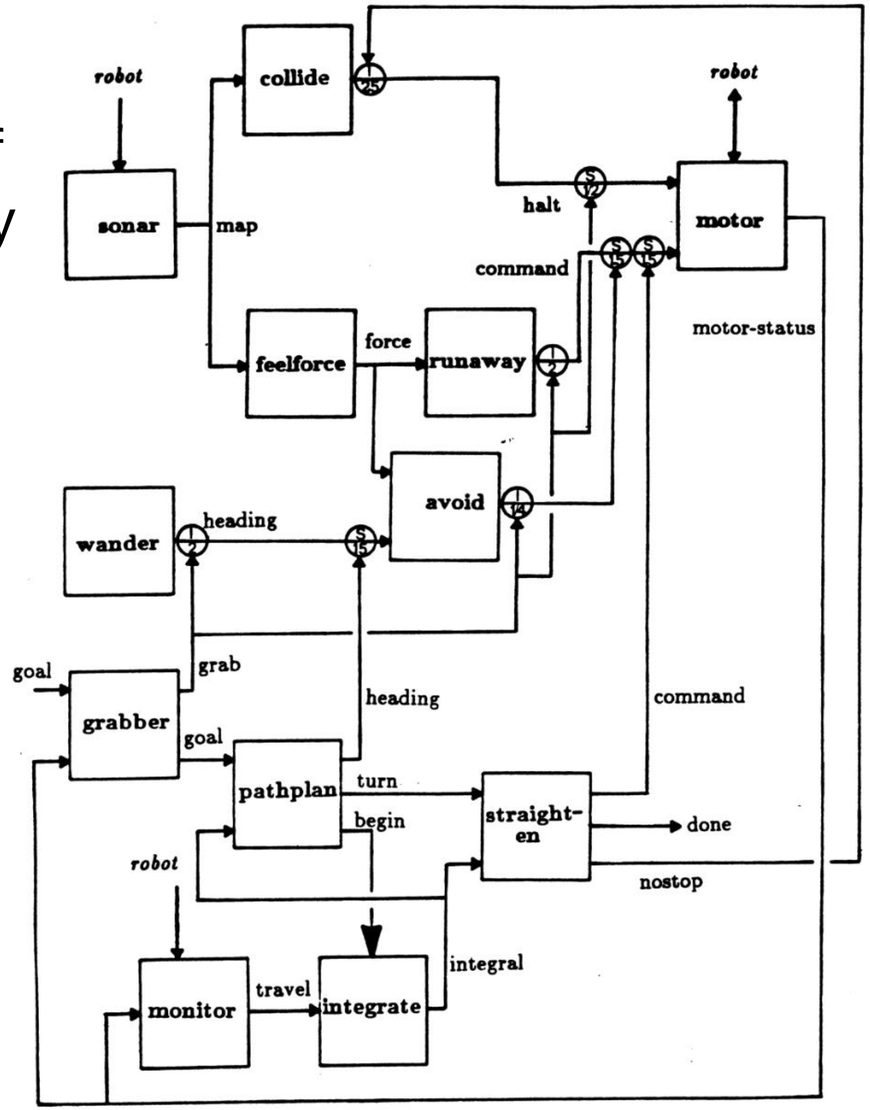
Computation through Augmented Finite State Machines

Computation is organized as an asynchronous network of active computational elements (AFSM) with fixed topology

- Messages have no implicit semantics, just few bits
- Message meanings are dependent on the dynamics designed into both the sender and receiver
- Sensors and actuators are connected through asynchronous two-sided buffers.
- Only internal timers

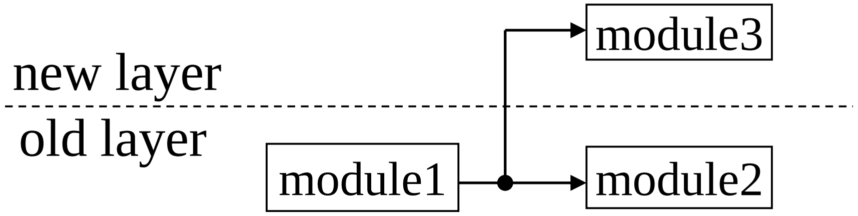
The system is broken down into parallel behaviors

- Each behavior has direct access to sensor readings and can control the robot's motors directly

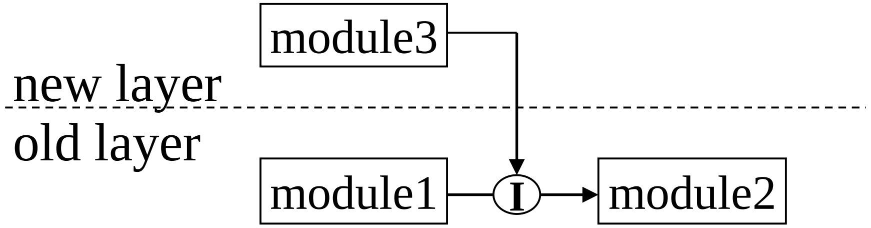


Communication among AFSMs

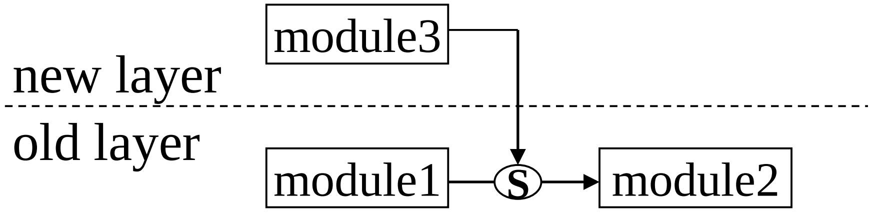
A new layer **monitors** messages in the previous layer using the same connection



It can **inhibit** the communication for a given time (e.g., 40 ms)



It can **substitute** the message for a limited time (40 ms)

