Subsumption Architectures

Support to Lecture 6

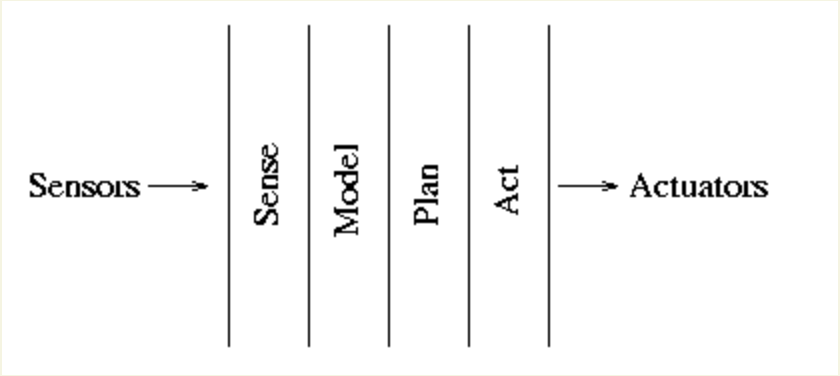
Overview

- Reactive control
- Complete control space
- *Action selection*
- The subsumption architecture
  - *Vertical vs. horizontal decomposition*

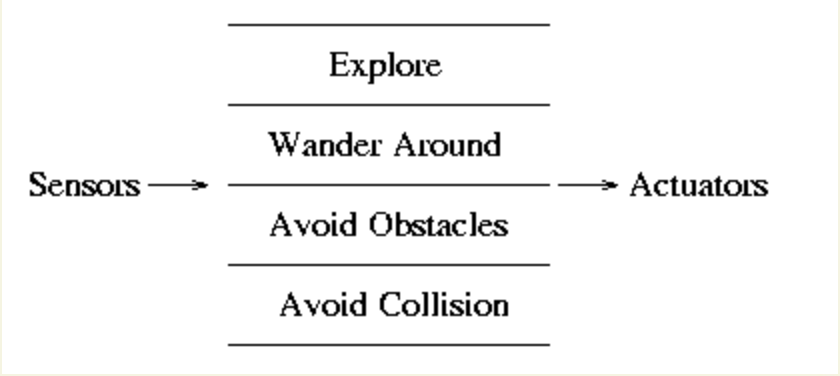
Vertical v. Horizontal Systems

Traditional (SPA):

sense – plan – act

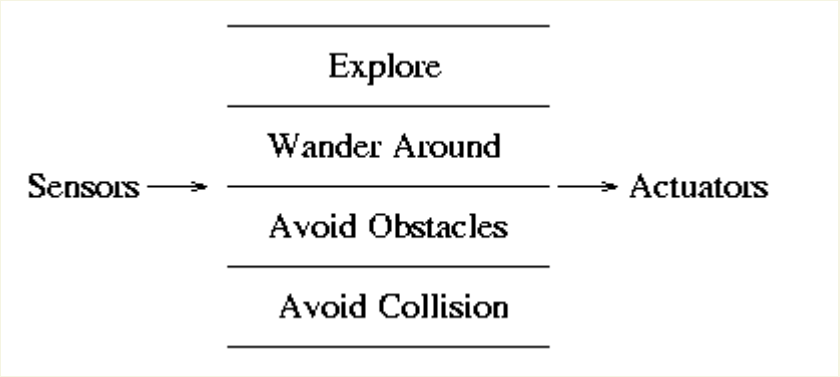


Subsumption:



