Evolutionary Computation

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Outline

- Introduction to Evolutionary Computation
- Genetic Algorithms
- Genetic Programming
- “Real World” Example

Motivation for Evolutionary Computation (EC)

- Science
  - Understand evolutionary mechanisms
    - mutation
    - crossover
    - co-evolution
    - etc.
  - Understand evolved characteristics
    - behavior
    - learning
    - etc.
- Engineering
  - Create better designs

Implementation of Evolutionary Computation (EC)

- *Inspired* by biological evolution
- Required components:
  - Replicators (genes)
  - Replication (copying)
  - Selection mechanism (survival)
- Requirement:
  - Replication must be high fidelity
- Result:
  - Differential reproduction of replicators

Details of Biological Evolution

- Additional terminology
  - Chromosome: A collection of genes
  - Locus: A location within a chromosome
  - Allele: A possible gene at a given locus
  - Genotype: All the genes of an individual
  - Phenotype: The expression of an individual's genes
    - may be environmentally influenced

Details of Biological Evolution

- At what level does selection take place?
  - Gene
  - Chromosome
  - Individual
  - Species
  - Genus
  - Other Group (e.g., Family, family, colony)
- Why does this matter to us?

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EC Types

- Genetic Algorithms
- Genetic Programming
- Evolution Strategies
- Evolutionary Programming
- Grammatical Evolution
- Learning Classifier Systems
- Estimation of Distribution Systems
- Etc.

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Genetic Algorithms (GAs)

- Genes – bits, integers, floats, etc.
- Chromosome – array of genes, e.g.:
  `00100000101101110111000010111101`
  - Also called genotype or individual
  - Note lack of distinction between:
    - chromosome and genotype
    - genotype and phenotype
- Locus – position in array
- Population – collection of individuals
- Generation – population at a given time

GA Operators 1

- Crossover
  - Example two point, two offspring
    - Parents:

00001|011011101110|0010

11111|111111111111|1111

- Off-spring:

11111|011011101110|1111

↕ ↕

00001|111111111111|0010

GA Operators 2

- Mutation
  - Example single point mutation
    - Original: 111110110111011101111
    - Mutated: 111010110111011101111

GA Procedure – Steady State

Randomly initialize population

Repeat

  Selection

  Reproduction – Crossover

  Mutation

Until *solution found or resources exhausted*

GA Procedure – Generational

Randomly initialize population

Repeat

  Repeat

   Selection

   Reproduction – Crossover

   Mutation

  Until *new generation created*

Until *solution found or resources exhausted*

GA Selection

Randomly initialize population

Repeat

    Repeat

      Selection – using fitness function

      Reproduction – Crossover

      Mutation

    Until *new generation created*

Until *solution found or resources exhausted*

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GA Fitness Function

- Example: Onemax
- Chromosomes:

label	string	fitness
A	`00000110`	2
B	`11101110`	6
C	`00100000`	1
D	`00110100`	3

GA Selection

label	string	fitness
A	00000110	2
B	11101110	6
C	00100000	1
D	00110100	3

- Can do selection proportional to fitness:

  AABBBBBBCDDD

- Generate numbers from 1 to 12
- Select corresponding parents

GA Selection

label	string	fitness
A	00000110	2
B	11101110	6
C	00100000	1
D	00110100	3

- Can do selection proportional to fitness:

  AABBBBBBCDDD

- Generate numbers from 1 to 12 (6, 10, 9, 6)
- Select corresponding parents (B, D, C, B)

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GA Procedure – Generational

Randomly initialize population

Repeat

Repeat

Selection

Reproduction – Crossover

– e.g., Probability 60%

Mutation

Until *new generation created*

Until *solution found or resources exhausted*

GA Crossover

- Suppose *one* crossover
- Use selected chromosomes:

  B 11101110

  D 00110100

- Generate numbers from 1 to chromosome length (here 8), say 1 and 5, and generate offspring:

  B' 1|0110|110

  D' 0|1101|100

GA Procedure – Generational

Randomly initialize population

Repeat

  Repeat

   Selection

   Reproduction – Crossover

   Mutation

    – e.g., Probability 0.1% per gene

  Until *new generation created*

Until *solution found or resources exhausted*

GA Mutation & Results

- Suppose *no mutation*, then population of next generation is:

label	string	fitness
B'	10110110	5
D'	01101100	4
B	11101110	6
C	00100000	1

Results of One Generation

- Has average population fitness gone up, gone down, or stayed the same?
- ***Why?***
- Are we making progress?
- ***Why?***

GA Procedure – Generational

Randomly initialize population

Repeat

✓**Repeat**

Selection

Reproduction – Crossover

Mutation

Until *new generation created*

Until *solution found or resources exhausted*

GA Procedure – Generational

Randomly initialize population

Repeat

✓**Repeat**

Selection

Reproduction – Crossover

Mutation

Until *new generation created*

Until *solution found or resources exhausted*

– need a criterion,

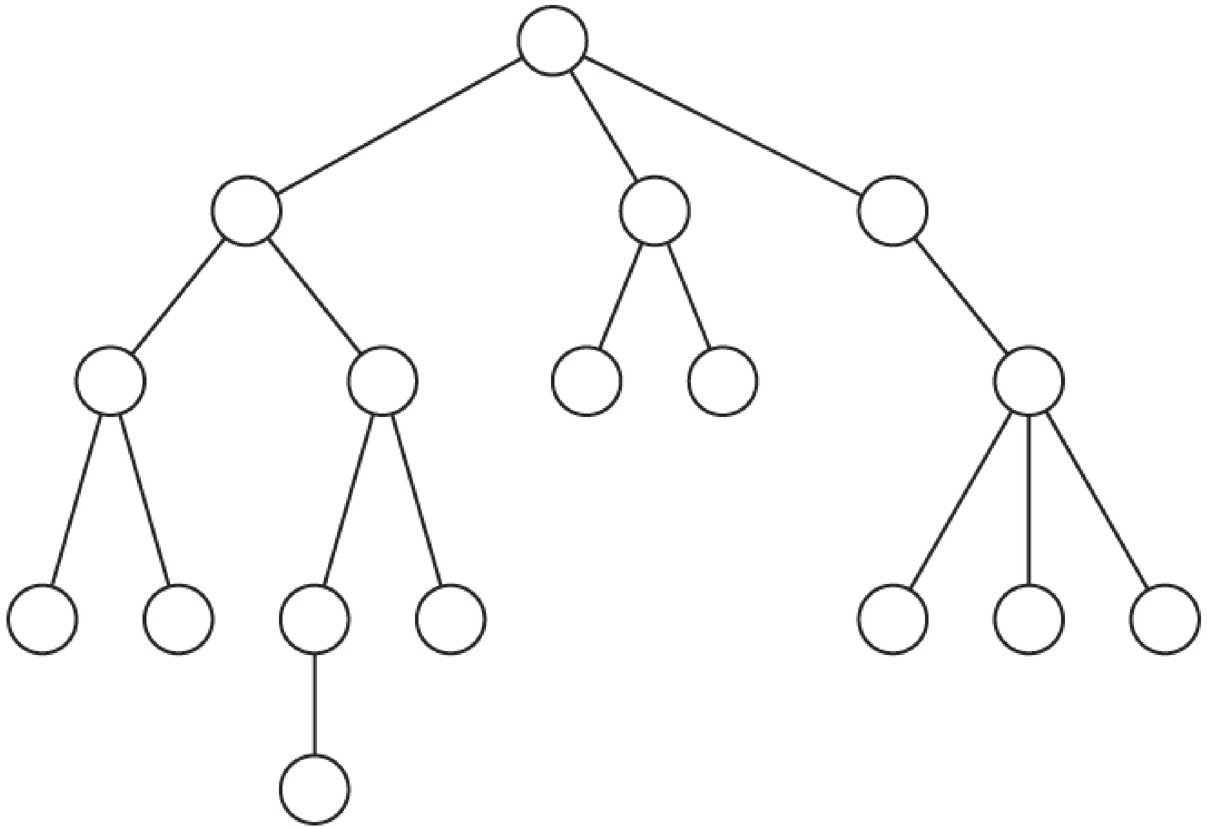
e.g., an individual has all ones

Genetic Programming (GP)