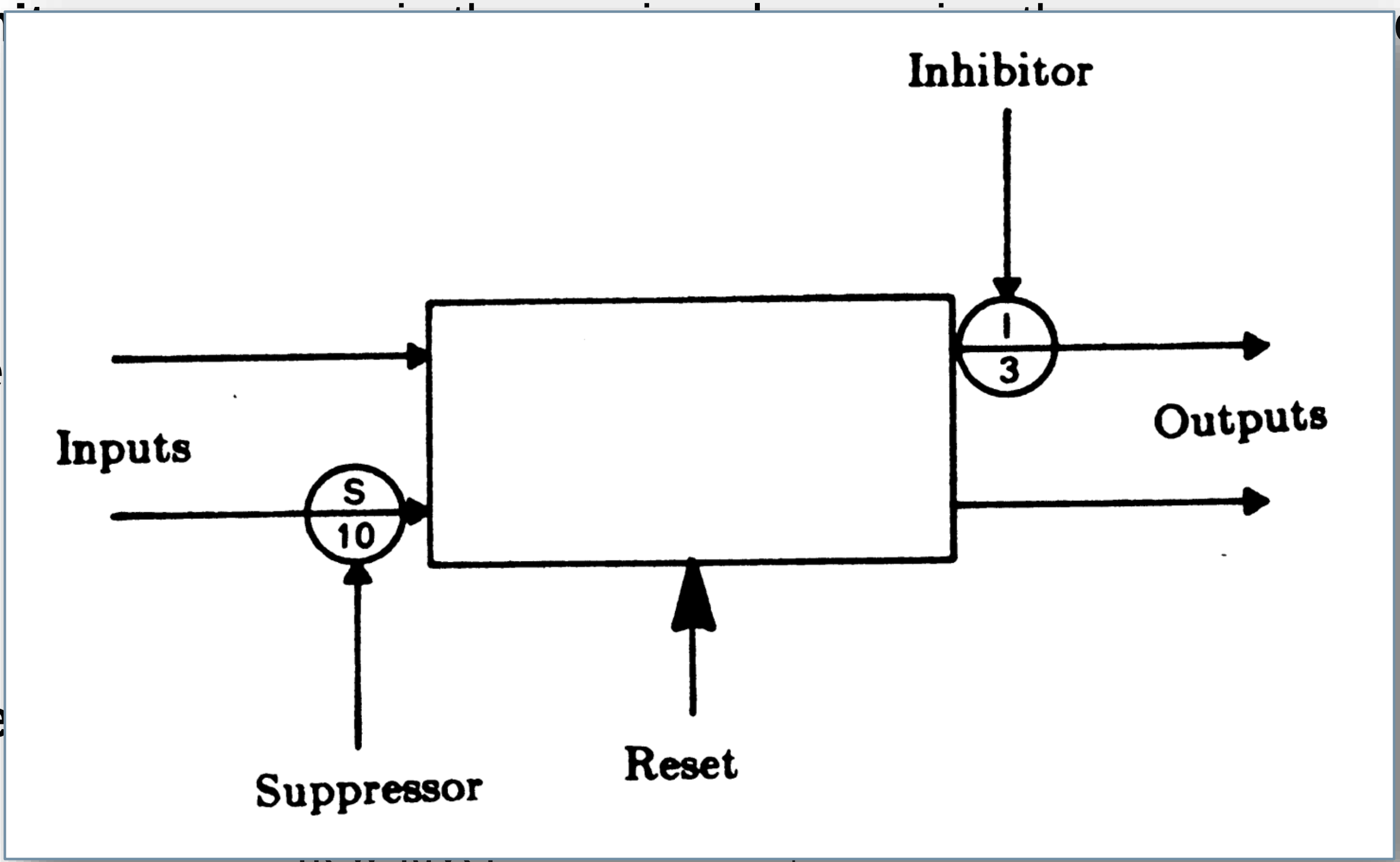


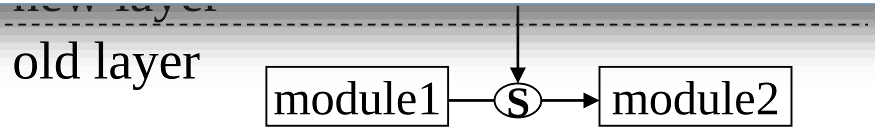
Communication among AFSMs

A new layer **mon** ... ction

It can **inhibit** the

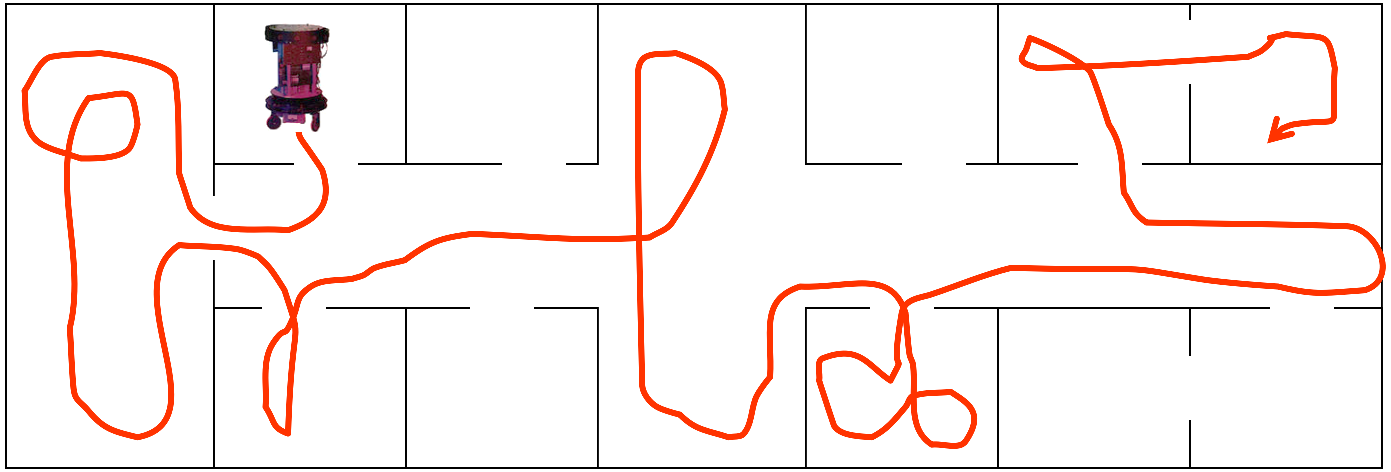
It can **substitute**

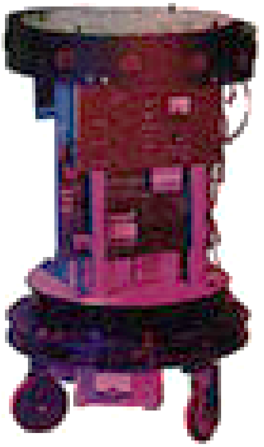


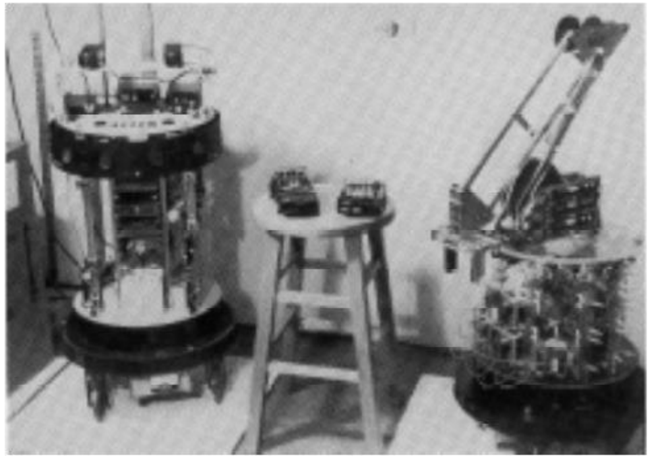


