Psychology 354
Elements Of Embodied Cognitive Science

Methodological Solipsism
Embodiment In Robots
Embodiment And Human Cognition

Shakey Beginnings

- Autonomous robots have been a testing ground for much work in artificial intelligence
- Historically they have used a symbolic approach
  - Build an internal representation or model of the world
  - Use it to plan movements
  - Carry out the plan
- SRIs Shakey (1966-1972) was one of the most notable of these efforts, guided by Nils Nilsson

Nils Nilsson

Shakey Behavior

- The trouble with Shakey was that it simply took too much computational effort to create, and update, a usable model of the world
  - "Its most impressive feat – moving a wedge to a block, ascending it, and pushing off a smaller block – was recorded on film piecemeal, requiring multiple takes – and several hours – for each error-prone stage" (Moravec, 1999)
  - "Eventually Shakey would get to its goal a few meters from where it started and carry out its task – six or eight hours after it started. Most of the time Shakey, the robot shell, sat idle while its remote brain contemplated a long series of moves to accomplish its ultimate goal" (Brooks, 2002)

Hans Moravec

Rodney Brooks

Methodological Solipsism

- In general, the source of such problems is the classical position called methodological solipsism
- "Methodological solipsism in psychology is the view that psychological states should be construed without reference to anything beyond the boundary of the individual who has those states" (Wilson, 2004, p. 77)
- Methodological solipsism is a consequence of the classical sandwich, and reflects the disembodiment of the classical approach

Rob Wilson

Abandoning The Classical Sandwich

- Shakey, production systems, and classical cognitive science in general emphasize thinking or planning at the expense of sensing and acting
- Sensing and acting are peripheral processes that sandwich (the more important) thinking
- What if the purpose of cognition is not to plan, but rather to control our actions?
- Why plan with a costly model of the world, when we can act on the world that is there for us to sense?

Susan Hurley

Rodney Brooks

Embodiment And Situation

- "Biological brains are first and foremost the control systems for biological bodies. Biological bodies move and act in rich real-world surroundings."
- Embodiment
  - Build the agent a body that can move or act in the world
- Situation
  - Provide the agent the means to sense the world in which it moves or acts

Andy Clark

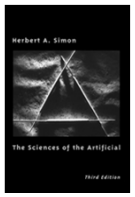
Machina Speculatrix

- **Consider an earlier autonomous robot, the "tortoise" elsie, created by William Grey Walter in the late 1940s.**
- **Imagine observing the behavior of this robot**
- **What kind of theory would explain the behavior?**

Grey Walter & co, with Elsie above and below

The Parable Of The Ant

- **"Viewed as a geometric figure, the ant's path is irregular, complex, hard to describe. But its complexity is really a complexity in the surface of the beach, not a complexity in the ant" (Simon, 1996, p. 51)**
- **Embodied cognitive science takes this parable to heart in its view of the importance of the environment**



Stigmergy

- **Embodiment and situation permit a very different kind of control to be considered in cognitive science**
- **Stigmergy was proposed in 1959 by biologist Grassé in his theory of termite nest construction**
  - **From the Greek *stigma*: sting and *ergon*: work**
- **The behavior of individuals is triggered by environmental stimuli**
- **Behaviors change the environment**
- **Changes in the environment affect later behaviors, perhaps of other organisms**
- **<u>In short, the nest controls its own construction!</u>**

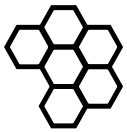
Pierre-Paul Grassé

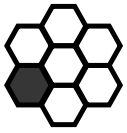
Where Will Wasps Add The Next Cell?

- **Stigmergy has been studied extensively for the role that it might play in guiding the construction of nests by the *Polistes* wasps**
- **Cell growth occurs with equal probability in all directions of space**
- **How do wasps bring this principle to life?**
- **Théraulaz and Bonabeau (1999) propose that stigmergy provides the answer**

Rules For Building New Cells On Old

- **It makes sense to build new cell on existing structures to ensure nest strength**
- **Probability of 0.057 that a cell will be added to a two-wall location**
- **Probability of 0.55 that a cell will be added to a three-wall location**
- **Théraulaz and Bonabeau (1999) used these two nest driven rules to create a model that generated realistic-looking cell development**
- **Addition of new cell changes nest as stimulus for new building**

