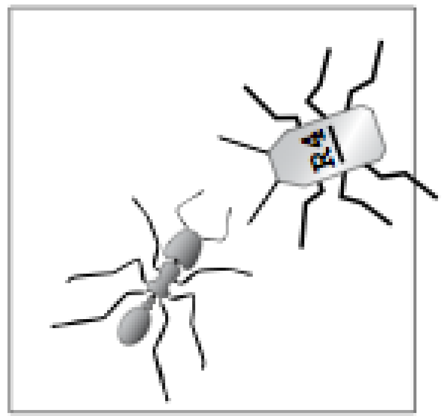
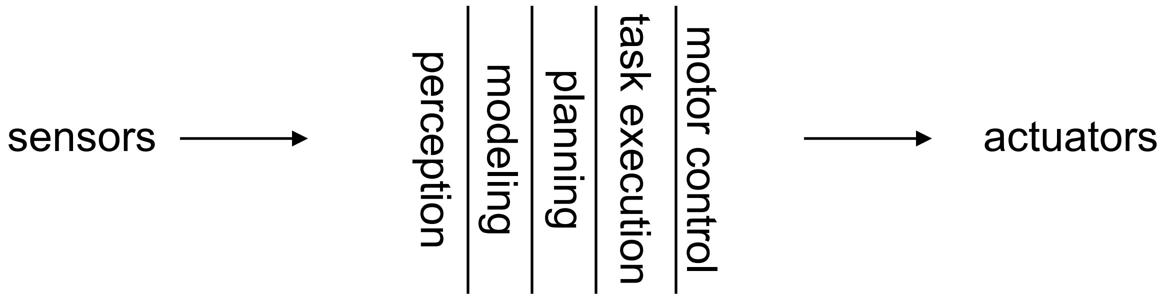
Behavior-Based Robotics



A.I. Robotics

In traditional Artificial Intelligence robot brains are serial processing units.

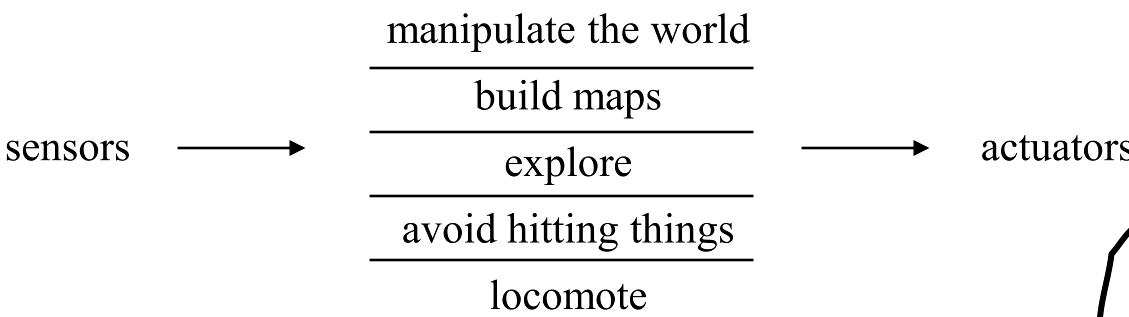


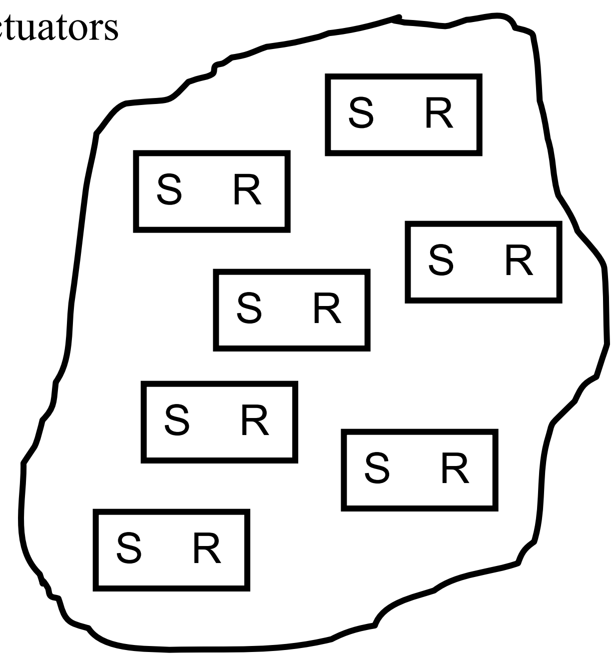
The keystone ideas behind this approach are:

- Representations, Reasoning, Planning
- Model Building (for example, geometric maps)
- Functional Decomposition, Hierarchical systems
- Symbol manipulation

Behavior-Based Robotics *(Brooks, 1996)*

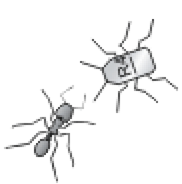
The Behavior-Based approach states that intelligence is the result of the interaction among an asynchronous set of behaviors and the environment.





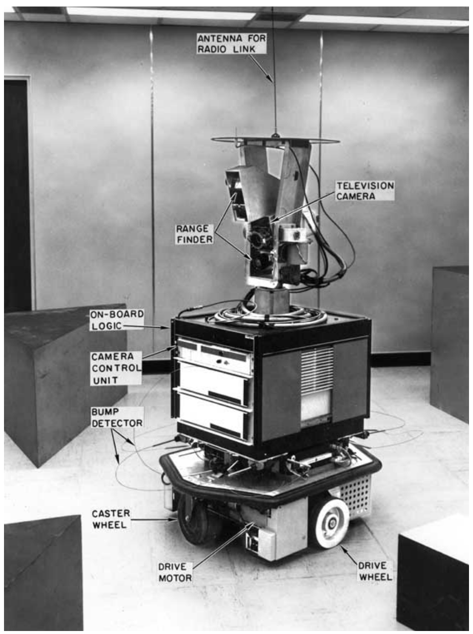
The keystone ideas behind this approach are:

- Embodiment
- Situatedness
- Emergent complexity
- No planning



A Paradigm Shift

- Thinking and reasoning → Acting and behaving
- Seat of intelligence: brain → Seat of intelligence: organism
- Artificial Intelligence → Artificial Life
- Information processing → Sensory-motor coordination
- Cartesian thinking → Agent-centered; action based