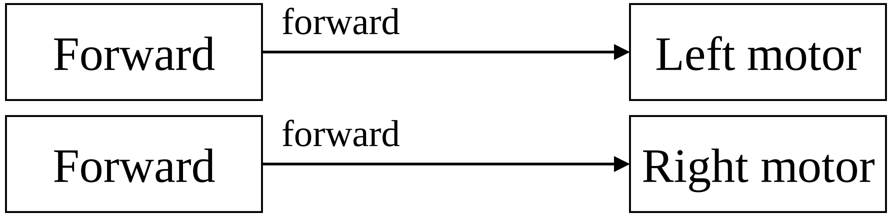
Example: Allen

1. *The robot moves only forward*



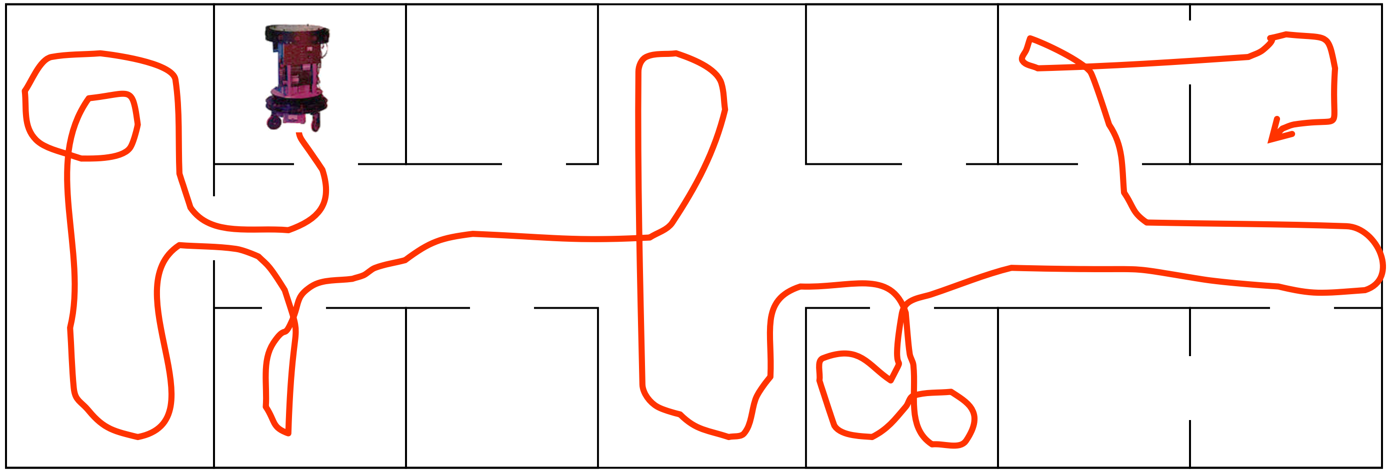


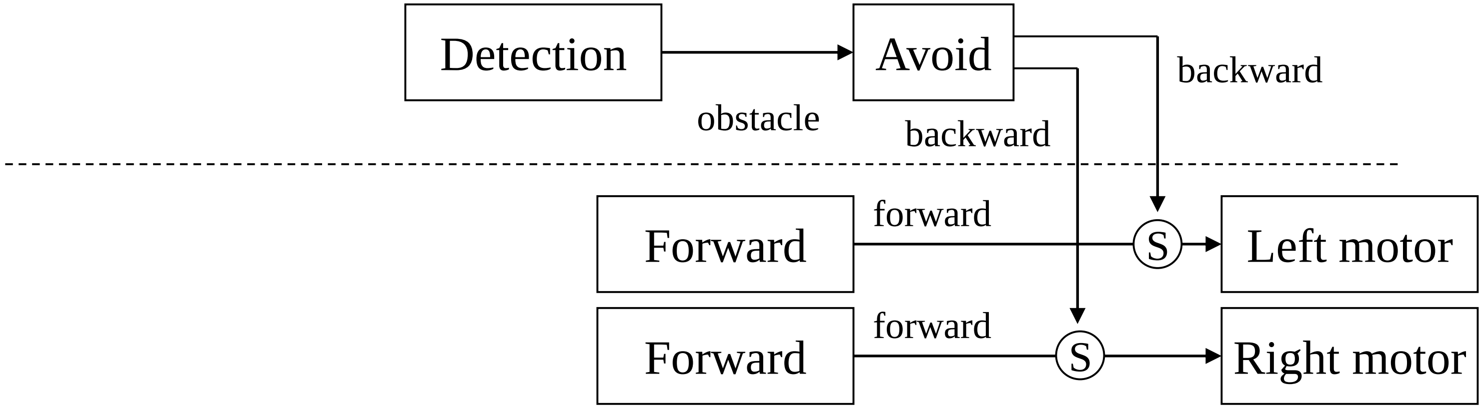




Example: Allen

1. *The robot moves only forward*
2. *A new layer to look for obstacles. If obstacle detected, one wheel backwards to change direction.*





