PSYCO 457
Week 2: Mind Control – Internal or External?

Our Special Intelligence
Animal Control of Environments
Stigmergy
Is Human Intelligence Stigmergic?

Preliminary Discussion

- **Seeking comments or questions concerning the main themes of readings to this point in "From Bricks To Brains"**

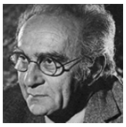
The Essence of the Soul is to Think

- **Descartes used the "thinking soul" to differentiate man from the animals**
- **"If there were any machines which had the organs and appearance of a monkey or of some other unreasoning animal, we would have no way of telling that it was not of the same nature as these animals" (Descartes, 1637)**

René Descartes

Man versus Beast

- **Descartes' view is held by modern thinkers**
- **"Man is distinguished from other animals by his imaginative gifts. He makes plans, inventions, new discoveries, by putting different talents together; and his discoveries become more subtle and penetrating, as he learns to combine his talents in more complex and intimate ways" (Bronowski, 1973).**
- **"Symbolism, if you will, is the divine spark distinguishing the poorest specimen of true man from the most perfectly adapted animal" (Bertalanffy, 1967)**

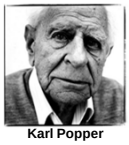


Jacob Bronowski

Ludwig von Bertalanffy

Environmental Control

- **Thinking is central to the sense-think-act cycle that defines classical cognitive science**
- **Thinking mediates planning. According to Popper, this permits our hypotheses to die in our stead**
- **Planning also releases humans from the control of the environment: "Among the multitude of animals which scamper, fly, burrow and swim around us, man is the only one who is not locked into his environment. His imagination, his reason, his emotional subtlety and toughness, make it possible for him not to accept the environment, but to change it" (Bronowski, 1973, p. 19)**



Karl Popper

Jacob Bronowski

Beaver Control

- **Is man the only animal who controls the environment?**
- **Beavers are remarkable environmental engineers, whose lodges, dams and canals seem to reflect intelligence similar to our own**
- **Such activities "involve as well as prove a series of reasoning processes indistinguishable from similar processes of reasoning performed by the human mind" (Morgan, 1868/1986, pp. 262-263).**
- **Perhaps man's mind does <u>not</u> separate him from the beasts!**

The Simple Insect

- On an individual level, it is fair to say that insects are not particularly intelligent
- Insects are primarily controlled by instinct (Hingston, 1933), where instinct is "a force that is innate in the animal, and one performed with but little understanding" (p. 132).
- Surely man can be differentiated from the invertebrates!

Major Richard Hingston

Insect Architecture

- But social insects like bees, wasps, and termites, are incredible manipulators of their environment who rival other animals
- Consider such examples like the giant termite mound on the right. How can insects create such artifacts?
- "The problem before us is a very old one. Are the lower animals blind creatures of impulse or are they rational beings?" (Hingston, 1929).

The Rational Insect

- Some theories of nest construction agree with classical cognitive science, such as Thorpe's notion of an ideal releaser:
- "The bird must have some 'conception' of what the completed nest should look like, and some sort of 'conception' that the addition of a piece of moss or lichen here and here will be a step towards the 'ideal' pattern, and that other pieces there and there would detract from it (Thorpe, 1963, p. 22).
- "So far as I can judge from the evidence given, we are not justified in making barriers between insect and human mentality. I mean we have no right to regard their minds as being totally different in kind" (Hingston, 1933, p. 183).

The Intelligent Whole

- Most researchers do not view insects, and other nest constructing animals, as rational
- How, then, are nests built? Wheeler argued that insect colonies as a superorganism, and that nest construction was the result of colonial intelligence
- "The unique qualitative character of organic wholes is due to the peculiar non-additive relations or interactions among their parts. In other words, the whole is not merely a sum, or resultant, but also an emergent novelty, or creative synthesis." (Wheeler, 1926, p. 433)


William Morton Wheeler, American entomologist

Holistic Problems

- The problem with the view that colonies are organisms is that it is very difficult to provide a scientific account of the laws that govern them
- This is a general problem with *holism*, of which Wheeler's superorganism is an example
- "Holism is an idea that has haunted biology and philosophy for nearly a century, without coming into clear focus" (Wilson, 1991, p. 401)
- Where does colonial intelligence come from?
- How do laws governing the whole emerge from the actions of individual parts?