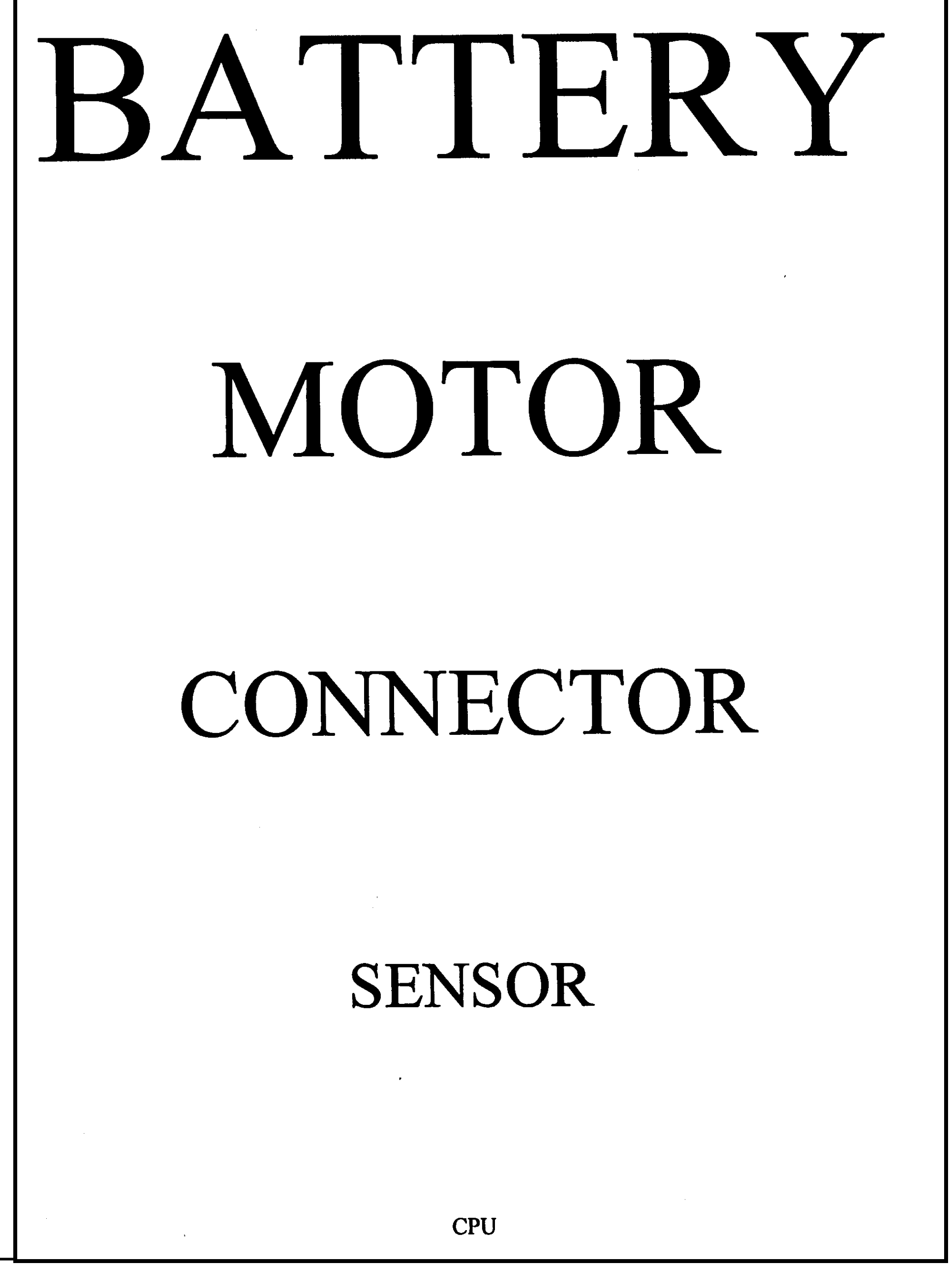
Shakey, 1970, Stanford

Behavior-Based paradigm affects both software and hardware design

Ghenghis, 1985, MIT

Priorities for Robotics

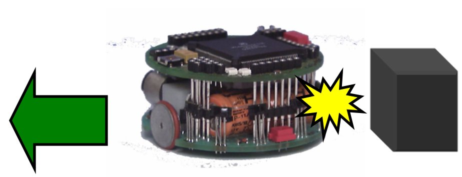
From Brooks, 1998



A behavior

- A behavior is a reaction to a stimulus

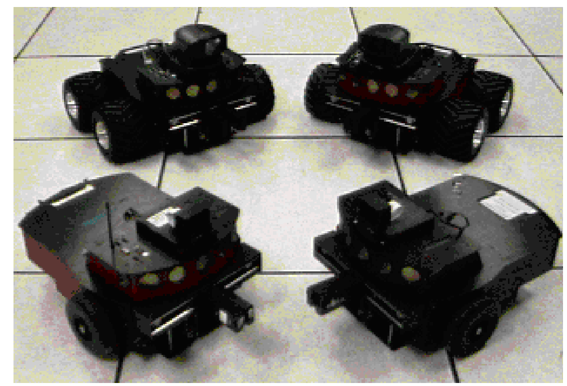
stimulus ⟶ **BEHAVIOR** ⟶ response



TURN-RIGHT

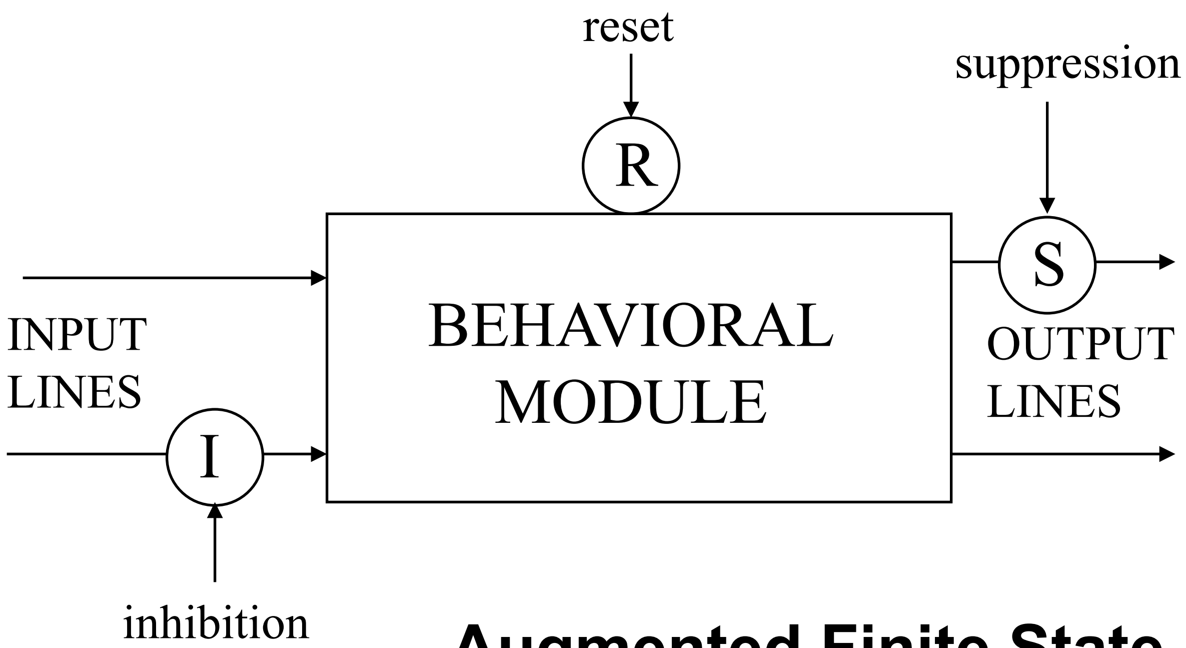
Examples of behaviors

- **Exploration/directional behaviors (move in a general direction)**
  heading based, wandering
- **Goal-oriented appetitive behaviors (move towards an attractor)**
  discrete object attractor, area attractor
- **Aversive/protective behaviors (prevent collision)**
  avoid stationary objects, elude moving objects (escape), aggression
- **Path following behaviors (move on a designated path)**
  road following, hallway navigation, stripe following
- **Postural behaviors**
  balance, stability
- **Social/cooperative behaviors**
  sharing, foraging, flocking
- **Perceptual behaviors**
  visual search, ocular reflexes
- **Walking behaviors (for legged robots)**
  gait control
- **Manipulator-specific behaviors (for arm control)**
  reaching, moving
- **Gripper hand behaviors (for object acquisition)**
  grasping

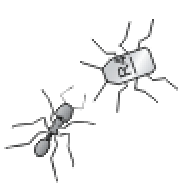


[from Arkin, 1998]