Example: Allen

1. *The robot moves only forward*
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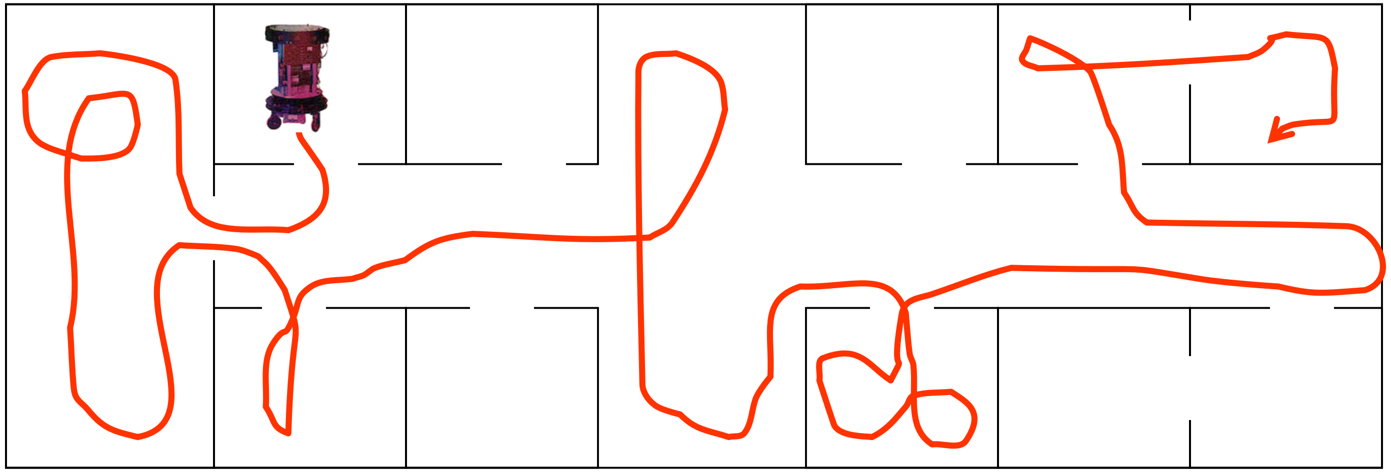
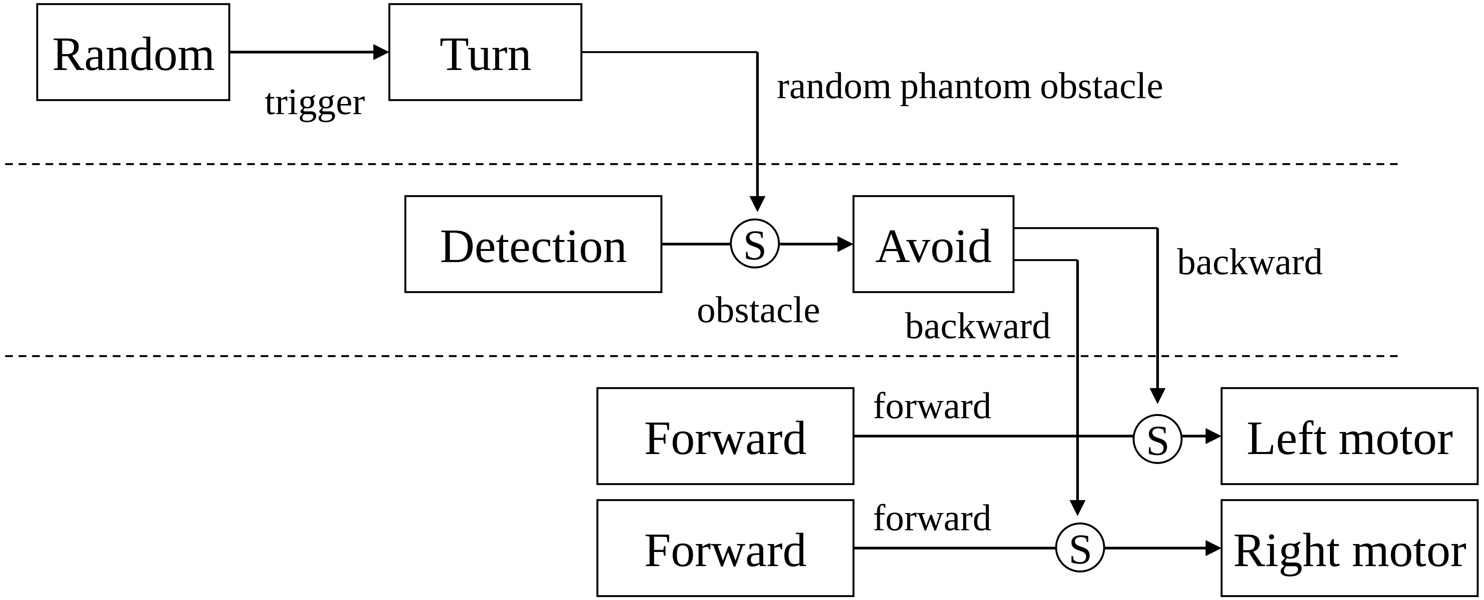
3. *To avoid the robot continues to move in a small region, a new level will introduce random "phantoms" to make the robot change direction*





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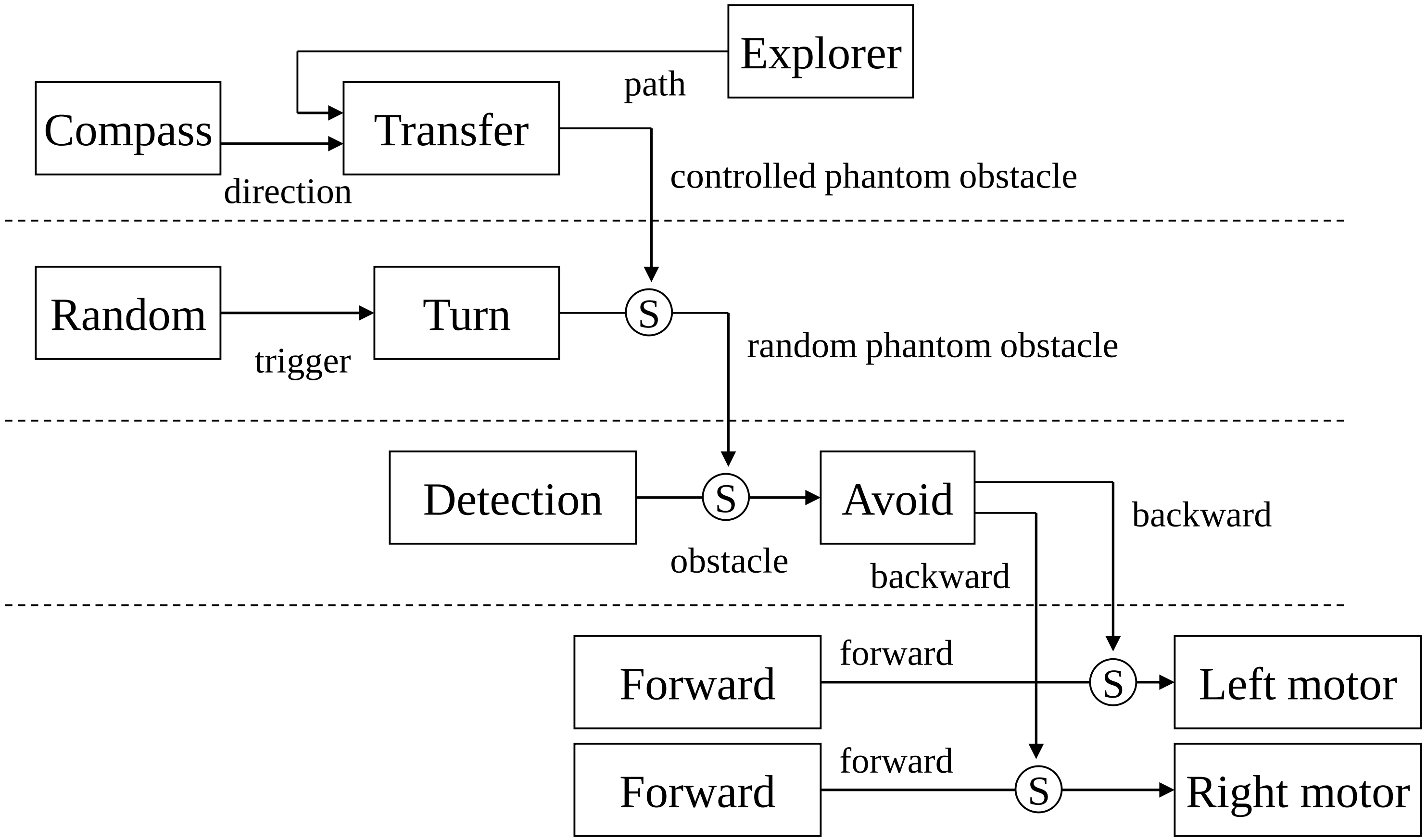
4. *To follow a wanted direction, we control the phantom obstacle*