- Genes – typically operators and operands
- Chromosome – typically tree of genes
  - Also called genotype or individual
  - Note lack of distinction between:
    - chromosome and genotype
    - genotype and phenotype
- Locus – not well defined
- Population – collection of individuals
- Generation – population at a given time

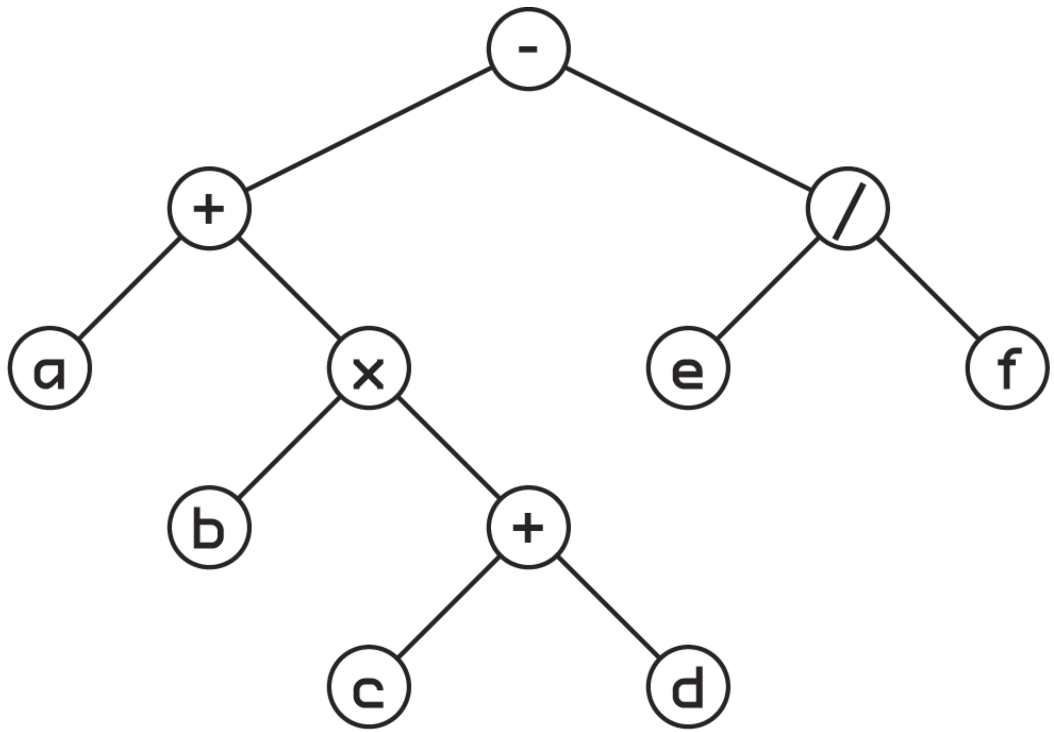
GP Individual

- Structure



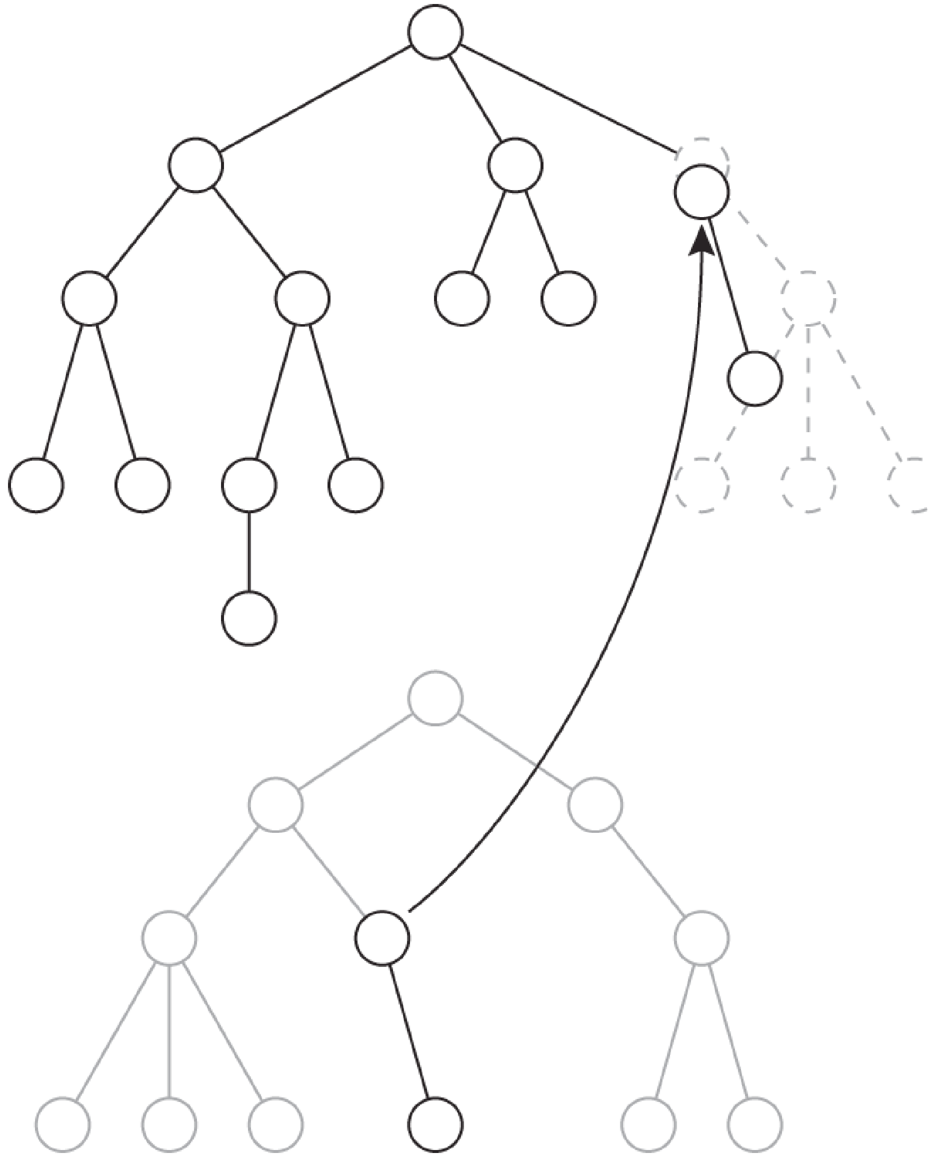
GP Individual

- Complete