E.O. Wilson

Collections Of Independent Individuals

- French biologists Etienne Rabaud espoused a view that was a radical reaction to Wheeler's superorganism
- "His entire work on insect societies was an attempt to demonstrate that each individual insect in a society behaves as if it were alone" (Theraulaz & Bonabeau, 1999)
- Swarm or colonial intelligence wasn't real – it was just in the eye of the beholder
- Note that such a view could separate humans, again, from the beasts by denying colonial rationality

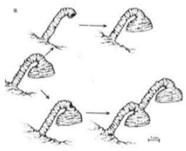
Stigmergy

- Stigmergy was proposed in 1959 by biologist Grassé in his theory of termite nest construction
  - From the Greek *stigma*: sting and *ergon*: work
- It accounts for how swarm intelligence emerges from individual behaviour
- 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

Individual Example

- *Paralastor* wasp has a 5 stage nest building sequence
- Completion of one stage triggers the next
- Introduction of trigger in wrong part of sequence (e.g., hole in existing structure) leads to triggering of wrong behavior, and of aberrant nests



Explaining Colonial Intelligence

- Stigmergy has been studied extensively for the role that it might play in guiding the construction of nests by the *Polistes* wasps
- Nest structure cannot be explained by appealing to "innate model"
- Nor can it be explained by appealing to a "motor and evaluation program"
- Instead, models show how it can be explained by appealing to stigmergic control

Where Will Wasps Add The Next Cell?

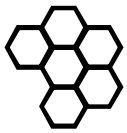
- One key issue is predicting where the next cell will be initiated by building wasps
- Cell growth occurs with equal probability in all directions of space
- How do wasps bring this principle to life?
- Théraulaz and Bonabeau (1999) propose that stigmergy provides the answer

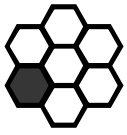
Guy Théraulaz

Eric Bonabeau

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





When Will Wasps Lengthen A Cell Wall?

- In a *Polistes* nest, each cell contains one larva
- As it grows, the cell must be lengthened
- But empty cells will be lengthened too, particularly a new cell that will soon be lengthened to be similar to its neighbours
- Karsai (1999) argues that stigmergy might guide this as well

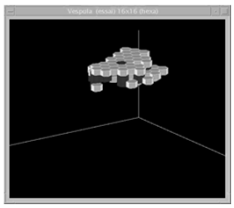
Karsai's Algorithm

- Larger local irregularities in the nest trigger the addition of new nest material with higher probability
- This will smooth the local irregularity, but will likely cause other irregularities at other locations
- Basic rule: if the difference between the shortest and longest wall of a cell is below threshold, leave it alone. Otherwise, add new material to the short wall
- Karsai found that this algorithm generated realistic 3D nests

Istvan Karsai

The Synthetic Approach

- The utility of different approaches to studying nests and stigmergy is typically done synthetically
- Propose a (local) rule using stigmergy
- Build a model that uses the rule
- Does the rule build nests that look natural?
- For more info, see http://www-iasc.enst-bretagne.fr/PROJECTS/SWARM/nest.html



Insect-Inspired Machines

- Collective intelligence in social insects may provide a model for developing such robot collections
- The theme here is that one can get complex results "for free", without having to program rationality or communication into the machines
- Again, this maintains the Cartesian view is that it is the possession of a rational soul that separates man from both machines and beasts!

Demo from http://www.ifi.ntnu.no/grupper/ai/eval/

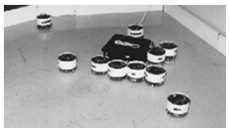
Collective Robotics

- Example: Ronald Kube's work on collective robotics at the University of Alberta
- His focus is on cooperative tasks that cannot be accomplished by a single robot
- Example of such a task is box pushing – weighted box cannot be moved by one robot
- Issue is to create control structure for individuals to accomplish such cooperative tasks

C. Ronald Kube

Stigmergy And Collective Robotics

- Social insects inspire control structures for collective robotics
- Stigmergy is one important example
- "Although it seems intuitive that communication between robots would allow greater cooperation, researchers have begun to investigate cooperative behavior without communication between robots. The advantage of such a noncommunicating system lies in its ability to scale upwards without incurring a communication bottleneck as more robots are added" (Kube & Zhang, 1993)

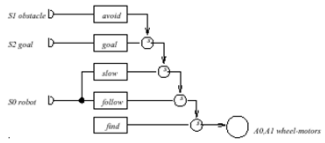


Robot Architecture

- CRIPS robot
- Sensors for detecting the goal (the box), obstacles, other robots
- Left and right motors
- 5 behaviors programmed in, with each behaviour under local control of environmental stimulation

Behaviors And A Subsumption Architecture

- Find: move in a large arc
- Follow: follow another robot
- Slow: slow down to avoid hitting another robot (enables herds to form)
- Goal: turn towards the box
- Avoid: turn away from an obstacle
- These can be arranged in a subsumption architecture as illustrated below



Stigmergy And Box Pushing

- The five behaviors combine to result in collective intelligence
- If you didn't know how they worked, how would you explain this behavior?
- The robots cooperate to push a box to a goal without direct communication
- All communication is accomplished by moving the box, getting in another robot's way, etc.

Human Stigmergy?

- Even though animals can manipulate their environment, it would appear that we can create powerful theories of this behavior that does not require us to assume animals are rational
- These theories can be used to create working robot colonies
- However, this raises an issue that must be addressed: if complex animal structures can be built via environmental control, then is it not possible that complex human artifacts and activities are the result of similar processes?
- To what extent might nonrational processes, or environmental control, govern human cognition?