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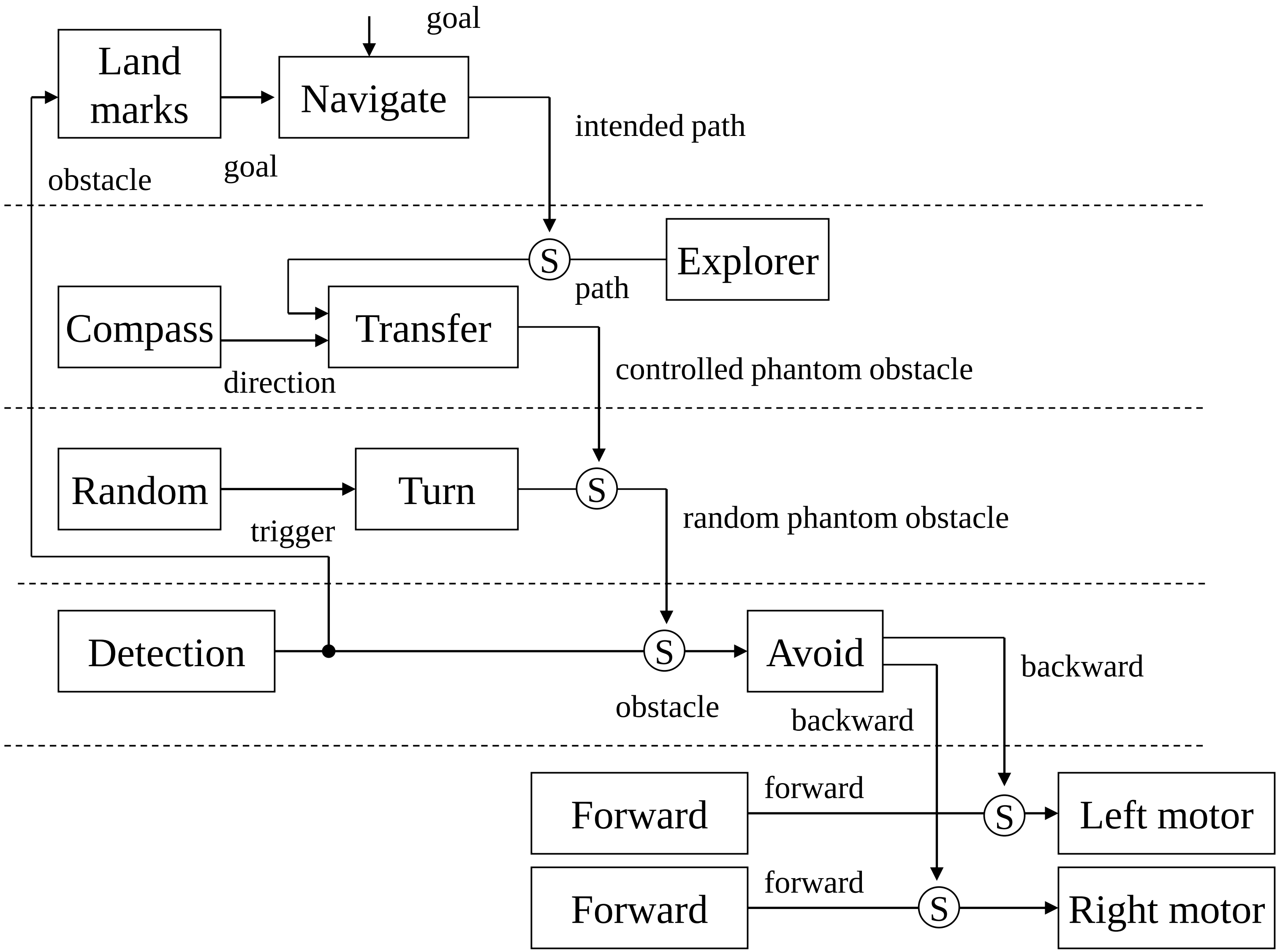
3. *To avoid the robot continues to move in a small region, a new level will introduce random "phantoms" to make the robot change direction*
4. *To follow a wanted direction, we control the phantom obstacle*
5. *Find landmarks. The user sends a direction, the robot moves toward the landmark*



Behavior Design

"The world really is a rather good model of itself"

- No internal model of the real world (No free communication, No shared memory)
- Use real world as the model (Very accurate, Never out of date,
  No computation needed to keep model up to date, Real world used for sub-system communication because sub-systems just sense the real world)

Nevertheless behavior design is more an art than a science

- In what situation does the behavior apply?
- What is the result of the behavior?
- What robustness can we expect?
- What is the real scalability of the approach?

The emergent behavior is difficult to predict!

