Coevolutionary Learning with Genetic Algorithms
Problem for learning algorithms:

How to select “training environments” appropriate to different stages of learning?

One solution:

Co-evolve training examples, using inspiration from host-parasite coevolution in nature.
Host-parasite coevolution in nature

- Hosts evolve defenses against parasites
- Parasites find ways to overcome defenses
- Hosts evolve new defenses
- Continual “biological arms race”
Heliconius-egg mimicry in Passiflora

http://www.ucl.ac.uk/~ucbhdjm/courses/b242/Coevol/Coevol.html
• Darwin recognized the importance of coevolution in driving evolution
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• Coevolution was later hypothesized to be major factor in evolution of sexual reproduction
Coevolutionary Learning
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Candidate solutions and training environments coevolve.
Coevolutionary Learning

Candidate solutions and training environments coevolve.

– **Fitness of candidate solution (host):** how well it performs on training examples.
Coevolutionary Learning

Candidate solutions and training environments coevolve.

- **Fitness of candidate solution (host):** how well it performs on training examples.

- **Fitness of training example (parasite):** how well it defeats candidate solutions.
Sample Applications of Coevolutionary Learning
Sample Applications of Coevolutionary Learning

– Coevolving minimal sorting algorithms (Hillis)

- Hosts: Candidate sorting algorithms
- Parasites: Lists of items to sort
Sample Applications of Coevolutionary Learning

- Game playing strategies (e.g., Rosin & Belew; Fogel; Juillé & Pollack)

  • Hosts: Candidate strategies for Nim, 3D Tic Tac Toe, backgammon, etc.

  • Parasites: Another population of candidate strategies
Sample Applications of Coevolutionary Learning

- HIV drug design (e.g., Rosin)
  - Hosts: Candidate protease inhibitors to match HIV protease enzymes
  - Parasites: Evolving protease enzymes
Sample Applications of Coevolutionary Learning

- Robot behavior (e.g., Sims; Nolfi & Floreano)

  - Hosts: Robot control programs
  - Parasites: Obstacles; mazes; competing robot control programs;
Why should we expect coevolutionary learning to speed-up and/or improve evolution?
Why should we expect coevolutionary learning to speed-up and/or improve evolution?

“Biological” arms races

Increased “biodiversity”? 
Practical problems observed in coevolutionary learning
Practical problems observed in coevolutionary learning

- Cycling:

  low "true" fitness
• Loss of gradient for hosts
- Over-“virulence” of parasites
**Hypothesis**

Distributing host and parasite populations in space will overcome these impediments by:

– Preserving diversity in the populations

– Fostering arms races between hosts and parasites
Our Experiments
(Mitchell, Thomure, & Williams, 2006)

Spatial                  Non-spatial

Coevolution

Evolution
Problem domains used in experiments

1. Function induction from data

I.e., given a set of points generated by a “secret” function, find the function.

- **Hosts**: Candidate functions
- **Parasites**: Points generated by the secret function

http://webscripts.softpedia.com/scriptScreenshots/Polynomial-curve-fitting-Screenshots-62898.html

2. Cellular automata
**Spatial Coevolution**

- Host and parasite populations live on a two-dimensional toroidal (i.e., donut-shaped) grid with one host ($h$) and one parasite ($p$) per site

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Fitness of host $h = \text{fraction of 9 neighboring parasites (p) dealt with correctly}$

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Fitness of parasite $p = \text{fraction of 9 neighboring hosts (h) which get p wrong}$

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**Spatial Coevolution**

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At each generation, each $h$ is replaced by mutated copy of winner of tournament among itself and 8 neighboring hosts.

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At each generation, each $p$ is replaced by mutated copy of winner of tournament among itself and 8 neighboring parasites.

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Non-Spatial Coevolution

- Host and parasite populations live in a non-spatial world (no notion of “neighbor” or “distance)

Fitness of host $h = \text{fraction of } 9 \text{ random parasites (p) dealt with correctly}$

Fitness of parasite $p = \text{fraction of } 9 \text{ random hosts (h) which get } p \text{ wrong}$
Non-Spatial Coevolution

- Host and parasite populations live in a non-spatial world (no notion of “neighbor” or “distance)

At each generation, each $h$ is replaced by mutated copy of winner of tournament among itself and 8 random hosts.

At each generation, each $p$ is replaced by mutated copy of winner of tournament among itself and 8 random parasites.
• **Spatial Evolution:**

  – Same as spatial coevolution, except parasites don’t evolve.

  – A new population of random parasites is generated at each generation.
• **Non-Spatial Evolution:**

  – Same as non-spatial coevolution, except parasites don’t evolve.

  – A new sample of random parasites is generated at each generation.
## Results

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<th>Function Induction</th>
<th>Cellular Automata</th>
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<td><strong>Spatial Coev.</strong></td>
<td>78% (39/50)</td>
<td>67% (20/30)</td>
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<tr>
<td><strong>Non-Spatial Coev.</strong></td>
<td>0% (0/50)</td>
<td>0% (0/20)</td>
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<td><strong>Spatial Evol.</strong></td>
<td>14% (7/50)</td>
<td>0% (0/30)</td>
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<td><strong>Non-Spatial Evol.</strong></td>
<td>6% (3/50)</td>
<td>0% (0/20)</td>
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Percentage of successful runs
In short: Spatial coevolution significantly out-performs other methods on both problems
Analysis

Why was spatial coevolution successful?

Hypotheses:

1. Maintains diversity over long period of time

2. Creates extended “arms race” between hosts and parasite populations

Here we examine these hypotheses for the cellular automaton task.

[That is, we will do so after the lecture on cellular automata. To be continued…]