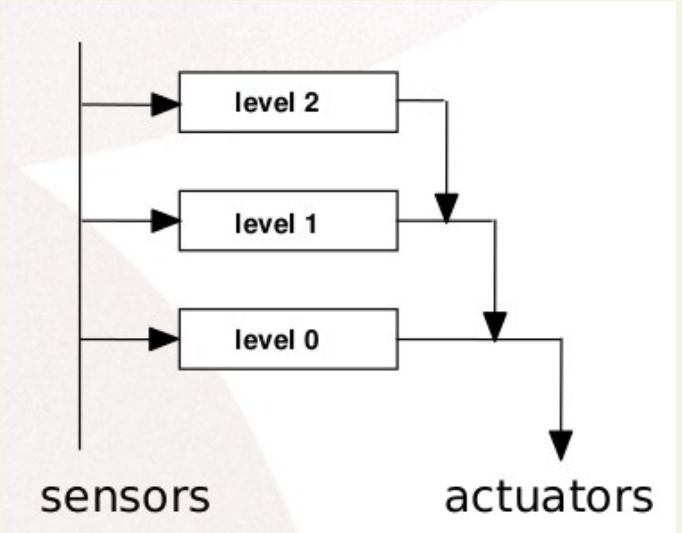
The Subsumption Architecture

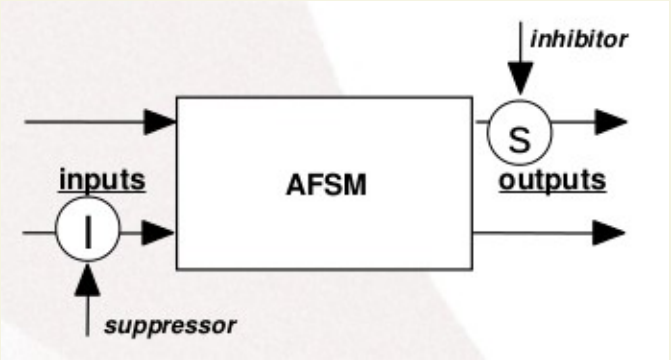
- *Principles of design*
  - *systems are built from the bottom*
  - *components are taskachieving*
  - *actions/behaviors (avoidobstacles, find-doors, visitrooms)*
  - *components are organized in layers, from the bottom*
  - *lowest layers handle most basic tasks*
  - *all rules can be executed in parallel, not in a sequence*
  - *newly added components and layers exploit the existing ones*



Subsumption Layers

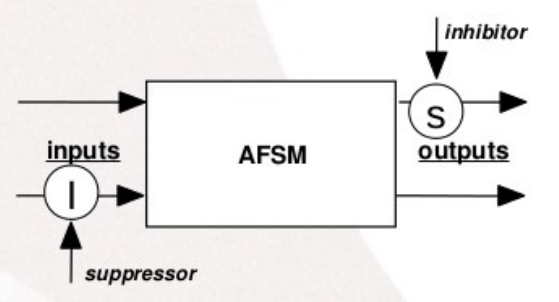
- First, we design, implement and debug layer 0
- Next, we design layer 1
  - When layer 1 is designed, layer 0 is taken into consideration and utilized, its existence is subsumed
  - Layer 0 continues to function
- Continue designing layers, until the desired task is achieved
- Higher levels can
  - Inhibit outputs of lower levels
  - Suppress inputs of lower levels





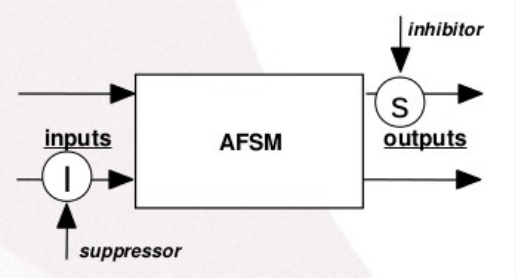
Subsumption Language and AFSMs

- The original Subsumption Architecture was implemented using the *Subsumption Language*
- It was based on *finite state machines* (FSMs) augmented with a very small amount of state (AFSMs)
- AFSMs were implemented in Lisp



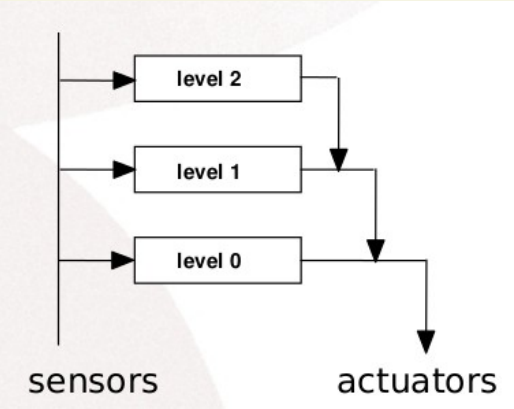
Subsumption Language and AFSMs

- Each behavior is represented as an *augmented finite state machine* (AFSMs)
- Stimulus (input) or response (output) can be *inhibited* or *suppressed* by other active behaviors
- An AFSM can be in one state at a time, can *receive* one or more inputs, and *send* one or more outputs
- AFSMs are *connected with communication wires*, which pass input and output messages between them; only the last message is kept
- AFSMs run *asynchronously*