Example: herbert

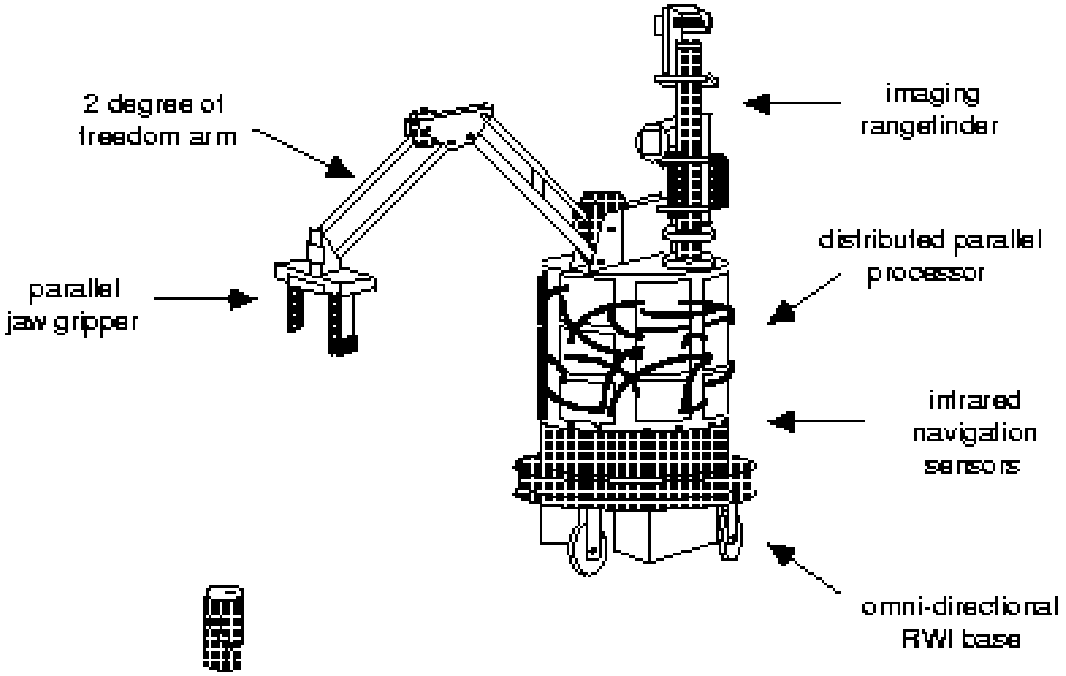
MIT AI Lab in 1988

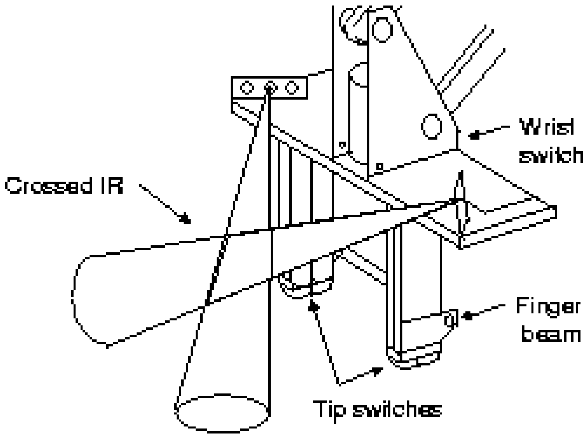
Primary Goal

- To wander in the office following walls and avoiding obstacles
- Look for soda-like objects, pick it up and drop it at a base location

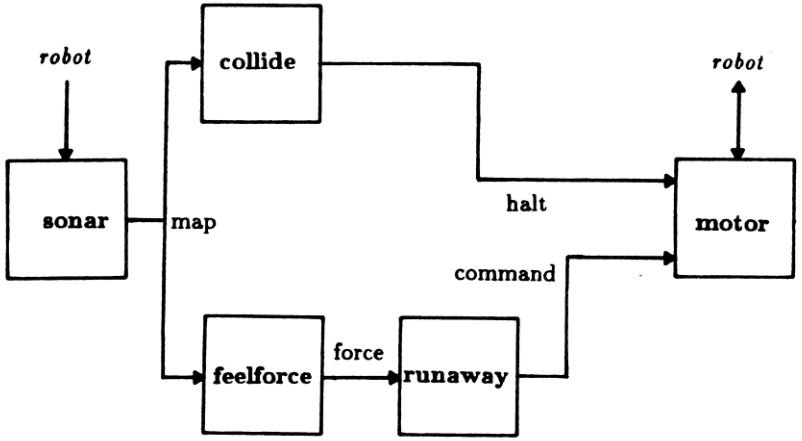
Sensors

- vision and a laser striper to find soda cans, and sonars and IRs to wander around safely.