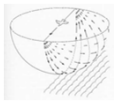


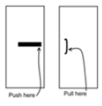


Affordance

- **The notions of embodiment and affordance highlight an interaction between body and world**
- **How we sense the world, and how we act upon it, depends upon the nature of our bodies**
  - **"It is often neglected that the words *animal* and *environment* make an inseparable pair" (Gibson, 1979, p. 8)**
- **An affordance is a possible action that the environment makes possible**
  - **"The affordances of the environment are what it offers the animal, what it provides or furnishes, either for good or ill" (p. 127)**

J.J. Gibson





Feedback

- The interaction between body and world is a central property of feedback
- Feedback was a core idea in cybernetics
- Embodied cognitive science can be seen as returning to some of cybernetic theory's emphasis on the role of the environment

Norbert Wiener

The Logic of Action

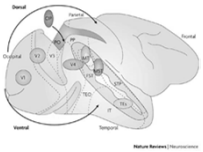
- Why should action on the world become more important in theories of human cognition?
- Theories of cognitive development, which culminate in formal processes that are swayed by logicism, have long argued that cognition is derived from action
  - Piaget concluded that formal abilities like classification and seriation are "closely linked with certain actions which are quite elementary: putting things in piles, separating piles into lots, making alignments, and so on" (Inhelder & Piaget, 1964, p. 291).
  - "The starting-point for the understanding, even of verbal concepts, is still the actions and operations of the subject" (Inhelder & Piaget, 1964, p. 284).

Bärbel Inhelder

Jean Piaget

The Acting Brain

- Cognitive neuroscience supports the notion that the brain is an organ of control
- Goodale has studied brain injured patients who cannot classify or recognize objects, but can still act upon them with exquisite precision
- His duplex theory challenges the old what/where distinction between dorsal and ventral pathways in the brain
  - "The functional distinction is not between 'what' and 'where', but between the way in which the visual information about a broad range of object parameters are transformed either for perceptual purposes or for the control of goal-directed actions" (Goodale & Humphrey, 1998, p. 187).



Mel Goodale

Cognitive Scaffolding

- The world can also be used to carry out or support computations, again freeing resources – for human information processing
  - "By failing to understand the source of the computational power in our interactions with simple 'unintelligent' physical devices, we position ourselves well to squander opportunities with so-called intelligent computers" (Hutchins, 1995, p. 171).
- This is called *cognitive scaffolding*
  - "Advanced cognition depends crucially on our abilities to dissipate reasoning: to diffuse knowledge and practical wisdom through complex social structures, and to reduce the loads on individual brains by locating those brains in complex webs of linguistic, social, political, and institutional constraints" (Clark, 1995).

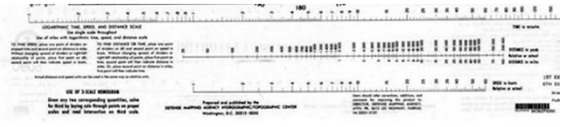
Edwin Hutchins

Andy Clark

Nomograms And Other Examples

- A nomogram is a graphical tool that is an example of scaffolding
  - "It seems that much of the computation was done by the tool, or by its designer. The person somehow could succeed by doing less because the tool did more" (Hutchins, 1995, p. 151)
- Can you think of other scaffolding examples?

Maneuvering board



The Leaky Mind

- Scaffolding causes incredible rethinking of the locus of an agent's intelligence
- It as if the mind has leaked into the world!
  - "It is the human brain plus these chunks of external scaffolding that finally constitutes the smart, rational inference engine we call mind" (Clark, 1995, p. 180)
- The world can serve as a common memory, or computing device, for groups of agents to think collectively
  - "Organized groups may have cognitive properties that differ from those of the individuals who constitute the group" (Hutchins, 1995)

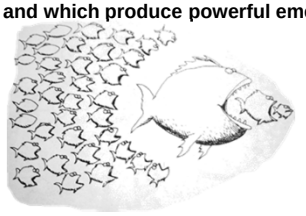
Robert Wilson

Stigmergic Thought

- **By leaking the working memory of a production system into the world, and by letting at least some sense-act processing proceed (without using internal representations), the control of a production system becomes very familiar – *stigmergy!***
- ***When working memory leaks into the world via scaffolding, cognitive control becomes as stigmergic as a wasp nest's control of its own creation***