A Behavioral Module *(Brooks, 1986)*



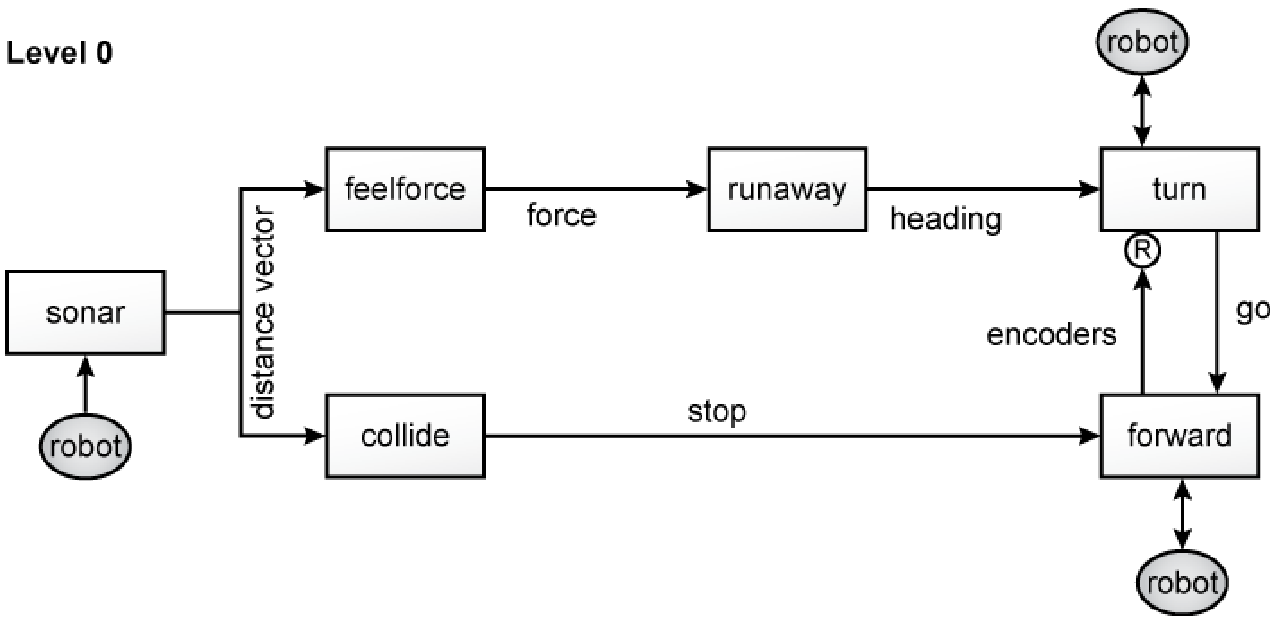
Augmented Finite State Machine
- local computation
- mappable into hardware
- no global clock, memory, bus
- no central models



Subsumption architecture *(Brooks, 1986)*

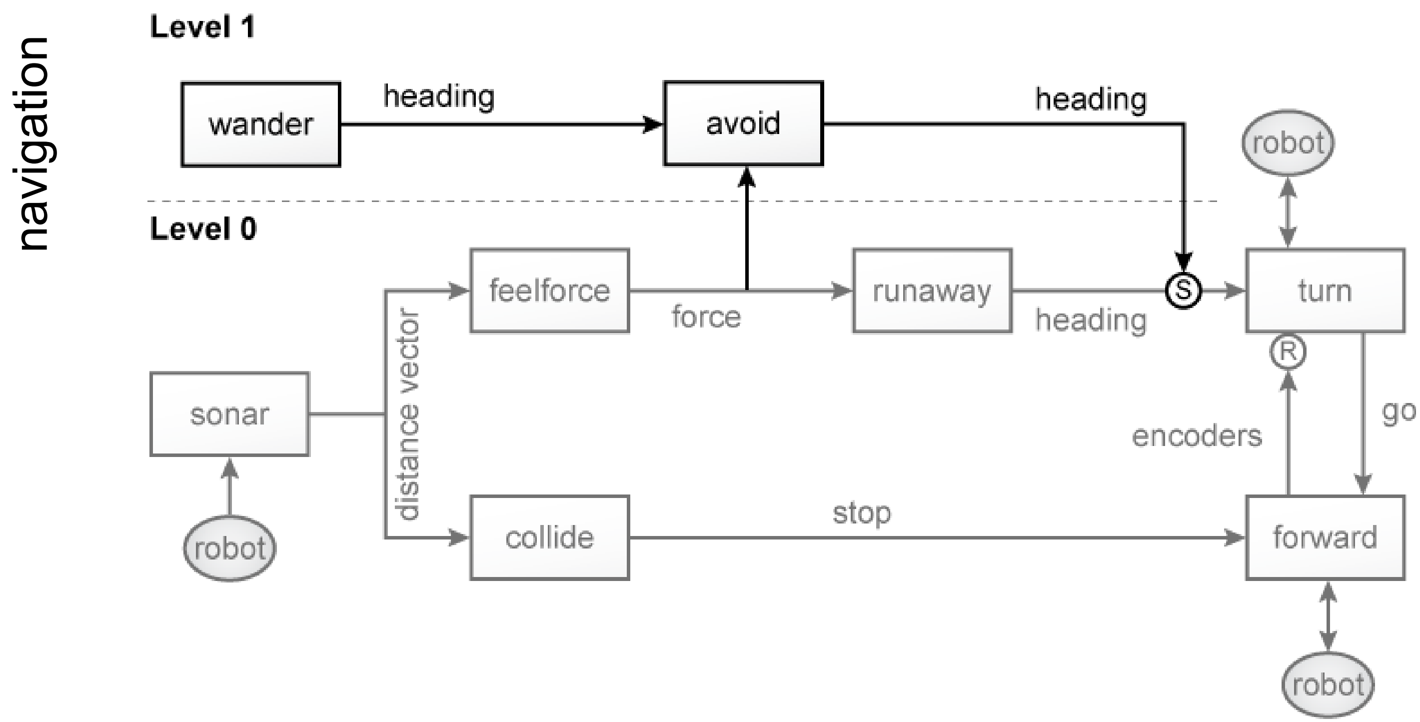
- The architecture is built incrementally
- Start by building in lowest level of competence
- Validate on robot, debug, adjust, validate, adjust, …
- Robot is immediately operational