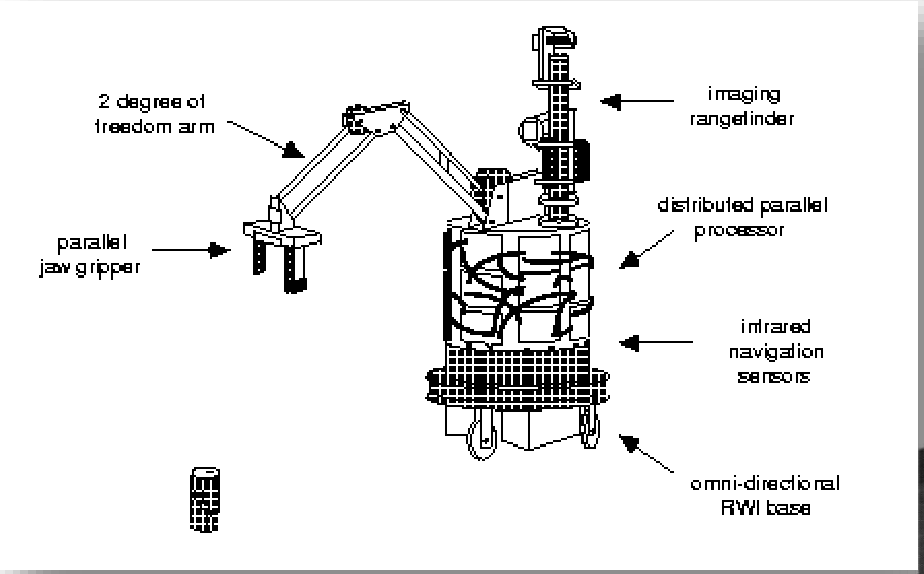


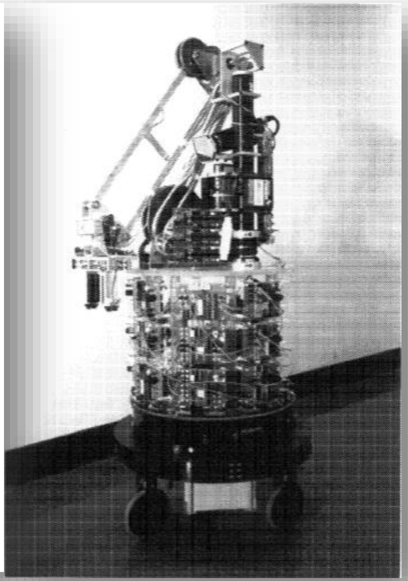
Example: Herbert



Allen was first Brook's subsumption robot

- Lev. 0: Runs away if approached, Avoids objects





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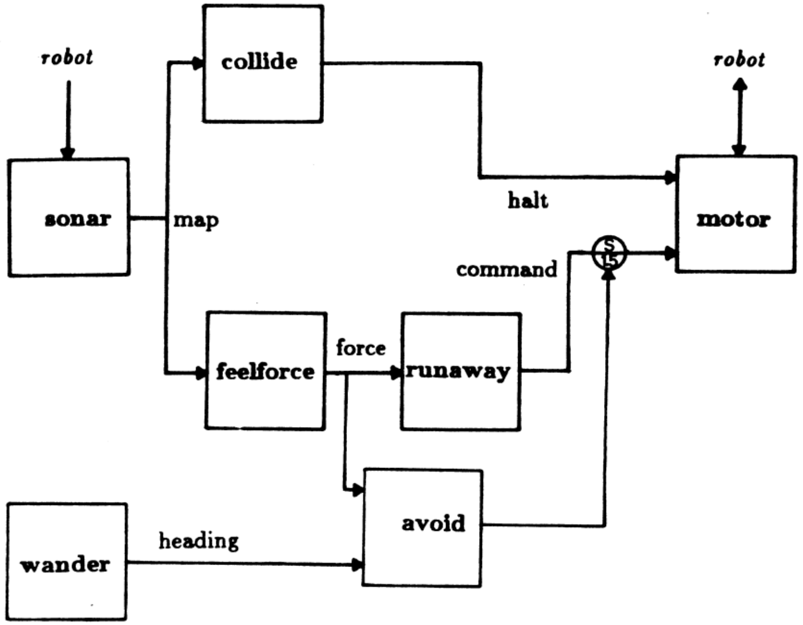
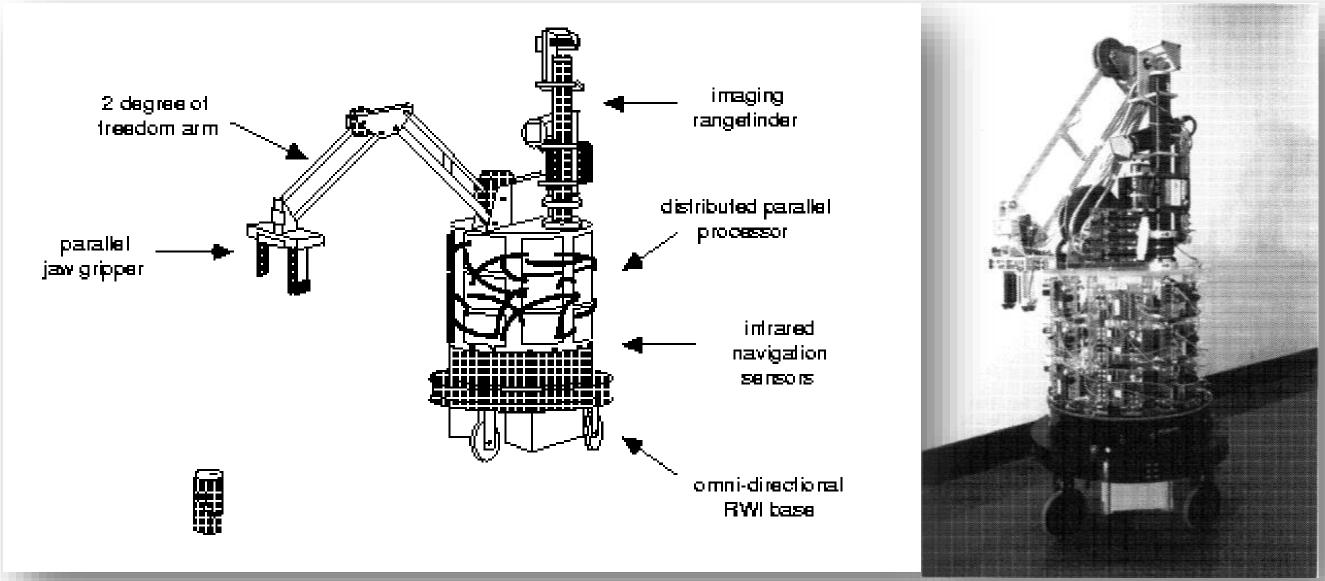


Allen was first Brook's subsumption robot

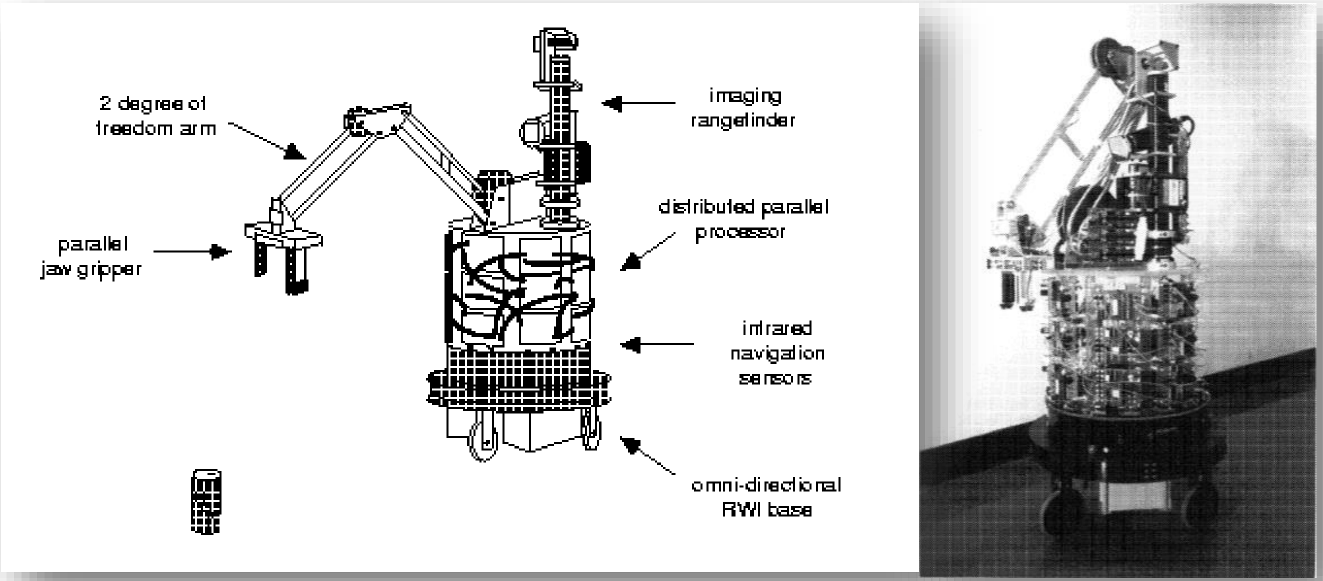
- Lev. 0: Runs away if approached, Avoids objects
- Lev. 1: Adds Wandering

