Robot Architectures

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91.450

Spring 2014
Three Types of Robot Architectures

Hierarchical

Reactive

Hybrid

From Murphy 2000
Hierarchical Organization is “Horizontal”

From Murphy 2000
Horizontal Behaviors: Accomplish Steps Sequentially

From Brooks 1986
Stanford Cart, 1979
Biology and Reactive Architectures are more “Vertical”

From Murphy 2000
Vertical Behaviors: Many Active at Once

From Brooks 1986

Sensors → reason about behavior of objects → plan changes to the world → identify objects → monitor changes → build maps → explore → wander → avoid objects → Actuators

From Brooks 1986
Reactive Architectures

• Historically, two main reactive styles:
  – Subsumption architecture
    • Layers of behavioral competence
    • How to control relationships
  – Potential fields
    • Concurrent behaviors
    • How to navigate

• They are equivalent in power
• In practice, see a mixture of both layers and concurrency

From Murphy 2000
Subsumption: Main Ideas

• Modules should be grouped into *layers of competence*
• Modules in a higher level can override or *subsume* behaviors in the next lower level
  – Suppression: substitute input going to a module
  – Inhibit: turn off output from a module
• *No internal state* in the sense of a local, persistent representation similar to a world model.
• Architecture should be *taskable*: accomplished by a higher level turning on/off lower layers

From Murphy 2000
Subsumption: Layers

From Brooks 1986
Subsumption: Modules

• A module at a higher level can suppress the input of a module at a lower level thereby preventing the module from seeing a value at its input.

• A module can also inhibit the output of a module at a lower level thereby preventing that output from being propagated to other modules

From Brooks 1986
Subsumption Example: Level 0

From Brooks 1986
Subsumption Example: Levels 0 and 1

From Brooks 1986
Subsumption Example: Levels 0, 1 and 2

From Brooks 1986
Subsumption-based Robots
Potential Fields: Main Ideas

• The motor schema component of a behavior can be expressed with a potential fields methodology
  – A potential field can be a “primitive” or constructed from primitives which are summed together
  – The output of behaviors are combined using vector summation

• From each behavior, the robot “feels” a vector or force
  – Magnitude = force, strength of stimulus, or velocity
  – Direction

• But we visualize the “force” as a field, where every point in space represents the vector that it would feel if it were at that point

From Murphy 2000
Example: Run away via repulsion

From Murphy 2000
Five Types of Primitive Potential Fields

From Murphy 2000
Types of Potential Fields

- Uniform (a on prior slide): Move in a particular direction, corridor following
- Repulsion (d): Runaway (obstacle avoidance)
- Attraction (c): Move to goal
- Perpendicular (b): Corridor following
- Tangential (e): Move through door, docking (in combination with other fields)

*Random: Do you think this is a potential field? What would it look like? What would it do?*  
From Murphy 2000
Combining Fields for Emergent Behavior

From Murphy 2000
Fields and Their Combination

From Murphy 2000
• If robot started at this location, it would take the following path
• It would only “feel” the vector for the location, then move accordingly, “feel” the next vector, move, etc.
• Potential field visualization allows us to see the vectors at all points, but robot never computes the “field of vectors”, just the local vector

From Murphy 2000
Adding Two Fields

\[ \begin{array}{c}
\text{+} \\
\text{=}
\end{array} \]
Resulting Robot Trajectory
Example: follow-corridor or follow-sidewalk

Note use of
Magnitude profiles:
Perpendicular decreases

From Murphy 2000
But how does the robot see a wall without reasoning or intermediate representations?

only pieces of the "wall" are seen by 4 of the sensors

- Perceptual schema “connects the dots”, returns relative orientation

From Murphy 2000
OK, But why isn’t that a representation of a wall?

- It’s not really *reasoning* that it’s a wall, rather it is reacting to the stimulus which happens to be smoothed (common in neighboring neurons)

From Murphy 2000
Level 0: Runaway

Note: multiple instances of a behavior vs. 1:
Could just have 1 Instance of RUN AWAY, Which picks nearest reading; Doesn’t matter, but this Allows addition of another Sonar without changing the RUN AWAY behavior

From Murphy 2000
Level 1: Wander

Wander is Uniform, but Changes direction aperiodically

From Murphy 2000
Level 2: Follow Corridor

Should we Leave Run Away In? Do we Need it?

From Murphy 2000
Pfields

• Advantages
  – Easy to visualize
  – Easy to build up software libraries
  – Fields can be parameterized
  – Combination mechanism is fixed, tweaked with gains

• Disadvantages
  – Local minima problem (sum to magnitude=0)
    • Box canyon problem
  – Jerky motion

From Murphy 2000
Example: Docking Behavior

From Murphy 2000
Emergent Behavior

• When behaviors combine to create an unexpected behavior, called an emergent behavior
• Some definitions:
  – Emergence is “the appearance of novel properties in whole systems” [Moravec 1988]
  – “Global functionality emerges from the parallel interaction of local behaviors” [Steels 1990]
  – “Intelligence emerges from the interaction of the components of the system” [Brooks 1991]
  – “Emergent functionality arises by virtue of interaction between components not themselves designed with the particular function in mind.” [McFarland and Bosser 1993]
Competitive Behavior Selection: Arbitration via suppression network

From Arkin 1998
Competitive Behavior Selection: Arbitration via Action-Selection

From Arkin 1998
Competitive Behavior Selection: Voting-based Coordination

From Arkin 1998
Cooperative Behavior Selection: Behavioral fusion via vector summation

From Arkin 1998
Cooperative Behavior Selection: Fuzzy Control

- Can define variables that can be somewhat true or somewhat false
- Allows for combination of different active behaviors, depending upon their degree of truth (can think of this as their amount of activation)
Thursday’s Lab

• More reactive robots
• Wall following