Collision avoidance

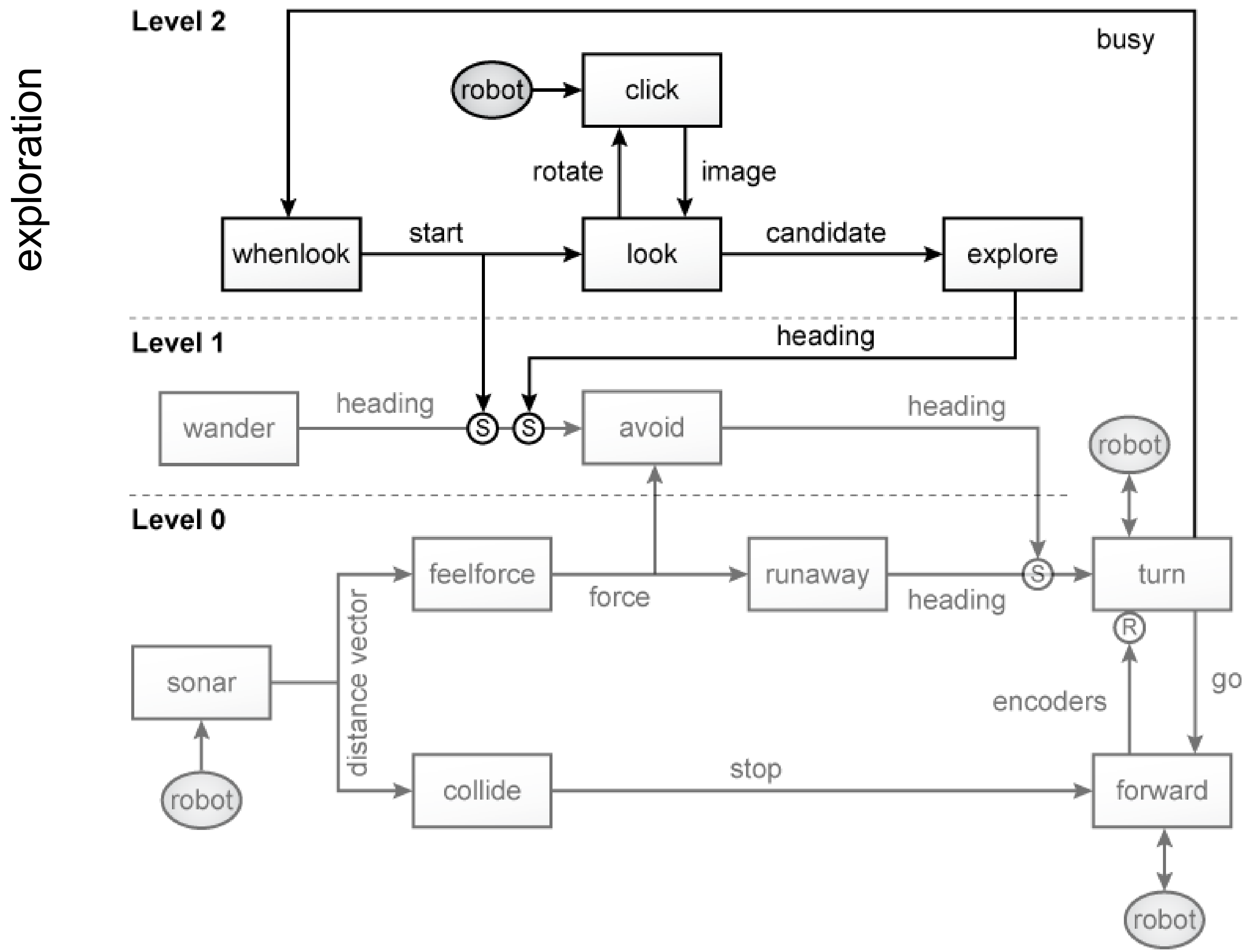


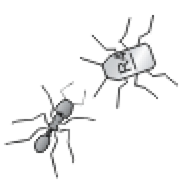
Subsumption architecture *(Brooks, 1986)*

- Novel layer exploits (subsumes) earlier competence
- Earlier behaviors are not modified
- Design, test, debug, adjust, test, adjust,…

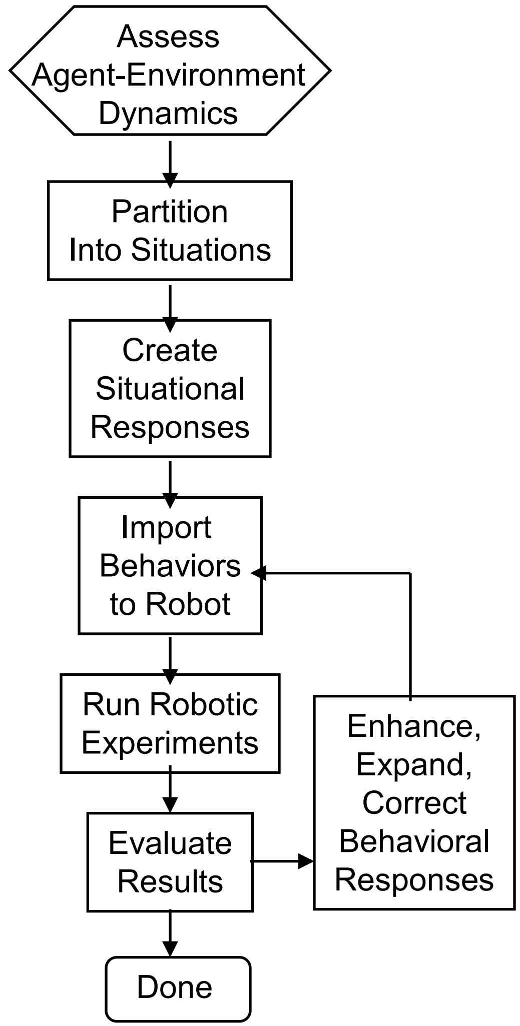


Subsumption architecture (Brooks, 1986)



