Assignments: 35%
- Students will complete 4/5 assignments based on algorithms presented in class

Lab meets in I1 (West) 109 on Lab Wednesdays
- Lab 0: January 14th (completed)
  - Introduction to Python (No Assignment)
- Lab 1: January 28th
  - Measuring Information (Assignment 1)
  - Graded
- Lab 2: February 11th
  - L-Systems (Assignment 2)
  - Graded
- Lab 3: March 25th
  - Cellular Automata & Boolean Networks (Assignment 3)
  - Graded
- Lab 4: April 8th
  - Genetic Algorithms (Assignment 4)
    - Due: April 22nd
- Lab 5: April 22nd
  - Ant Clustering Algorithm (Assignment 5)
    - Due May 4th
Readings until now

- **Class Book**
    - Chapters 1, 2, 3, 7, 8
      - Chapter 3, all sections
      - Sections 7.8 (evolving L-Systems), 8.3.2 (biomorphs)
    - Chapter 5, all sections
    - Section 7.7, 8.3.1, 8.3.6, 8.3.8-10

- **Lecture notes**
  - Chapter 1: “What is Life?”
  - Chapter 2: “The Logical Mechanisms of Life”
  - Chapter 3: “Formalizing and Modeling the World”
  - Chapter 4: “Self-Organization and Emergent Complex Behavior”
  - Chapter 5: “Reality is Stranger than Fiction”
    - posted online @ [http://informatics.indiana.edu/rocha/i-bic](http://informatics.indiana.edu/rocha/i-bic)
Projects

- Due by May 4th in Oncourse
  - ALIFE 15 (14)
    - Actual conference due date: 2016
    - [http://blogs.cornell.edu/alife14nyc/](http://blogs.cornell.edu/alife14nyc/)
      - 8 pages (LNCS proceedings format)
    - [http://www.springer.com/computer/lncs?SGWID=0-164-6-793341-0](http://www.springer.com/computer/lncs?SGWID=0-164-6-793341-0)
  - Preliminary ideas *overdue!*

- Individual or group
  - With very definite tasks assigned per member of group
The workings

1) Generate Random population of bit-strings
2) Evaluate Fitness Function for each decoded solution
3) Reproduce next generation
   - Selection by fitness
   - Variation
     - crossover and mutation
   - Fill new population
4) Go back to 2) until stop criteria is met
   - Desired fitness
   - Specified number of generations
   - Convergence
     - Lack of variability in population and/or fitness
       - Tends to a peak

\[ f(x_1) \]
\[ f(x_2) \]
\[ f(x_3) \]
\[ f(x_4) \]

Parents

Crossover

No crossover
Search algorithms based on the mechanics of Natural Selection
Based on distinction between a machine and a description of a machine
Solution alternatives for optimization problems

Traditional Genetic Algorithm

Genotype

Variation

Selection

Phenotype

Code:

Inherited variation

transcription

RNA

translation (code)

amino acid chains

development

environmental ramifications

organism

Genotype

DNA

RNA transcription

Translation

Amino acid chains

Development

Phenotype

Inherited variation

Selection

Variation

Genotype

Code:

Environmental ramifications
Types of encoding

- **Binary encodings**
  - Typically fixed-length

- **Many-letter encoding**
  - Larger alphabet (e.g. graph-generation grammars)

- **Real-valued encodings**
  - Genes take real values

- **Tree Encodings**
  - Genetic programming

- **Indirect Encodings**
  - Modeling Phenotype **development** or post-**transcription** processes
    - L-Systems, Dynamical systems, evolutionary robotics
The artificial genome
Including transcription regulation and translation


TATA box

Gene A

Gene B

0213202023010132021202032102031323312010132292

Translation

031323

Gene product

Gene A

Gene B

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RNA Editing: post-transcriptional alteration of genetic information

- can be performed by ncRNA structures and proteins (i.e. enzyme cascades).