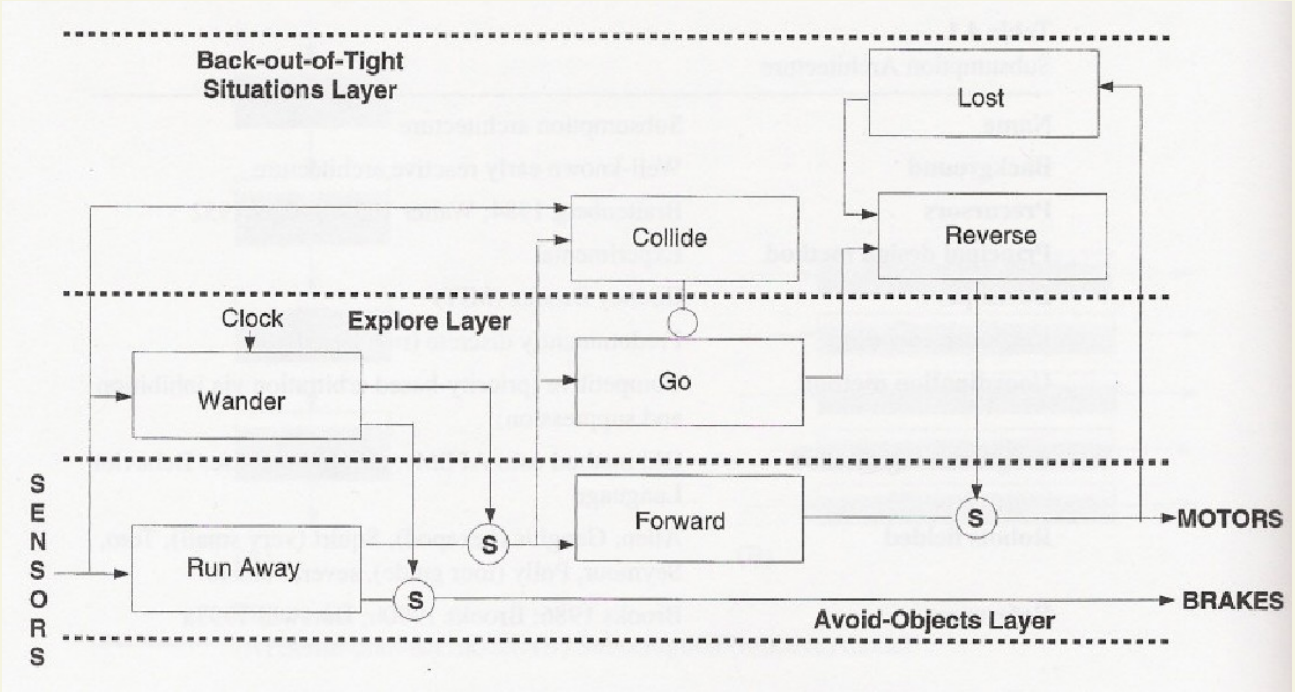
Networks of AFSMs

- Layers represent *task achieving behaviors*
  - Wandering, avoidance, goal seeking
- Layers work *concurrently and asynchronously*
- A Subsumption Architecture controller, using the AFSM-based programming language, is a *network of AFSMs divided into layers*
- Convenient for *incremental system design*



Wandering in Subsumption

- *Brooks '87*



Layering in AFSM Networks

- Layers modularize the reactive system
- Bad design:
  - putting a lot of behaviors within a single layer
  - putting a large number of connections between the layers, so that they are strongly coupled
- Strong coupling implies dependence between modules, which violates the modularity of the system
- If modules are interdependent, they are not as robust to failure
- In Subsumption, if higher layers fail, the lower ones remain unaffected

Module Independence

- Subsumption has one-way independence between layers
  - With upward independence, a higher layer can always use a lower one by using suppression and inhibition
- Two-way independence is not practical
  - No communication between layers is possible
- Do we always have to use these wires to communicate between parts of the system?

