(Phil321h) Computational Modeling: Autonomous Robots and Embodied Cognition
William P. Seeley, Bates College
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Course Description:
This lab/seminar explores to research in embodied cognition and artificial intelligence that uses simulations, robotics, and genetic algorithms to model the kinds of flexible and adaptive behavior constitutive of our conception of intelligence. This research provides an alternative model for intelligent behavior that challenges traditional representational and computational theories of mind. Students will use hands robotics exercises to explore the ideas they encounter in the class. Topics covered include: the nature of intelligence, the computational theory of mind, representation, embodied cognition, behavior-based robotics, biorobotics modeling, dynamic systems, neural networks, genetic algorithms, and philosophical questions surrounding the use of computer simulations and robotics as research tools in psychology and cognitive science. No prior programming experience is necessary.

Narrative:
This lab/seminar explores to research in embodied cognition and artificial intelligence that uses simulations, robotics, and genetic algorithms to model the kinds of flexible and adaptive behavior constitutive of our conception of intelligence. This research provides an alternative model for intelligent behavior that challenges traditional representational and computational theories of mind. Standard computational theories of mind model intelligent behavior on the human capacity for rational decision making and general problem solving. On this account thoughts are constructed from abstract symbols that represent aspects of the environment, and minds are treated as general purpose symbol manipulation systems that can be realized in any of a potentially infinite number natural organisms or artificial systems. Although the computational model of mind has been a powerful research tool in cognitive science, it has proven difficult to implement in computer simulations and mobile robotics. For instance, general purpose problem solvers fall prey to what is called the frame problem in artificial intelligence: they have difficulty filtering task salient information out of noisy signals and so often follow inefficient procedures or get stuck in blind alleys. This and other difficulties have inspired researchers in embodied cognition and artificial life to look towards insect and animal models of intelligent behavior for alternatives. Bodies evolve in lock step with cognitive systems, and both can be thought of as adaptations fine-tuned to the kinds of environmental features necessary to help satisfy an organisms’ basic needs and interests. As a result the general structure of an organisms body (i.e., its effectors and the structure and placement of its peripheral sensory organs) is a strong constraint on the ways it acquires, manipulates, and uses information from its environment – a constraint that focuses cognitive systems on task salient information in the environment, simplifying the computational demands of flexible and adaptive behavior. Researchers in embodied cognition and artificial life therefore challenge the assumption that minds are general purpose symbol manipulation systems. They argue instead that intelligent behavior emerges from the interaction between (evolved and well adapted) bodies and the environment. To this end research in autonomous (sometimes called agent- or behavior-based) robotics is used to explore the role of agent-environment interactions in the production of intelligent behavior.

Embodied theories of cognition have proven to be equally powerful research tools. However, one can question whether the kinds of adaptive behaviors that can be successfully captured by insect and animal models have the structure necessary to explain the full range of human cognitive behaviors that interest us (e.g., counterfactual reasoning processes involved in long term planning). At the very least these types of processes seem to require abstract conceptual apparatuses that enable organisms to consider alternative strategies, model potential environmental change, and represent novel outcomes. This suggests that rather than think of embodied and computational approaches as mutually exclusive alternatives, perhaps it is better to argue that they compliment one another and can be used together to produce a more
comprehensive theory of cognition. The proposed seminar explores this dialectic. Readings are drawn from contemporary sources in philosophy, psychology, and computer science. In addition to course readings and written assignments, students use a range of computer simulations and robotics exercises to explore the ideas introduced in class.

Sample Robotics Exercises:

**Wanderer:** The first step in autonomous robotics is to build a machine that can explore its environment without getting stuck. Our first robot will use sonar to avoid objects so that it can run in any environment until it runs out of batteries.

**Light Seekers/Avoiders:** Once a platform for exploring has been built we need to add some sensitivity to the environment. Our next project will be to build a series of machine that interact differently with pools of light projected onto the floor. The goal of this project is to explore the concept of embodiment by experimenting with the ways different a) connections between sensors and motors and b) physical configurations of sensors affect the robot's behaviors.

Students will be asked to read Valentino Braitenberg, *Vehicles: Experiments in Synthetic Psychology* and construct implementations of the lightseeking/avoiding robots he describes in the first six chapters of the book.

**Cooperators:** Many insect and animal communities solve problems through cooperative behavior. This collective behavior is often not directed but emerges from simpler individual behaviors. We will build a group of robots that tidy up a messy room cluttered with paper boxes by simply avoiding piles of boxes and each other.