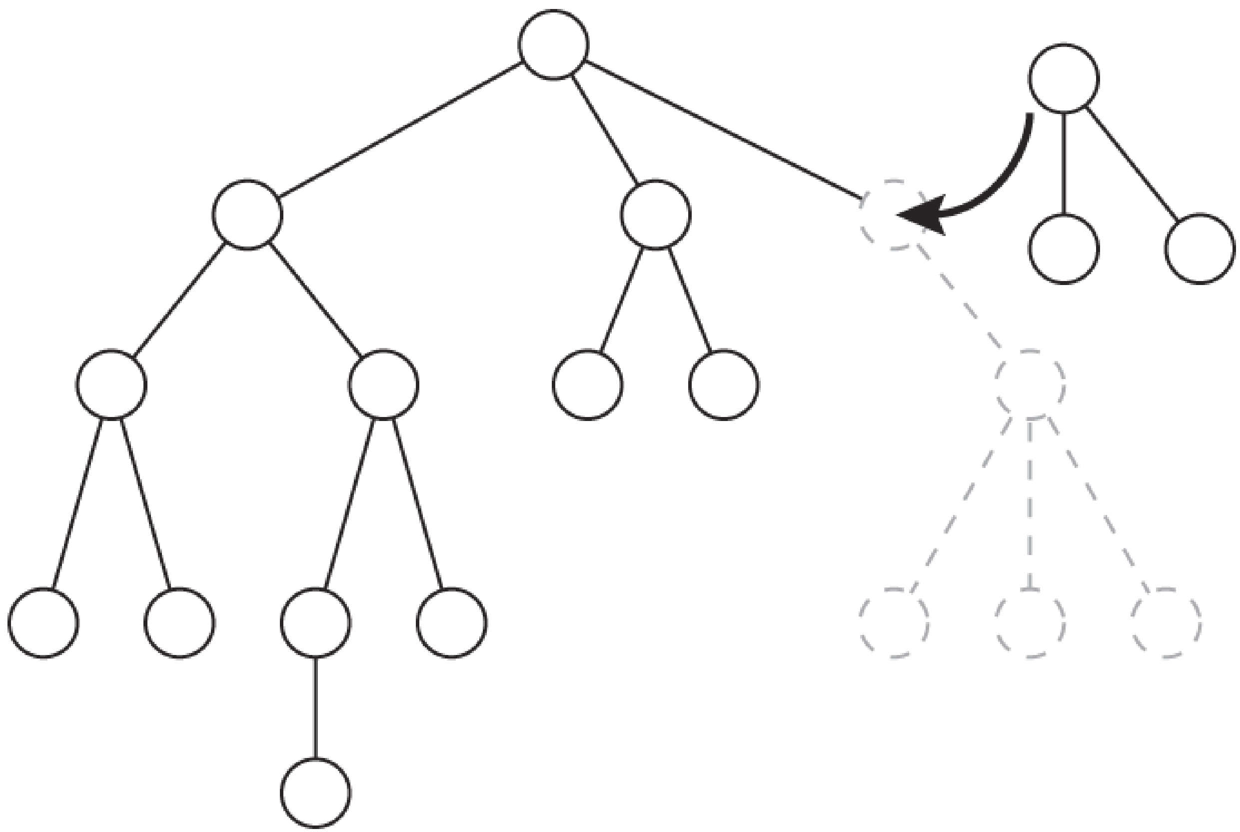


(a + (b x (c + d))) - (e / f)

GP Crossover



GP Mutation



Artificial Ant: Problem Definition

- Navigate along food trail (Koza, 1992)
  - Trail has
    - turns
    - gaps
    - maximum moves allowed