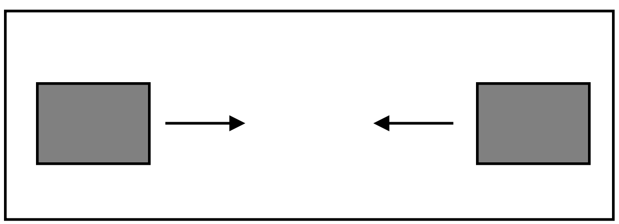


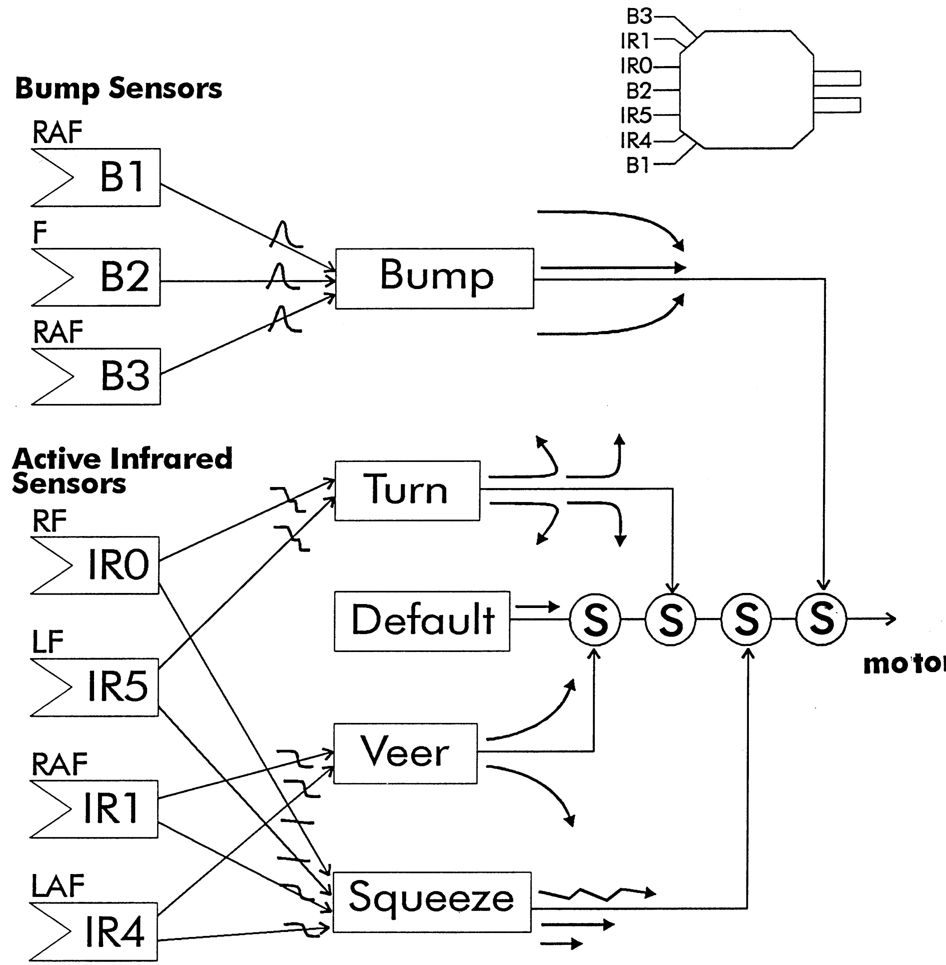
Methodology



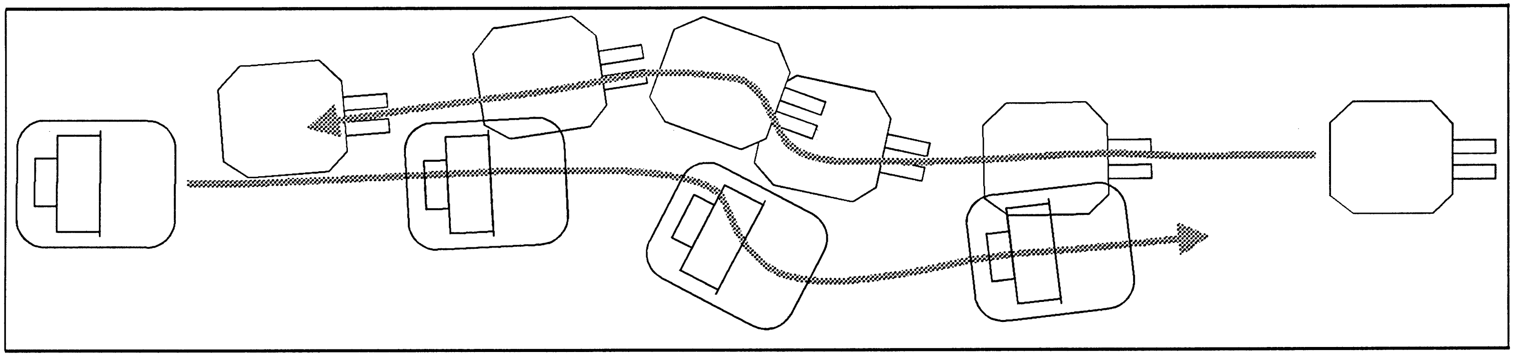
Conflict resolution

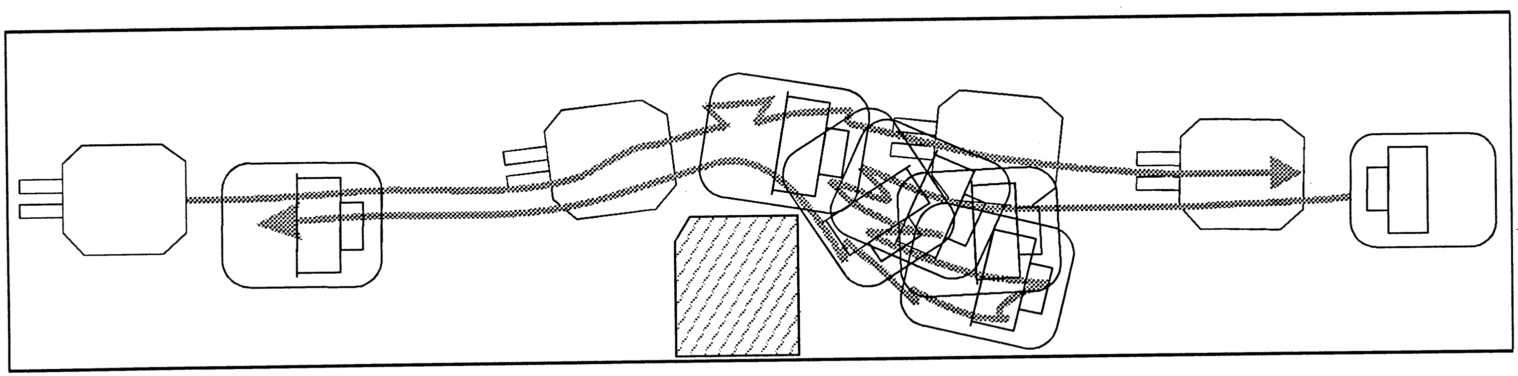
Two robots must get to the opposite end of a narrow corridor.