**Navigator:** Most of the robots we will build produce behaviors that appear intentional through simple reflexes. Of course what we are most interested in is more directed forms of behavior. In our final exercise we will explore whether the reactive procedures used in the previous robots can be used to teach a robot to efficiently navigate through an environment (rather than accidentally fall upon a path).

**Flocking Robots:** The goal of this project is to modify our cooperators so that the group of robots self-organizes into a flock, finding one another, aligning their paths of motion and maintaining an even distance from one another in the flock.

For instance, one "following strategy" is to pair the robots motors to a sonar sensor so that the motor speed slows down as the robot approaches a leader and speeds up as the leader gets away the follower will eventually settle into a speed that matches the leader.

See [http://www.red3d.com/cwr/boids/](http://www.red3d.com/cwr/boids/) for the basic principles governing flocking in these contexts.

**WallFinder Learner:** This robot employs an artificial neural network that learns to recognize and avoid walls and obstacles without bumping into them. The robot uses two sonar sensors, two touch sensors, and motor rotation sensors. At each bump it resets the connectivity in its neural network. It has learned when it no longer bumps objects. The ultimate goal is to for it to learn to differentiate freestanding obstacles from walls. It has learned this distinction when it follow walls but continues in a general direction once getting around an obstacle.

**Crossmodal WallFinder Light Seeker:** This robot uses an artificial neural network to learn to a) recognize and avoid walls by the combined reflected light and sound as it approaches one, b) but seeks out freestanding pools of light of equal luminance, and c) ignores ambient sounds in the environment of similar loudness.
**Wormeostat (the central pattern generator):** This exercise is adapted from Michael Dawson's book, *From Bricks to Brains* (Edmonton, Alberta: Athabasca University Press, 2010). Wormeostat couples four Lego Mindstorms motors in a series resembling a segmented worm - two bricks and four motors. The bricks at either end of the line act as breaks. The motors are set so that if they turn beyond a certain threshold they simply turn back, raising and activating the motor behind them. The robot falls into an inchworm gate, acting as a central pattern generator, and works its way down the hallway.

**Active Dynamic Walker:** One tenet of embodied cognition is that the body itself can be used to solve complex computational problems associated with behavior. Passive dynamic walkers are robots that do just this - they are built to naturally fall into different gaits that are most efficient for the speed they are walking (due to the slope they are descending). See: [http://www.youtube.com/watch?v=qwEWki9H0Ao](http://www.youtube.com/watch?v=qwEWki9H0Ao); [http://www.youtube.com/watch?v=N64KOQbyil](http://www.youtube.com/watch?v=N64KOQbyil); [http://groups.csail.mit.edu/robotics-center/public_papers/Tedrake04.pdf](http://groups.csail.mit.edu/robotics-center/public_papers/Tedrake04.pdf); [http://www.ai.mit.edu/projects/leglab/home.html](http://www.ai.mit.edu/projects/leglab/home.html)

The final challenge is to try to pair the general concept of a central pattern generator with a passive dynamic walker to develop a robot that generates its own motion, settling into different gates at different hip motor speeds.

**Sensorimotor Cues & Object Categorization:** This exercise is adapted from Pfeifer & Scheier's SMC models for object avoidance and categorization. An artificial neural network for a basic wall following robot is trained to couple differential sensorimotor cues from its wheels and ultrasound readings about relative distance from objects in order to develop two object categories: large cylinder and small cylinder.

**Source Materials:**


*Evolutionary Robotics*, Stefano Nolfi and Dario Floreano (Cambridge, MA: MIT Press, 2004).


Syllabus Topics:

Topic 1: Troubles with Classic AI: Formal Systems, the Symbol Grounding Problem, & the Frame Problem

Topic 2: Engineering Solutions: Behavior Based Robotics (Rodney Brooks, Maja Mataric)

Topic 3: Biorobotics Modeling: Insect Intelligence and Autonomous Robots (Barbara Webb)

Topic 4: Grounding Cognition in Action:
   Visual Routines (Mary Hayhoe)
   Deictic Markers (Dana Ballard)
   Indexical Representations (Agre & Chapman's Pengo Playing Program, Pengi)

Topic 5: Artificial Neural Networks: Architecture, Learning Rules, Concepts, and Categories (Pfeifer & Scheier)

Topic 6: Genetic Algorithms: Optimizing and Learning Across Generations (Nolfi & Floreano)

Topic 7: What is Memory (For)?: A Sensorimotor Model for Memory in Robots and Humans