Sequencing in Subsumption

- How can you sequence activities in Subsumption?
- Coupling between layers need not be through the system itself (i.e., not through explicit communication wires)
- It could be through the world. How?

Communication through the World

- Collecting soda cans: Herbert
- Herbert's capabilities
  - Move around without running into obstacles
  - Detect soda cans using a camera and a laser
  - An arm that could: extend, sense if there is a can in the gripper, close the gripper, tuck the arm in

Herbert

- Look for soda cans, when seeing one approach it
- When close, extend the arm toward the soda can
- If the gripper sensors detect something, close the gripper
- If can is heavy, put it down, otherwise pick it up
- If gripper was closed, tuck the arm in and head home
- The robot did not keep internal state about what it had just done and what it should do next: it just sensed!

More on Herbert

- There is no internal wire between the layers thatachieve can finding, grabbing, arm tucking, and going home
- However, the events are all executed in proper sequence. Why?
- Because the relevant parts of the control system interact and activate each other through sensing the world

World as the Best Model

- This is a key principle of reactive systems & Subsumption Architecture:
  - Use the world as its own best model!
- If the world can provide the information directly (through sensing), it is best to get it that way, than to store it internally in a representation (which may be large, slow, expensive, and outdated)

Subsumption System Design

- What makes a Subsumption Layer, what should go where?
- There is no strict recipe, but some solutions are better than others, and most are derived empirically
- How exactly layers are split up depends on the specifics of the robot, the environment, and the task

Designing in Subsumption

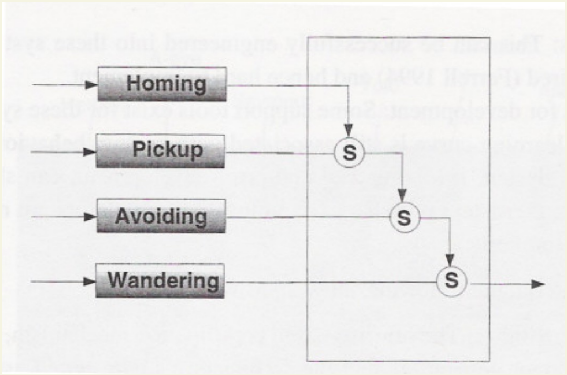
- Qualitatively specify the overall behavior needed for the task
- Decompose that into specific and independent behaviors (layers)
- Determine behavior granularity
- Ground low-level behaviors in the robot's sensors and effectors
- Incrementally build, test, and add

Genghis (MIT)

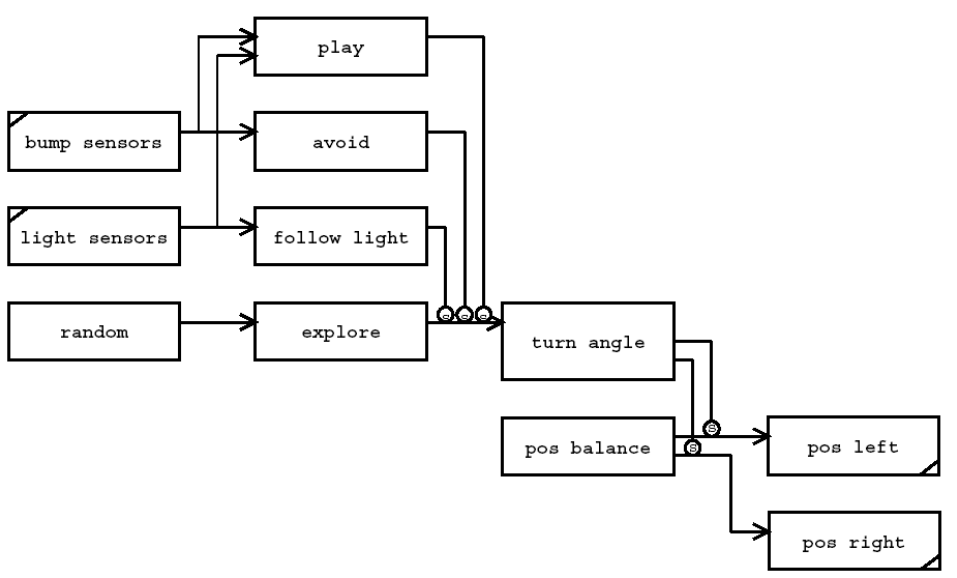
- Walk over rough terrain and follow a human (Brooks ’89)
  - *Standup*
    - Control leg’s swing position and lift
  - *Simple walk*
  - *Force balancing*
    - Force sensors provide information about the ground profile
  - *Leg lifting*: step over obstacles
  - *Obstacle avoidance* (whiskers)
  - *Pitch stabilization*
  - *Prowling*
  - *Steered prowling*