Behavioral outcome

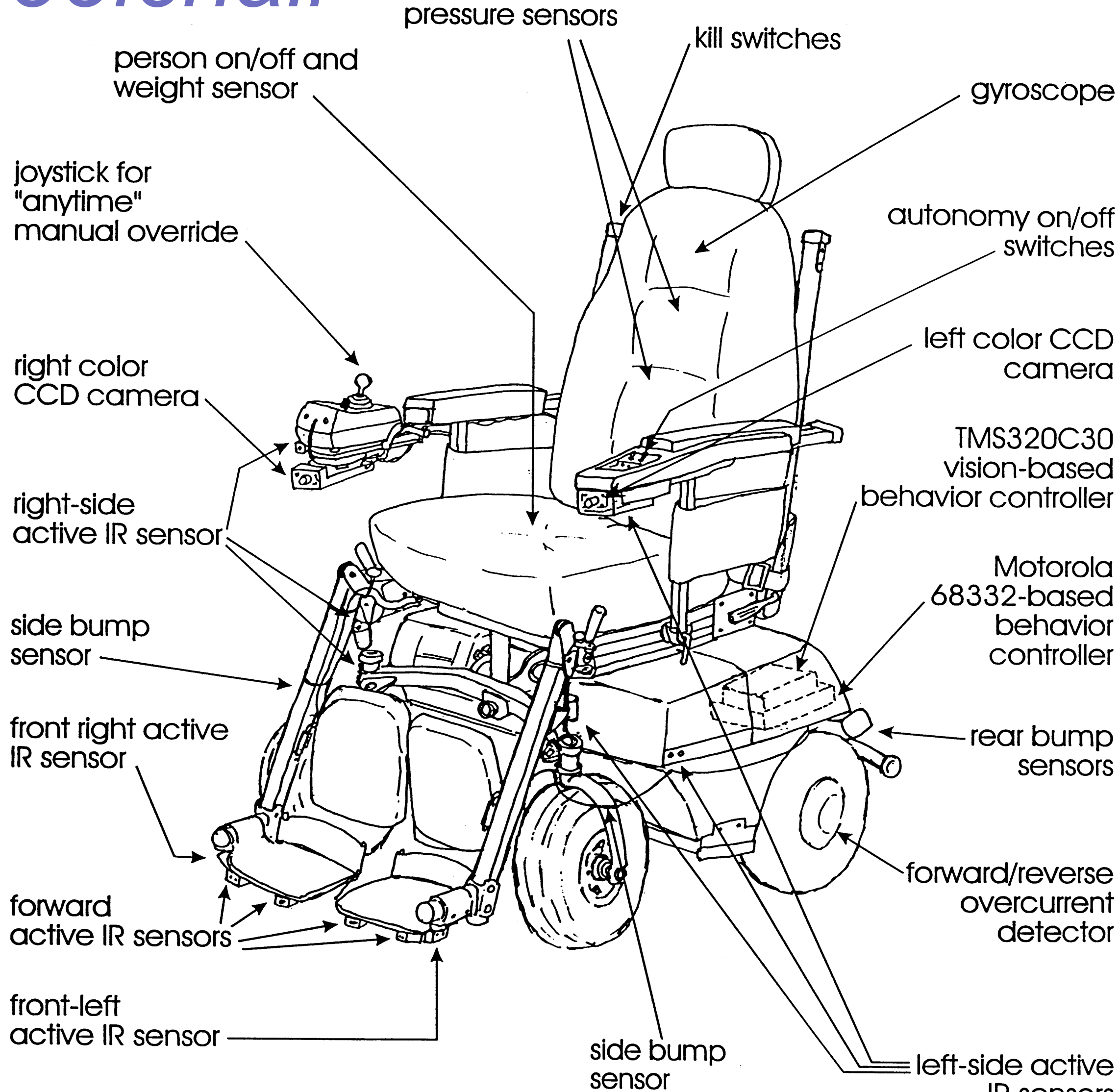




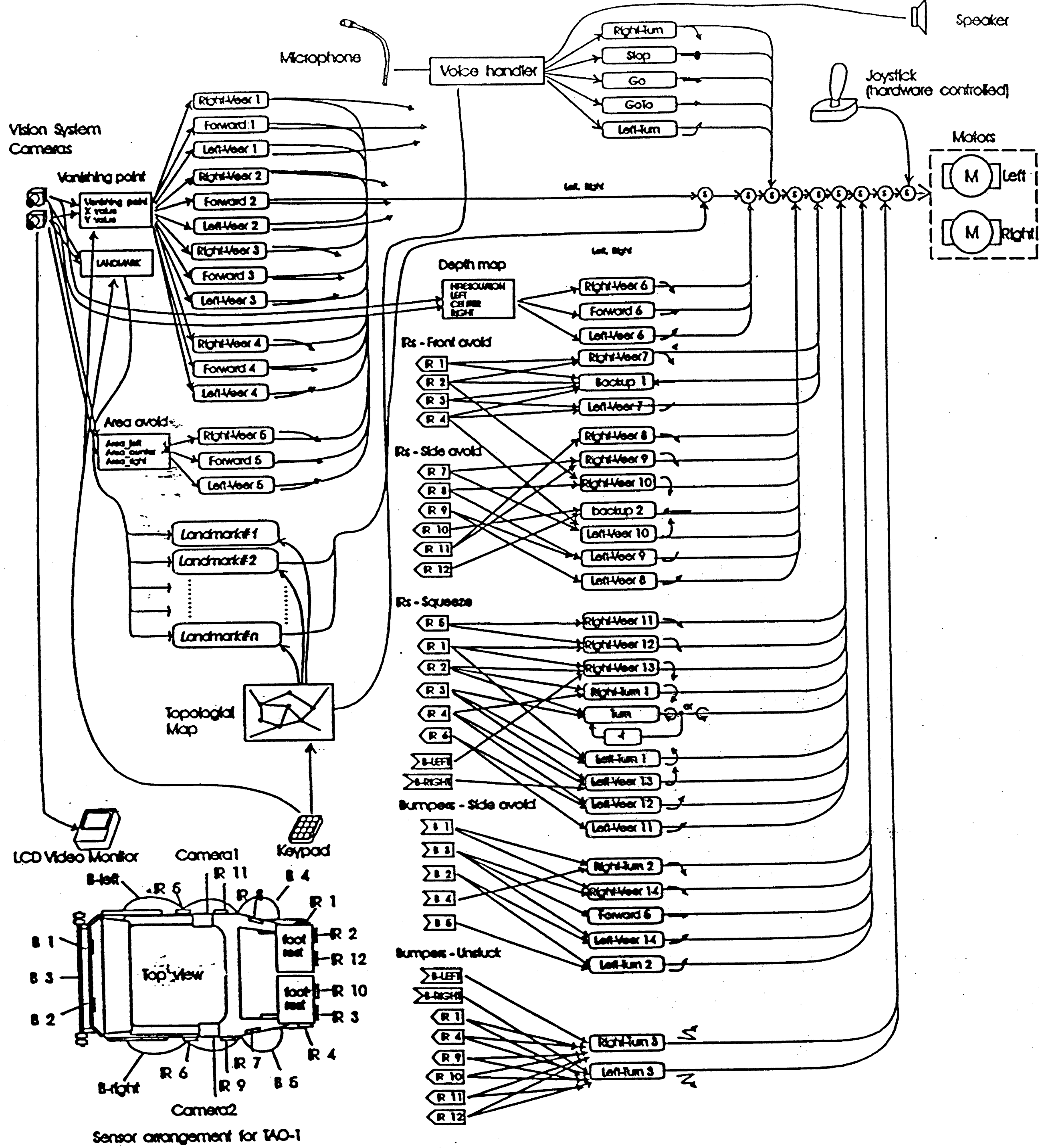
Courtesy of Applied AI Systems, Inc.

Intelligent wheelchair

TAO1 - Courtesy of Applied AI Systems, Inc.

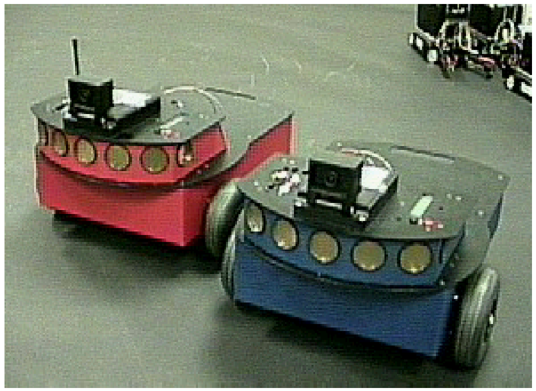


Architecture



Behavior coordination

In addition to Subsumption Architecture, there are a few other ways of coordinating behaviors



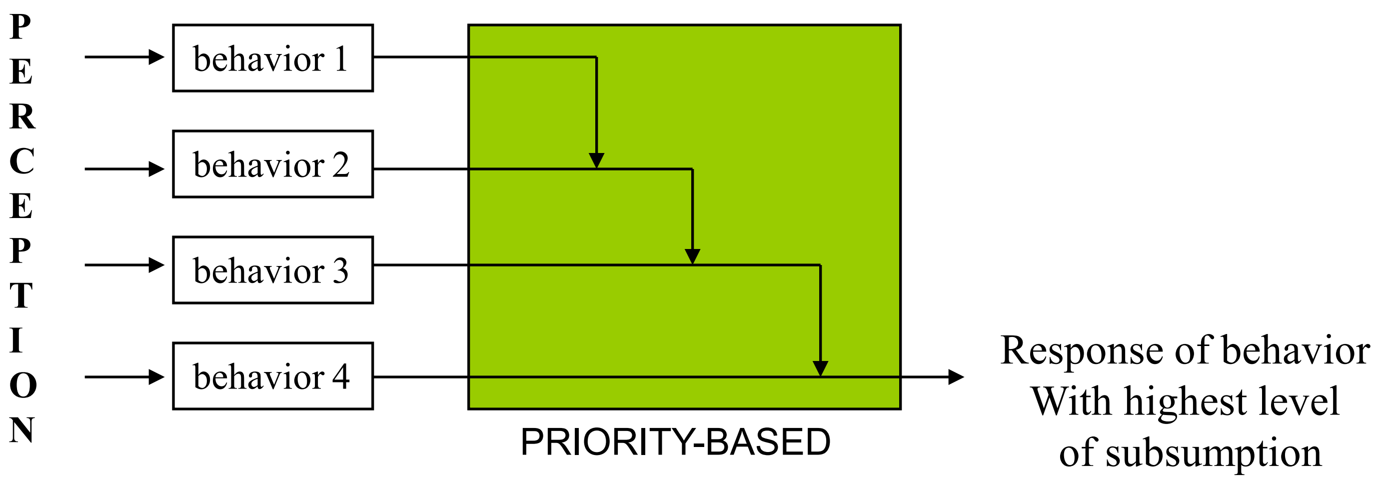
- obstacle avoidance
- seek gas leak
- battery recharge
- tele-operation

