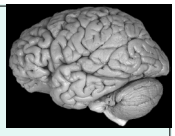
Embodiment & Situatedness

How Dependent is Intelligence on its Hardware? Traditional View

- Brain is no more powerful than Turing machine
- Human intelligence is a result of the program running on our brains
- The same program could be run on any Universal TM
- In particular, it could run on a Von Neumann machine and make it artificially intelligent

Connectionist View



- Information processing on Von Neumann computers (*hardware*) is fundamentally different from that in brains (*wetware*)
- The flexible, context-sensitive cognition we associate with human intelligence depends on the physical properties of biological neurons
- Therefore, true artificial intelligence requires sufficiently brain-like computers (*neurocomputers*)

Importance of Embodied Intelligence

- Traditional (dualist) view: mind is essentially independent of the body
  - in principle, could have an intelligent "brain in a vat"
- Now we understand that much of our knowledge is implicit in the fact that we have a body
- Also, our body teaches us about the world
- Structure of body is foundation for structure of knowledge
- A "disembodied intelligence" is a contradiction in terms?

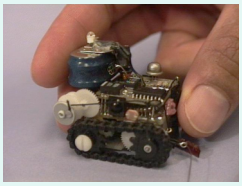
Structure of Embodied Intelligence

- Representational primitives are skills, not concepts
- Higher-level skills are built on lower-level
- Lowest-level skills are grounded in the body

Embodied & Situated Artificial Intelligence

- Therefore a genuine AI must be:
  - embedded in a body (*embodied*)
  - capable of interacting significantly with its world (*situated*)
- Intelligence develops as consequence of interaction of body with environment, including other agents
- How can we investigate embodied, situated intelligence?

"Ant" Microrobots (Brooks, MIT)



- About 1 cubic inch
- 17 sensors
- Can communicate with each other
- Goal: push limits of microrobotics
- Goal: explore social interactions inspired by ant colony
- Applications: explosives disposal, Mars exploration

Clustering Around "Food"

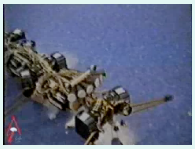
- "Food" amongst other objects in environment
- First "ant" to encounter food, signals others
- Others cluster at food source

Tag Game

- "It" robot wanders until bumps something
- Transmits "Tag"
- A "Not It" robot replies "I got tagged"
- First becomes "Not It"
- Second becomes "It"

Genghis (Brooks, MIT)

- Inspired by evolution in that more complex behaviors build on simpler ones
- Individual legs "do their jobs"
- Legs are coordinated to achieve stability
- Leg motion coordinated to achieve locomotion to goal



Genghis (Brooks, MIT)

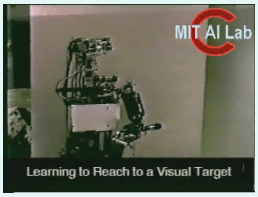
Front view & infrared sensing of person

Cog (Brooks, MIT)

- "Humanoid intelligence requires humanoid interactions with the world"
- Form of body is fundamental to cognitive representation
  - no "brains in vats"
- Human-like intelligence requires human-like body

Learning Hand-Eye Coordination

- Before learning to reach to a visual target
- Final position of hand different from where looking



Learning Hand-Eye Coord. (2)

- View from Cog's eyes during training trial
- Cog learns to coordinate appearance of arm's position with "feel" of arm's position
- Rapid motion is saccade
- Also see motion-detection & grouping algorithm

Learning Hand-Eye Coord. (3)

- After 3 hours self-training
- Robot instructed to reach toward any moving object
- Successfully reaches towards object
- (Hand is non-functional)

Cog: "Social Interaction"

- Cog attending to visual motion
- Orients head & eyes to motion
- (Arm & hand motion are not relevant to interaction)

Cog: Learning by Imitation

- Imitation is an important means of human learning
- Here, Cog learns to imitate head motions
- Recognizes the motion of faces
- Cog does not try to imitate non-faces

The Cog Project
Imitating Head Nods

Brian Scassellati
MIT Artificial Intelligence Lab

Cog: Learning by Imitation (2)

- Cog recognizes objects sufficiently like faces
- Imitates their motion with its own

The Cog Project
Imitating Head Nods

Brian Scassellati
MIT Artificial Intelligence Lab

Interactions with Other Agents

- Being situated includes interactions with other agents
- Cooperative interactions:
  - robots with robots
  - robots with humans
- Competitive interactions:
  - robots against robots
  - robots against humans
  - robots against animals

"Robonaut"

"Mind Reading" and Other Social Skills

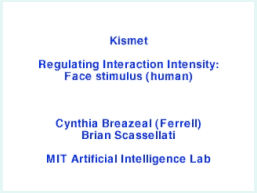
- Need to understand other agents' mental states & processes
- Need to communicate (or misrepresent) one's own mental state & processes
- Non-verbal communication: gesture, eye contact, gaze
- Imitation as basis of learning & social understanding

Shared Cooperative Activities

- Commitment to joint activity & mutual support
- Joint intention theory
- Simulation theory
- Ability to take perspective of other agent

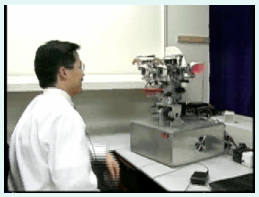
Kismet (Brooks, MIT)

- Responds to a face with a happy expression
- Responds to rapidly moving face with disgusted expression



Kismet (Brooks, MIT)

- Two-way conversational interaction
- Kismet understands intonation & body language, but not words



Kismet (Brooks, MIT)

- Example of three-way conversational interaction

Leonardo

- Cynthia Breazeal's Lab, MIT
- "Sociable Robots" Project
- Vehicle for exploring socially guided learning & cooperative activity

(video < Breazeal's Lab)

Touch-Sensitive "Skin"

- Touch-sensitive silicone skin over entire body
- Mapped to neural net-like "homunculus"
- Here Leo is programmed to notice & withdraw from contact

(video < Breazeal's Lab)

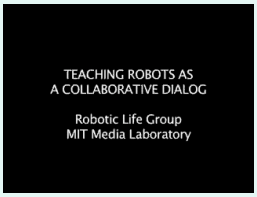
Learning to Mimic Expressions

- Imitation as a way to bootstrap social understanding & "theory of mind"
- Understand behavior in terms of mental states producing it
- Leo makes faces
- Human imitates
- Leo learns what his face looks like
- Learns to imitate humans

(video < Breazeal's Lab)

Socially Guided Learning

- Leo is taught to "turn on all the lights"
- Leo generalizes to new situation
- Leo displays commitment to joint activity in spite of incorrect action



(video < Breazeal's Lab)

Social Implications of Artificial Intelligence