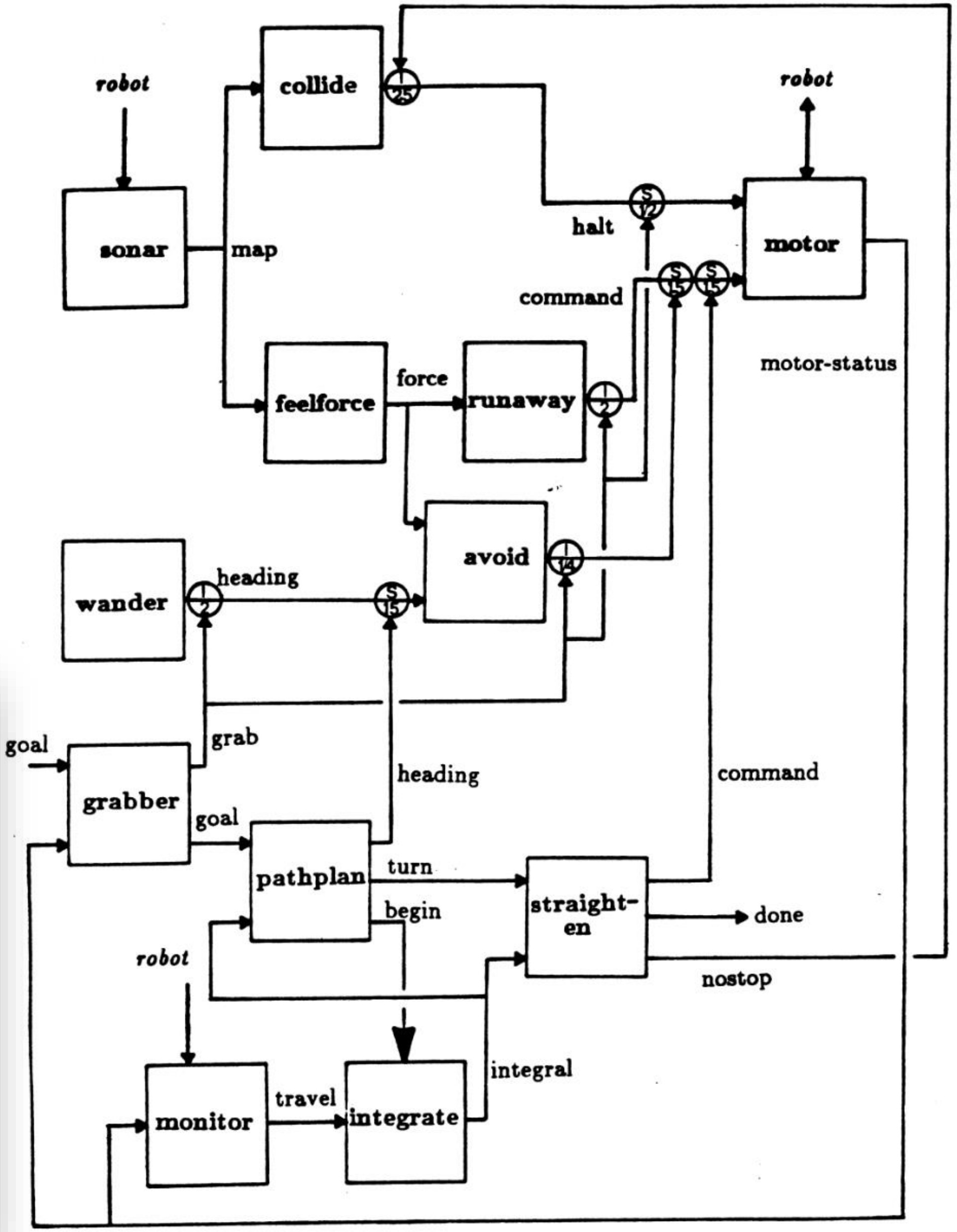


Example: Herbert

Allen was first Brook's subsumption robot

- Lev. 0: Runs away if approached,
  Avoids objects
- Lev. 1: Adds Wandering
- Lev. 2: Adds hallway following & grasping





Example: Herbert

Case 1: Can already between the fingers

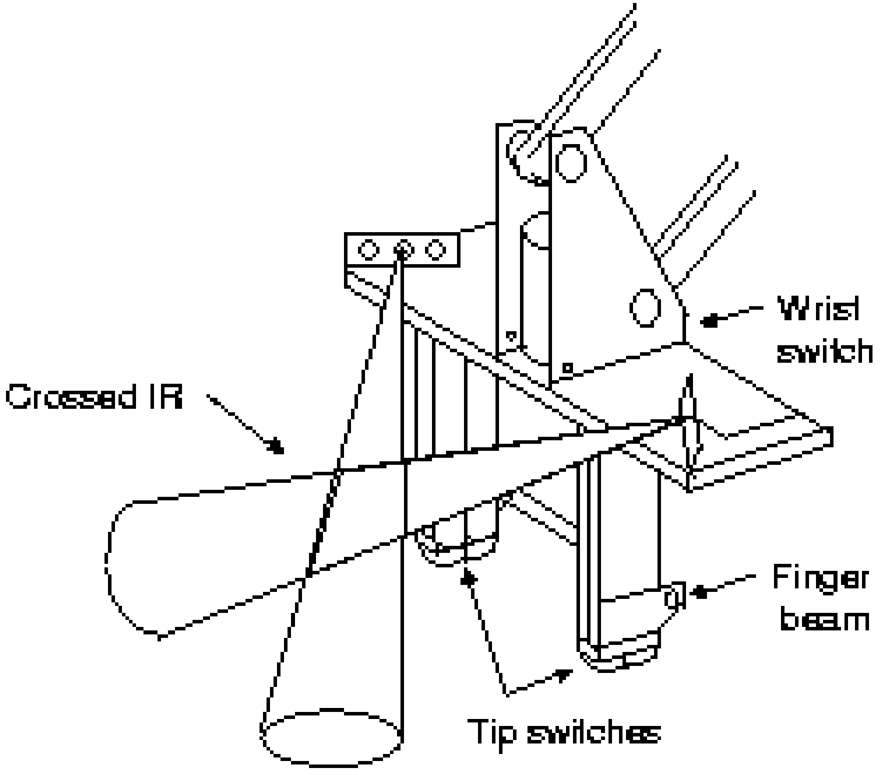
- Identified by the finger beam
- It grips everything that can be placed between the fingers

Case 2: Can placed in front of the hand

- Crossed IR beam identifies the object
- Extend arm till the finger beam is activated
- Hand can knock over the object
- Lift the hand

Case 3: Can is some distance away from hand

- Search for can near the surface than a few feet above
- Cruise the surface where can is placed
- Once IR detects a can, grab it



Subsumption pros and cons

PROS

- Provides a way to incrementally build/test a complex mobile robot control system
- Supports parallel computation in a straightforward, intuitive way
- Avoids centralized control; relies on self-centered and autonomous modules
- Leads to more emergent behavior: “Complex (and useful) behavior may simply be the reflection of a complex environment”

CONS:

- In the development of an individual, new representational structures are developed in response to the environment, not added by an experimenter.
- It would be more impressive if the robot learnt new behavior modules in response to the environment.
- Emphasis in this approach on reacting to the environment, but representations are needed for more complex tasks.