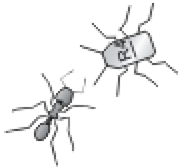
Behavior Coordination

Competitive methods:
priority
action-selection
vote-based

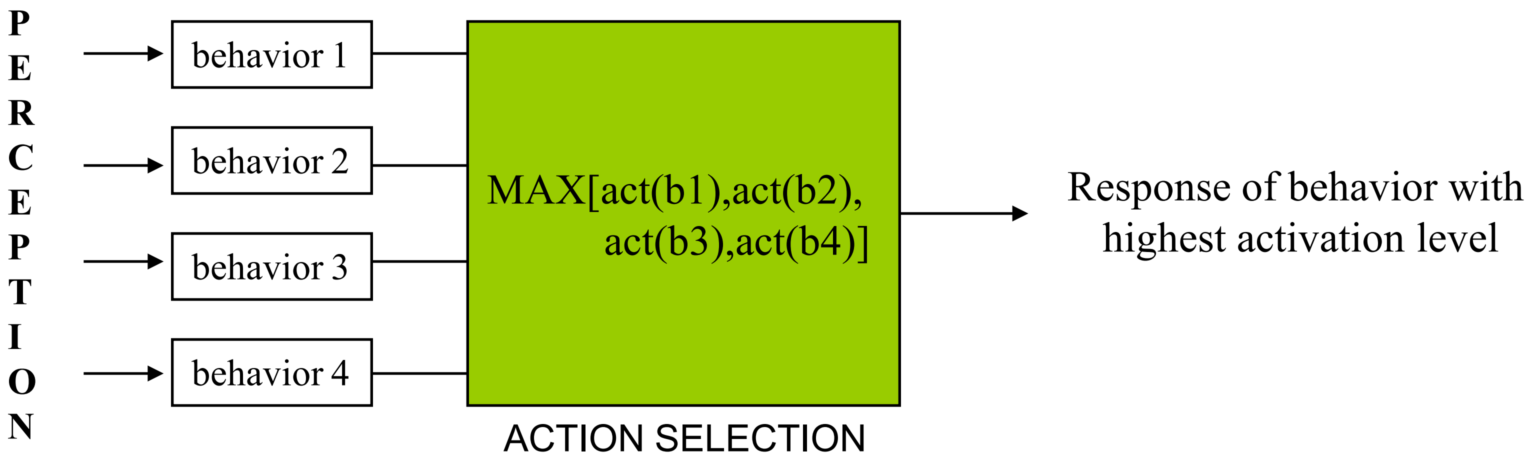
Cooperative methods:
fusion

Priority Based (subsumption)

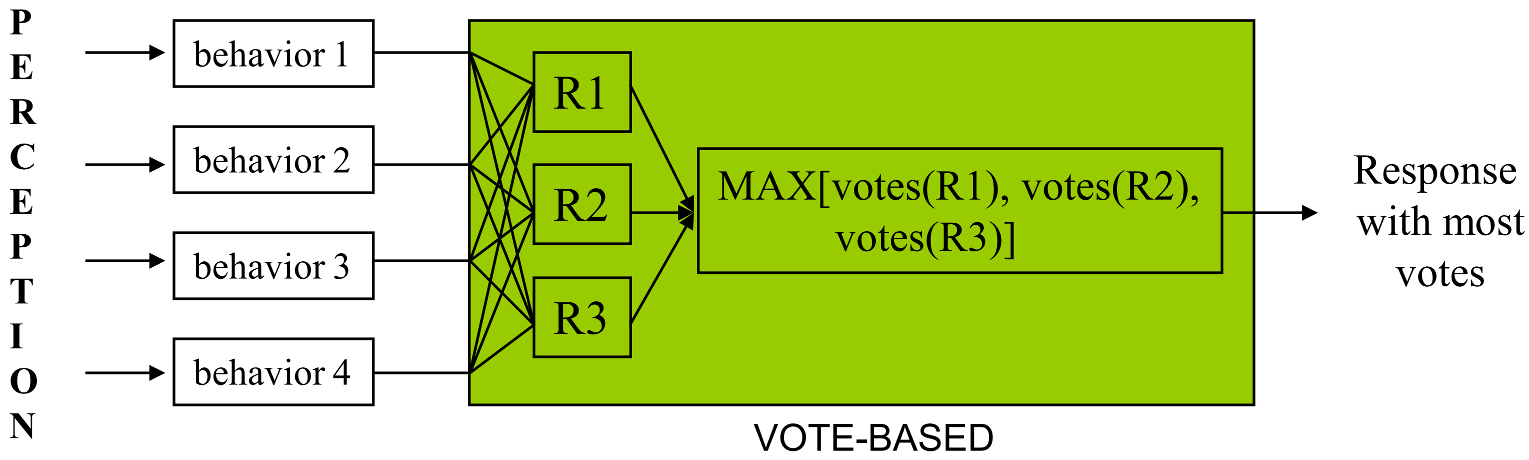


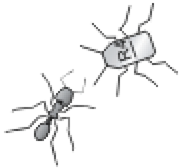


Action Selection *(Maes, 1989)*

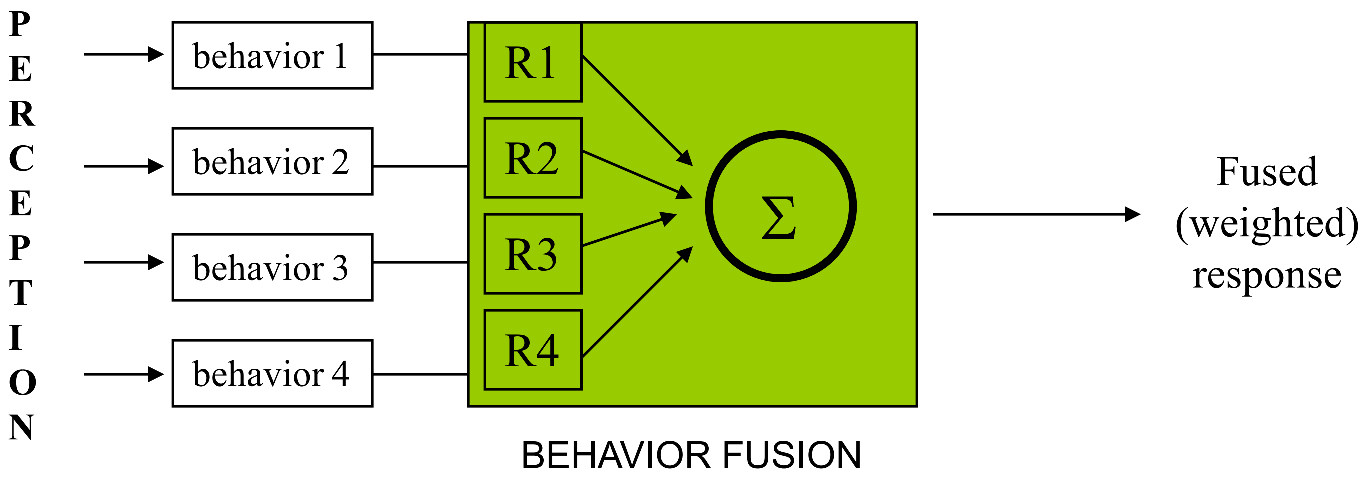


Vote Based

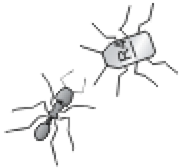

PERCEPTION
behavior 1
behavior 2
behavior 3
behavior 4
R1
R2
R3
MAX[votes(R1), votes(R2), votes(R3)]
Response with most votes
VOTE-BASED