- Fitness:
  - amount of uneaten food at run end

Artificial Ant: Setup

Non-Terminals

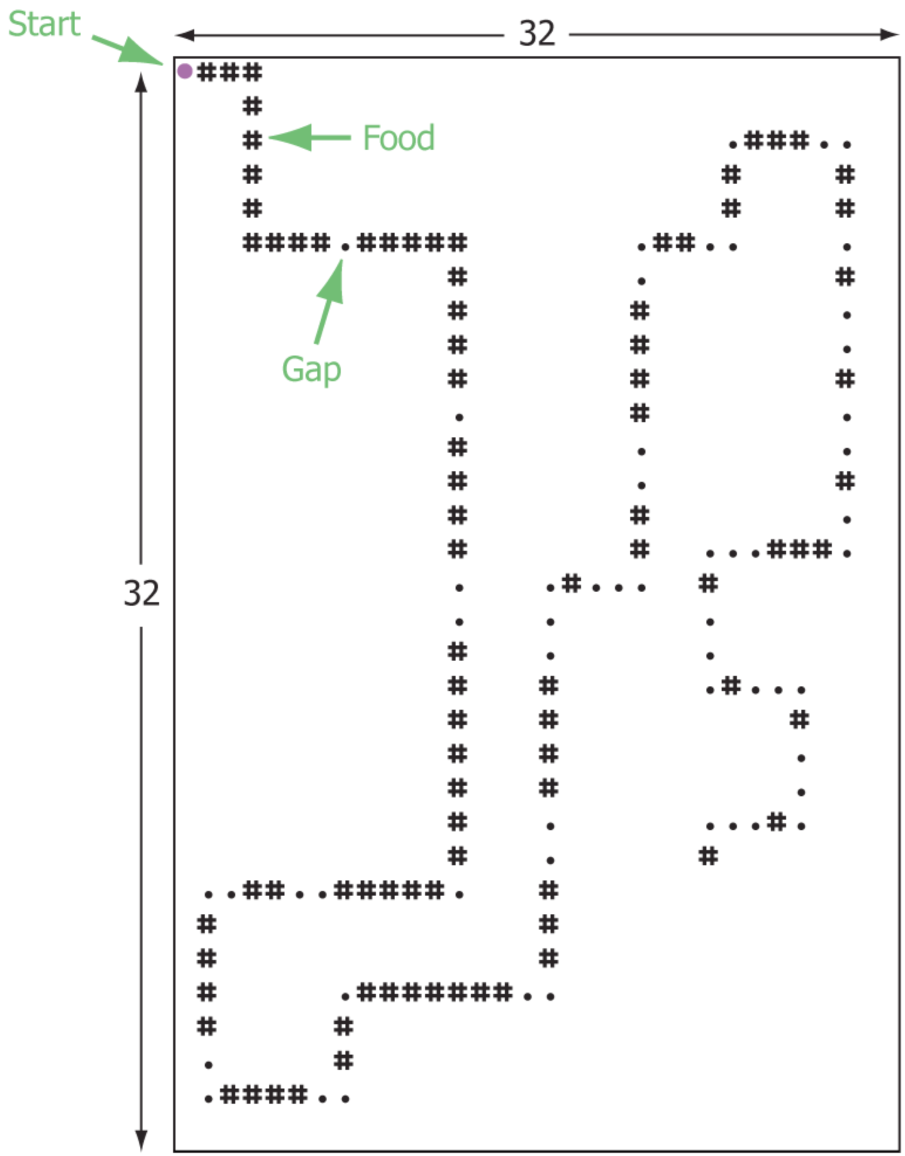
- IF-FOOD-AHEAD
- PROGN2
- PROGN3

Terminals

- MOVE (forward)
- LEFT (turn)
- RIGHT (turn)