U-Insertion/deletion RNA Editing (mitochondria of kinetoplastid protozoa)

- Involve small guide RNAs (gRNA) complementary to the target mRNA, and editosome (multi-protein complex)
  - gRNA is a template for editing
- insertion/deletion of Uracil (U) residues, usually in coding regions of mRNA transcripts
  - e.g. creation of open reading frames

U-insertion and A-to-I substitution

is there a **general principle** at play?
Agent-based models of evolutionary dynamics

RNA Editing

Simple fitness function

Royal road

\[ F(x) = \sum_{s_i \in S} c_i \sigma_{s_i}(x) \]

- Miniature of "Royal Road" function (Forrest and Mitchell, 1993)
  - Schemata \( S = (s_1, \ldots, s_8) \)
  - \( c_i \) is a value assigned to each schema \( s_i \)
  - \( \sigma_{s_i}(x) = 1 \) if \( x \) is an instance of \( s_i \) and 0 otherwise
  - Fitness of the global optimum string (40 1's) is 10*8 = 80

\[
\begin{align*}
  s_1 &= 11111\cdots; \quad c_1 = 10 \\
  s_2 &= \ast\ast\ast11111\cdots; \quad c_2 = 10 \\
  s_3 &= \ast\ast\ast\ast\ast1111\cdots; \quad c_3 = 10 \\
  s_4 &= \ast\ast\ast\ast\ast\ast1111\cdots; \quad c_4 = 10 \\
  s_5 &= \ast\ast\ast\ast\ast\ast\ast1111\cdots; \quad c_5 = 10 \\
  s_6 &= \ast\ast\ast\ast\ast\ast\ast\ast1111\cdots; \quad c_6 = 10 \\
  s_7 &= \ast\ast\ast\ast\ast\ast\ast\ast\ast1111\cdots; \quad c_7 = 10 \\
  s_8 &= \ast\ast\ast\ast\ast\ast\ast\ast\ast\ast1111; \quad c_8 = 10
\end{align*}
\]
Simple example

50 runs for small royal road testbed
example run: Schwefel function
Agent-based models of RNA Editing

ABMGE on oscillatory fitness landscapes

GA

ABMGE

Agent-based models of RNA Editing

ABMGE on dynamical environments

Delta = 1

Delta = -1


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Genomic complexity and multi-level selection

- Selection between groups within a population
- Selection between individuals within a group
- Selection between genes within an individual

Landscape
- Patchwork of regimes
  - Niches (novelty)

Increasing genome complexity:
- Multicellular animals and plants
- Cambrian explosion
- Eukaryotes
- Photosynthetic bacteria
- Bacteria
- Origin of life
  - Origin of Earth
  - Age of Earth (billions of years ago)
  - 4.5
  - 3.9
  - 2.5
  - 1.5
  - 0.5
  - 0
units of selection

moral men might not do any better than immoral men but tribes of moral men would certainly “have an immense advantage” over fractious bands of pirates. (Charles Darwin)

- Multilevel selection theory
  - Selection occurs in multiple levels simultaneously
  - No general-case scenario, each organism on a case-by-case basis
    - David Wilson and E.O. Wilson

- Experiments with *Pseudomonas fluorescens*
  - Oxygen-exhausting bacteria in liquid
  - Groups with enough altruists survive

- Kin-selection as special case of group selection
  - Leading to various, diverse (selectable) groups with high genetic similarity

- Sociobiology
  - Selfishness beats altruism within groups. Altruistic groups beat selfish groups.