Fusion



Often implemented as a neural network



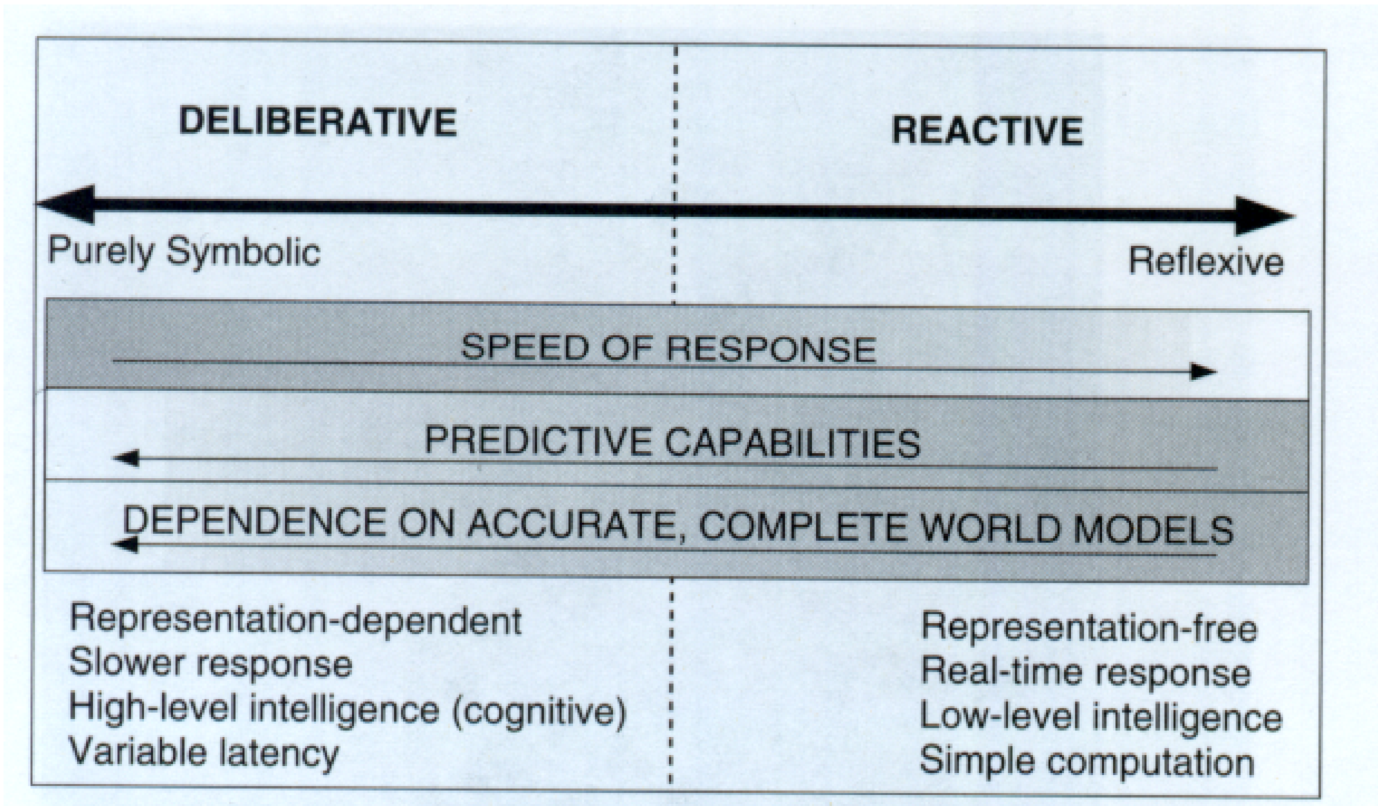
MIT historical behavior-based robots

video clips

MIT Artificial Intelligence Laboratory

Comparison *(Arkin, 1998)*

Traditional | Behavior-based



Applications: entertainment

Intelligence based on *behavior* technology

Speech and touch interaction

Excellent mechanics

Learning abilities (walk)

Mood change

Remote control

Behavior sticks

Picture snapshot

Robot-to-robot interaction

AIBO family
Sony

Applications: assistants

Coworker
iRobot

obstacle avoidance
internet video conference
office surveillance

Helpmate

no magnetic tracks
programmable path
interactive, radio-link

Minerva
CMU

stored programmable map
obstacle avoidance
information delivery on screen
voice interaction

Applications: transport

Construction robot
Applied AI Systems

color vision tracking
obstacle avoidance
active beamers

Agriculture mate
Applied AI Systems

obstacle avoidance
active beamers

Intelligent Wheelchair
Applied AI Systems

vision-based navigation
behavior-based control
interactive navigation

Applications: exploration

Packbot
iRobot

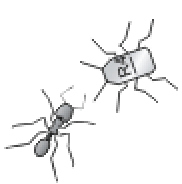
all terrain, including stairs
3 mt fall
radio steering
camera

Nomad
CMU

mobile camera
spectrometer
magnetometer
compass
mineral sampling

Ariel
iRobot

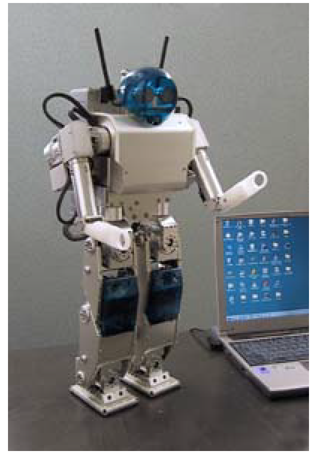
underwater, crab-like motion
double-sided
can be fitted with sensors



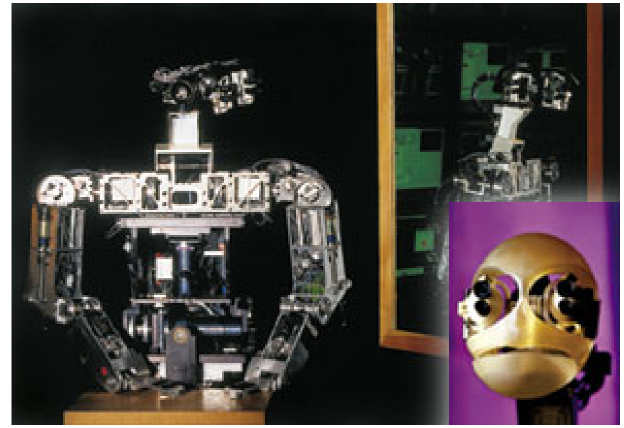
Applications: R&D humanoids

Honda

Fujitsu



COG, MIT



Dream, Sony

Pino, Sony

Kismet, MIT

Closing remarks (Brooks)

http://lis.epfl.ch/podcast

- Intelligence is in the eye of the observer
- The world is its own best model
- Simplicity is a virtue
- Planning is a way of avoiding figuring out what to do next
- Robustness in the presence of noise or failing sensors is a design goal
- Systems should be built incrementally
- No representations. No calibration. No complex computers.
- No high-bandwidth communication