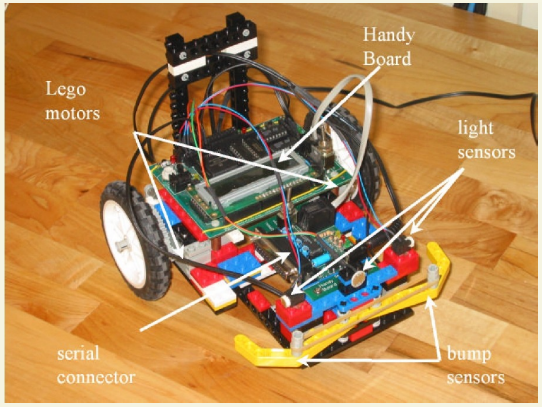
The Nerd Herd (MIT)

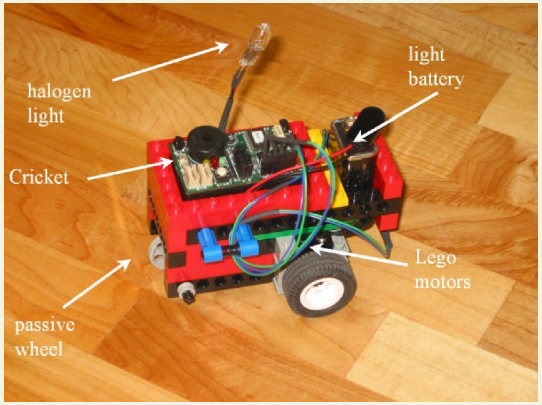
- *Foraging example* (Matarić ’93)
  - R1 robots (IS robotics)
- Behaviors involved:
  - *Wandering*
  - *Avoiding*
  - *Pickup*
  - *Homing*

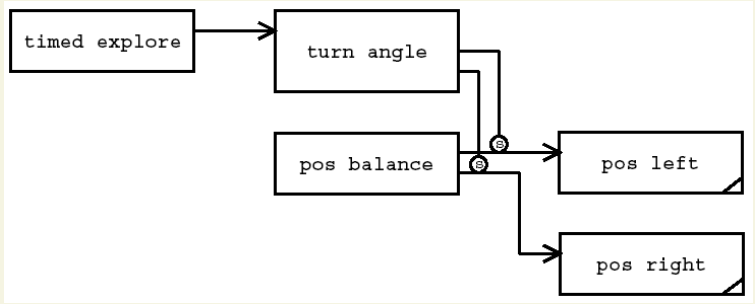


Tom and Jerry (MIT)









Pros and Cons

- Some critics consider the *lack of detail* about designing layers to be a *weakness of the approach*
- Others feel it is a strength, *allowing for innovation and creativity*
- *Subsumption has been used on a vast variety of effective implemented robotic systems*
- *It was the first architecture to demonstrate many working robots*

Benefits of Subsumption

- *Systems are designed incrementally*
  - Avoid design problems due to the complexity of the task
  - Helps the design and debugging process
- *Robustness*
  - If higher levels fail, the lower ones continue unaffected
- *Modularity*
  - Each “competency” is included into a separate layer, thus making the system manageable to design and maintain
  - Rules and layers can be reused on different robots and for different tasks

Behavior-Based Control

- **Reactive systems**
  - too inflexible, use no representation, no adaptation or learning
- **Deliberative systems**
  - Too slow and cumbersome
- **Hybrid systems**
  - Complex interactions among the hybrid components
- *Behavior-based control involves the use of "behaviors" as modules for control*