“Morality is herd instinct in the individual”. (Friedrich Nietzsche)
Iterated Prisoner's Dilemma

Encoding

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<th>P2</th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
<td>D</td>
</tr>
<tr>
<td>P1</td>
<td>C (3,3)</td>
<td>(0,5)</td>
</tr>
<tr>
<td></td>
<td>D (5,0)</td>
<td>(1,1)</td>
</tr>
</tbody>
</table>

\[ h_m = (a_{m-1}, \ldots, a_1, a_0) \]

Lindgren's iterated game for agents with memory

\[ h_1 = (a_1, a_0) \]

4 possible strategies
(genotype=2 bits)

16 possible strategies
(genotype=4 bits)

Used in the evolutionary search by GA (tournament selection)
memory 0 strategies

FIGURE 1 The evolution of a population of strategies starting with equal fractions of the memory one strategies [00], [01], [10], and [11] is shown for the first 600 generations. The fractions of different strategies are shown as functions of time (generation).

$$h_0 = (a_0)$$

4 possible strategies

D 0
C 1

0 0 1 1
0 1 0 1

TFT
higher memory rules

\[ h_1 = (a_1, a_0) \]

Used in the evolutionary search by GA (tournament selection)

GA uses variable length genotype

TFT

\[ \begin{align*}
0 & 0 \\
0 & 1 \\
1 & 0 \\
1 & 1
\end{align*} \]
### Natural design principles

**exploring similarities across nature**

- **self-similar structures**
  - Trees, plants, clouds, mountains
  - Morphogenesis
  - Mechanism
    - Iteration, recursion, feedback

- **Unpredictability**
  - From limited knowledge or inherent in nature?
  - Mechanism
    - Chaos, measurement

- **Collective behavior, emergence, and self-organization**
  - Complex behavior from collectives of many simple units or agents
    - Cellular Automata, Ant colonies, development, morphogenesis, brains, immune systems, economic markets
  - Mechanism
    - Parallelism, multiplicity, multi-solutions, redundancy

- **Adaptation**
  - Evolution, learning, social evolution
  - Mechanism
    - Reproduction, transmission, variation, selection

- **Network causality (complexity)**
  - Behavior derived from many inseparable sources
    - Environment, embodiment, epigenetics, culture
  - Mechanism
    - Interactivity, connectivity, stigmergy, non-holonomic constraints
biologically inspired computing

biological, social and complexity explanations

differences and explanations

- Emergent behavior
  - Intricate structures and behavior from the interaction of many simple agents or rules

- Examples
  - Cellular Automata, Ant colonies, development, morphogenesis, brains, immune systems, economic markets

- Mechanism
  - Parallelism, multiplicity, stigmergy, multi-solutions, redundancy

- Design causes
  - Natural selection, self-organization, epigenetics, culture
Artificial ecosystems

- Automata with diverse characteristics
  - Bugs have an identity separate from the world
    - Bug: data structure and set of rules
    - World: Arena for information exchange plus set of rules

Figure by Rudy Rucker in *Artificial Life Lab*.
Automata with diverse characteristics
- Bugs have an identity separate from the world
  - Bug: data structure and set of rules
  - World: Arena for information exchange plus set of rules

Typical bug implementation
- ID#
- Transition tables, rules of operations
- Position in world
- Fitness value
- State (e.g. mood)
- Velocity
  - Speed and direction
- Group membership

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<table>
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<th>1</th>
<th>2</th>
<th>3</th>
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<th>5</th>
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<tbody>
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<td>1</td>
<td>-1</td>
<td>-2</td>
<td>-1</td>
<td>1</td>
</tr>
<tr>
<td>Change in Y</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>-2</td>
<td>-2</td>
</tr>
</tbody>
</table>

Figures by Rudy Rucker in *Artificial Life Lab*. 
- Boids by Craig Reynolds (1986)
  - 3 Steering behaviors
    - **Alignment**: move towards the average heading of local flockmates
      - Adjust velocity direction according to others in vicinity
    - **Separation**: steer to avoid crowding local flockmates
      - Maintain minimum distance to others (adjusting speed)
    - **Cohesion**: steer to move toward the average position of local flockmates
      - Adjust velocity direction according to others in vicinity
  - Each boid sees only flockmates within a certain small neighborhood around itself.
Class Book
  - Chapter 5, all sections
  - Section 7.7, 8.3.1, 8.3.6, 8.3.8-10

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Optional materials