Decentralized Control

- **Scaffolding, and sense-act processing, remove control from central cognitive processing in the classical sandwich**
- **The result is collective power – individual agents (sense-act processes) that are stigmergically controlled, and which produce powerful emergent results**



The Synthetic Approach

- **The ideas driving the embodied approach suggest new methodologies**
- **For instance, synthetic psychology builds agents to interact with worlds in an attempt to understand intelligence**
  - **"If we want to achieve wall-following behaviour, we should design not a module for wall-following within the agent, but instead basic processes that together, interacting with the environment, engender this desired behaviour" (Pfeifer & Scheier, 1999)**
- **Cognitive science becomes forward engineering**

Rolf Pfeifer

Synthesis Vs. Analysis

"It is much more difficult to start from the outside and try to guess internal structure just form the observation of the data. [...] A psychological consequence of this is the following: when we analyze a mechanisms, we tend to overestimate its complexity" (Braitenberg, 1984).

Valentino Braitenberg

A Synthetic Alternative

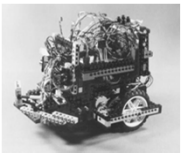
Only about 1 in 20 [students] 'gets it' -- that is, the idea of thinking about psychological problems by inventing mechanisms for them and then trying to see what they can and cannot do" (Minsky, 1995, personal communication)

Marvin Minsky

Synthetic Example

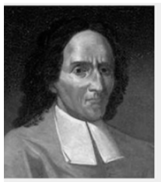
- **One example of the synthetic approach is Webb's use of robots to study cricket phonotaxis**
- **The original cricket robot was built from LEGO**
- **The model of phonotaxis uses two auditory neurons, which drive two motor neurons**
- **The behavior of the robot makes it appear as if it is doing signal processing – which it is not!**
  - **"Thus it is clear from our results that much of the evidence for the standard 'recognize and localize' model of phonotaxis in crickets is insufficient to rule out an alternative, simpler model" (Webb & Scutt, 2000, pp. 265-266)**

Barbara Webb



Verum-Factum

- Classical cognitive science is rooted in the philosophy of Rene Descartes
- Connectionist cognitive science appeals to British empiricists like John Locke
- The synthetic approach of embodied cognitive science is rooted in the philosophy of Giambattista Vico (1668-1744), who critiqued both Descartes and Locke
- Vico's philosophy is based on the central assumption that the Latin term for truth, *verum*, was identical to the Latin term *factum:*
  - "It is reasonable to assume that the ancient sages of Italy entertained the following beliefs about the true: 'the true is precisely what is made'"
  - "To know (*scire*) is to put together the elements of things"



Giambattista Vico

Bricolage

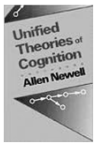
- Levi-Strauss introduced the notion of bricolage, but did so in a way that disparaged it in comparison to "classical" thought
  - "The 'bricoleur' is still someone who works with his hands and uses devious means compared to those of a craftsman"
- Modern researchers view bricolage as a distinct, powerful style of thinking – because of its nonlinearity
- This style of thinking is modern, and is consistent with decentralized theories and synthetic psychology
  - Turkle describes bricolage as a sort of intuitive tinkering, a dialogue mediated by a virtual interface. "As the computer culture's center of gravity has shifted from programming to dealing with screen simulations, the intellectual values of bricolage have become far more important. […] Playing with simulation encourages people to develop the skills of the more informal soft mastery because it is so easy to run 'What if?' scenarios and tinker with the outcome" (1995, p. 52)

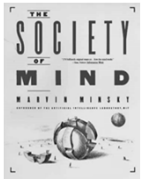
Claude Levi-Strauss

Sherry Turkle

Unified Theories vs Societies of Mind

- Production systems seek unified theories of mind
  - "All the higher cognitive processes, such as memory, language, problem solving, imagery, deduction and induction, are different manifestations of the same underlying system" (Anderson, 1983
- Collections of agents of diverse types, which somehow produce emergent phenomena, are theories of mind that are not unified
  - "The operations of our minds do not depend on similarly few and simple laws, because our brains have accumulated many different mechanisms over aeons of evolution. This means the psychology can never be as simple as physics, and any simple theory of mind would be bound to miss most of the 'big picture'. The science of psychology will be handicapped until we develop an overview with room for a great many smaller theories" (Minsky, 1985)



