

Evolution of Herding Behavior in Artificial Animals

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Presented by Jason McNair, February 20, 2003

Problem Addressed

- **Bottom-up exploration of the evolution of cooperative behavior and communication**
 - Evolving herding behavior in simple artificial animals (“biots”) that do not originally herd
- **Helps us to understand origins of animal behavior**
- **Provides models for cooperative behavior in robotics**

Approach

- **Create 2 species of artificial animals, “wolves” and “deer”**
 - Deer increase energy by eating plants
 - Wolves increase energy by eating deer
 - Both species expend energy in eating, mating, existence, etc.
- **Supply with initial population of plants to provide energy**
 - Plants added at constant rate

Approach: Environment

- **Toroidal simulation map**
 - Animals that go up through the top appear at the bottom, and so on
 - Effectively no boundaries
- **Populate with trees and edible plants**
 - Trees can not be eaten, simply add complexity to map
 - Plants tend to cluster, encouraging aggregation in “deer”

Approach: Environment, cont.

- Each type of object has a unique “smell”
 - Smell strength decays exponentially with distance

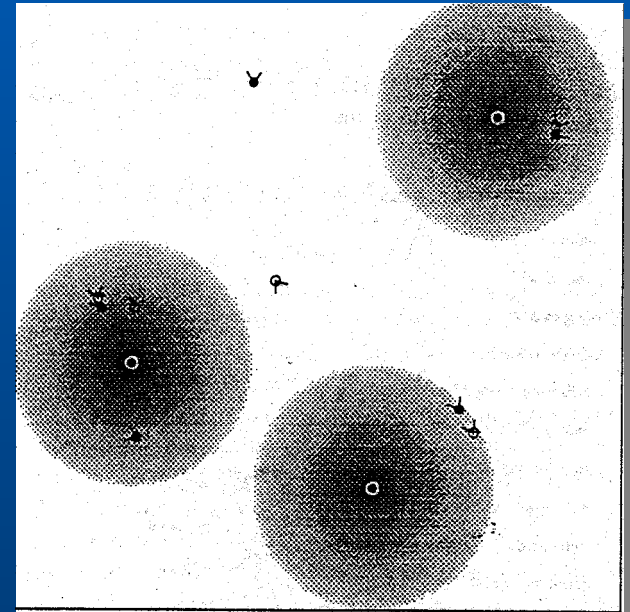


Figure 1: Each object in BioLand produces a number of gradients. Only plant smell gradients are shown here. Sensory neurons on the ends of the animals' “antennae” fire proportionally to the log of the gradient strength for which they are sensitive.

Approach: Environment, cont.

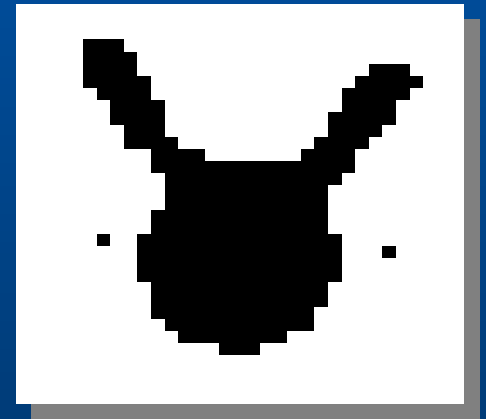
- **Animals have characteristic non-volitional “sounds”**
 - Volume of sound associated with movement is proportional to speed
 - Mating, Eating have characteristic sounds

Approach: Biots

- **Neural network architecture determines Biot behavior**
 - Sensory neurons detect “smells” and “sounds” (wolf, plant, tree, etc.) in environment, as well as other indicators (energy level, being eaten, etc.)
 - Motor neurons control movement, mating impulse, eating, etc.

Approach: Biots, cont.

- **Sensory neurons placed on two distinctly located antennae**
 - One on right, one on left
 - Difference between the two antennae allows Biots to determine directional gradients, locating objects by sound or smell



Approach: Biots, cont.

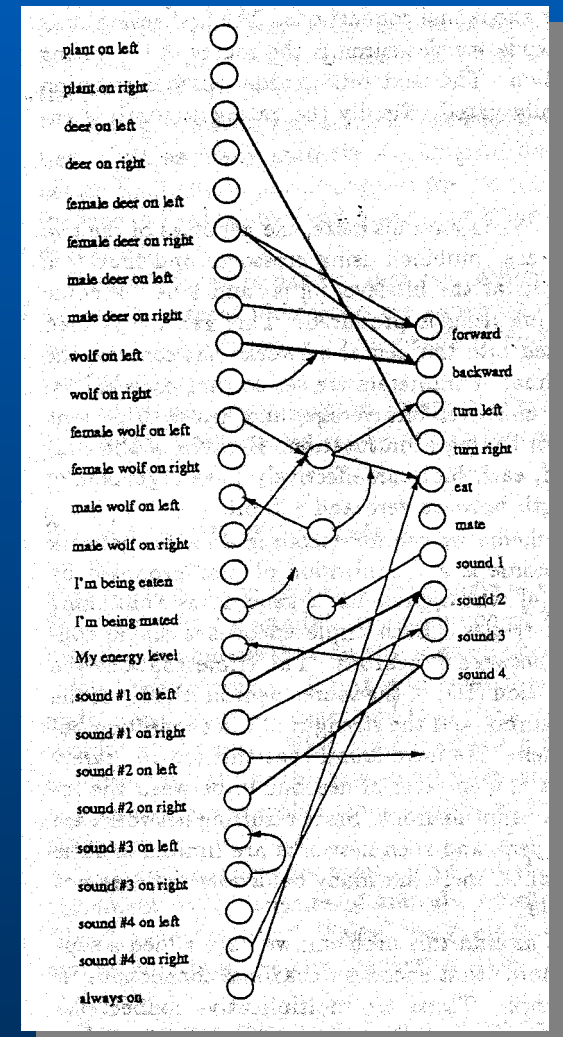
- **Genetic algorithm determines neural network architecture for individual Biots**
 - **Genetic string encodes synaptic strength, source, and destination**
 - **Also encodes axoaxonal connections (synaptic inhibitor gates) to allow for more complex behavior from 2 layer architecture**

Approach: Biots, cont.