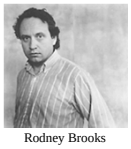


Mind and Method

- How do we make room for smaller theories?
- We can adopt forward engineering
- Researchers can think like the systems that they study – by becoming bricoleurs themselves
- The synthetic approach, which assembles available elements into embodied agents whose surprising behavior exceeds what might be expected of their simple components, is an example of a cognitive science that depends upon 'tinkering'

Against Representation

- The synthetic approach can lead to a radical reaction against classical cognitive science
- Behavior-based roboticists adopt a radical embodied cognitive science, and attempt to remove thinking or representation as much as possible
- "In particular I have advocated situatedness, embodiment, and highly reactive architectures with no reasoning systems, no manipulable representations, no symbols, and totally decentralized computation" (Brooks, 1999, p. 170)

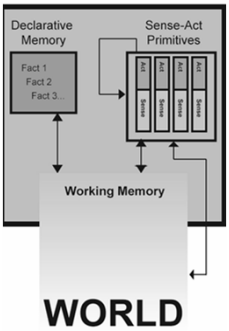


Rodney Brooks

Genghis

Porous Production System

- However, as in Goodale's duplex theory, there may be a need for both sense-act and sense-think-act processing
- "Minds may be essentially embodied and embedded and still depend crucially on brains which compute and represent" (Clark, 1997, p. 143)
- Production systems could be modified to reflect traditional computation as well as processes that have leaked into the world
- Productions can sense, and act on, internal or external representations in this model



Embodied Themes

- **Shapiro has recently summarized three themes that run through embodied cognitive science**
- **Conceptualization**
  - **The concepts that an agent requires to interact with its environment depend on the form of the agent's body**
- **Replacement**
  - **"An organism's body in interaction with its environment replaces the need for representational processes thought to have been at the core of cognition" (Shapiro, 2011, p. 4)**
- **Constitution**
  - **The body or the world has more than a causal role in cognition – they are literally constituents of cognitive processing**
- **All of these themes are controversial reactions to other approaches in cognitive science**

Lawrence Shapiro

Comparing Cognitive Sciences

	Classical Cognitive Science	Connectionist Cognitive Science	Embodied Cognitive Science
Core Ideas	•Mind as a physical symbol system •Mind as digital computer •Mind as planner •Mind as creator and manipulator of models of the world •Mind as sense-think-act processing	•Mind as information processor, but not as a digital computer •Mind as a parallel computer •Mind as pattern recognizer •Mind as a statistical engine •Mind as biologically plausible mechanism	•Mind as coordinator of action •Mind emerging from situation and embodiment, or being-in-the-world •Mind as extending beyond skull into world •Mind as sense-act processing
Preferred Formalism	Symbolic logic	Nonlinear optimization	Dynamical systems theory
Tacit Assumption	Gestalt, naïve realism	Empiricism	Embodied interaction
Type of Processing	Symbol manipulation	Pattern recognition	Acting on the world
Prototypical Architecture	Production system (Newell, 1973)	Multi-layer perceptron (Rumelhart, Hinton, & Williams, 1986)	Behavior-based robot (Brooks, 1999)
Prototypical Domain	• Problem solving • Language	• Memory/pattern learning • Perceptual categorization	• Locomotion • Social interaction
Philosophical Roots	• Hobbes • Descartes • Leibniz • Craik	• Aristotle • Locke • Hume • James	• Vico • Dewey • Heidegger • Merleau-Ponty
Some Key Modern Theorists	• Chomsky • Dennett • Fodor • Pylyshyn	• J.A. Anderson • Hinton • Rumelhart • McClelland	• Brooks • Clark • Noë • Wilson
Some Pioneering Works	• *Plans And The Structure Of Behavior* (Miller, Galanter, & Pribram, 1960) • *Aspects Of The Theory Of Syntax* (Chomsky, 1965) • *Human Problem Solving* (Newell & Simon, 1972)	• *Principles Of Neurodynamics* (Rosenblatt, 1962) • *Parallel Models Of Associative Memory* (Hinton & Anderson, 1981) • *Parallel Distributed Processing* (Rumelhart & McClelland, 1986)	• *Cognition And Reality* (Neisser, 1976) • *The Ecological Approach To Visual Perception* (Gibson, 1979) • *Understanding Computers And Cognition* (Winograd & Flores, 1987)

Table 9-1. Contrasts between the three schools of thought in cognitive science using a variety of features.