- **To successfully mate, Biot must have high energy level**
 - **Mating comes with high energetic costs, Biot must have enough energy to be “fertile”**
 - **Biot must mate with “fertile” member of opposite sex, same species**

Experiment

- Initialize Populations
 - 8,000 genetically random “wolves”
 - 8,000 genetically random “deer”
 - 1,000 by 1,000 Biot length toroidal environment, with initial clusters of plants



Experiment, cont.

- **Behavior of populations checked throughout run**
- **Genome sample taken every 20 generations**
 - **Genomic sample analyzed to determine how Biot behavior is implemented in the network**
 - **Generation length inexact measurement since Biots mate at different times**

Results

- **In early generations, Biot behavior is random**
 - **Most Biots die off, unable to find food**
 - **Population drops to around 400**
 - **Remainder have the few necessary sensory/motor connections to eat and mate**

Results, cont.

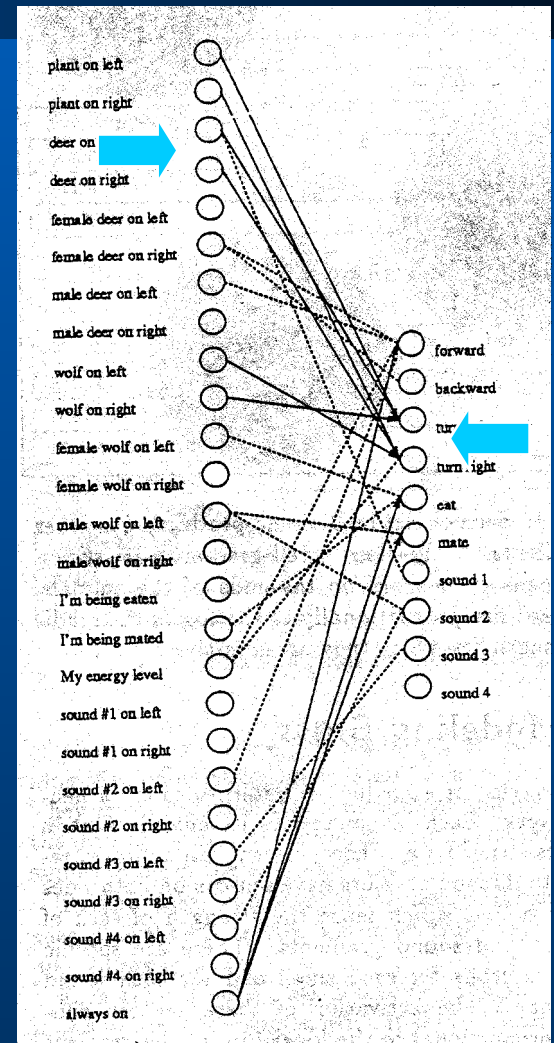
- **At around 30 generations Biots evolve to home toward food, away from predators**
 - **This tendency to move toward food and away from predators causes an elementary aggregation around food sources, safe locations**

Results, cont.

- **Elementary aggregation around food sources, safety is not herding**
 - **Biots being pushed together by environmental factors, not yet seeking out members of their own species and moving toward them (per connections in the neural net)**

Results, cont.

- **Biots do begin herding**
 - At around 80-100 generations Biots evolve to home toward members of same species
 - Neural connections that produce this behavior have evolved in Biots' neural networks



Results, cont.

- **3 pressures cause Biots to begin herding**
 - Pressure to find a mate
 - Herding confuses predators' sense of gradient toward prey
 - Finding food, herd can be thought of as a distributed sensor network where nodes implicitly communicate locations of food sources by moving toward them, or by the sound of eating

Strengths of Approach/Results

- **Smooth evolutionary space (mutation/crossover unlikely to produce individuals that are not viable)**
- **Clearly demonstrates evolution toward herding behavior**
- **Opens up many avenues toward further research in this area**

Weaknesses of Approach/Results

- **Metric not clearly defined**
 - Is herding being defined as the detection of certain sensory to motor connections in the network? This requires support.
 - Is the metric observed herding? Show us herding in action.

Contextual Comparisons

- In view of Mataric, can herding in this case be reduced to a set of basis behaviors?
- Uses in randomized search?
 - Biots require no pre-mapping of search area
 - Adaptation to dynamic challenges
 - Entirely local (including mating)

Major Contributions

- **From a behaviorist perspective, this helps us to understand the origin of simple cooperative/social behaviors in real animals**
- **This allows us to further dissect and understand biological models for cooperative behaviors**

Related Documents

- **Genetically Engineered Battle Boids**
 - <http://web.media.mit.edu/~lifton/proj/Boids/>
- **Shark and Fish Boids**
 - <http://www.codepuppies.com/~steve/aqua.html>
- **Evolving Artificial Neural Networks**
 - <http://citeseer.nj.nec.com/yao99evolving.html>

Questions?