All terminals modify state

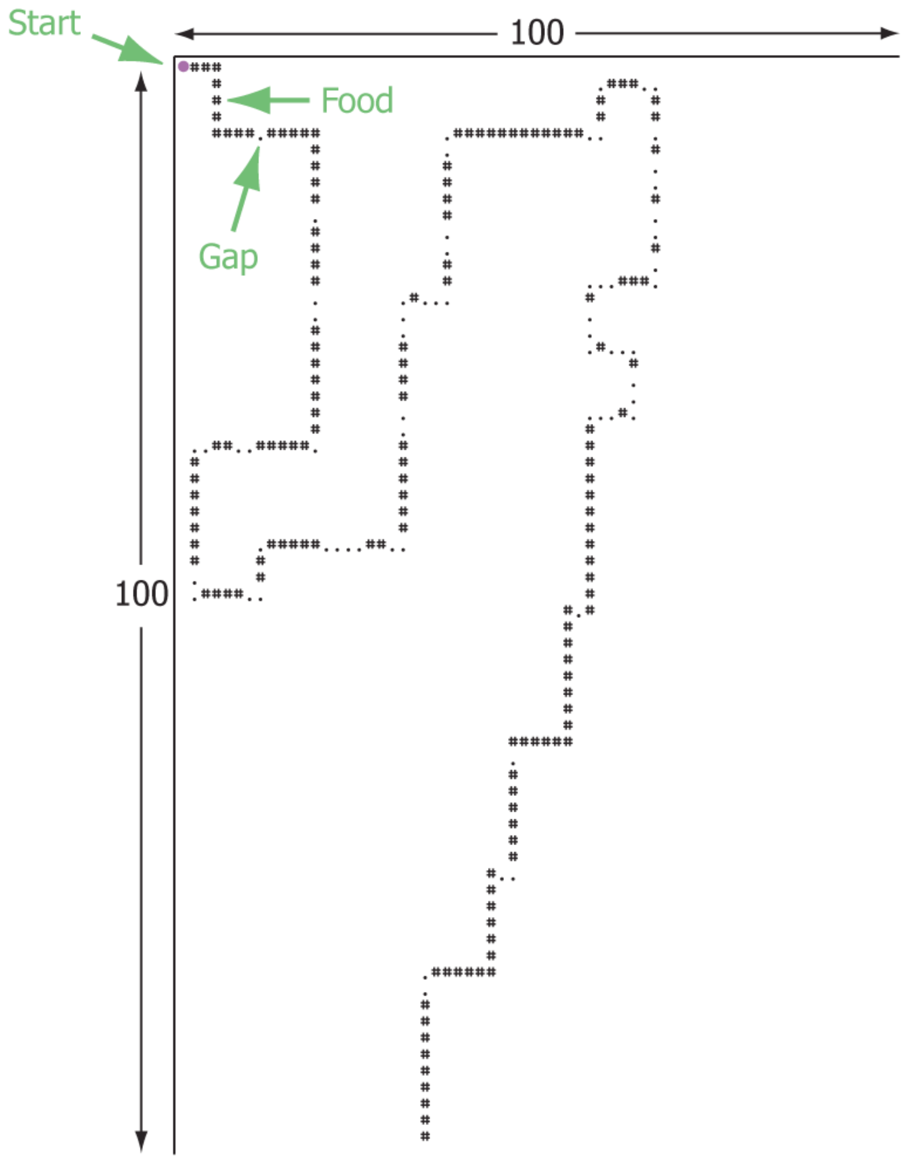
Artificial Ant: Sante Fe Trail



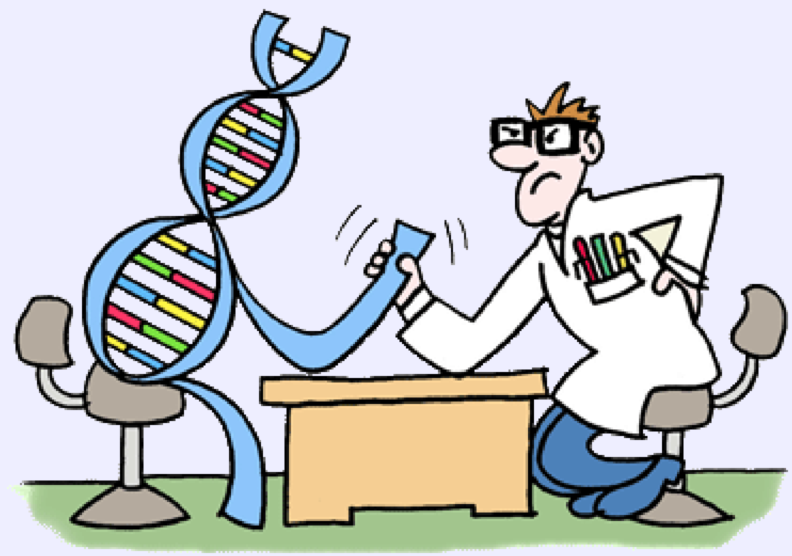
Sante Fe Trail: Sample Solution

```
(progn3
  (if-food-ahead left
    (if-food-ahead
      (progn2 move left)
      (if-food-ahead right right)
    )
 )
  (if-food-ahead
    (progn2 move left)
    (if-food-ahead right right)
  )
  (progn3
    (if-food-ahead move right)
    (progn2 move right)
    (progn2 right left)
  )
)
```

Artificial Ant: Los Altos Trail



ANNUAL **"HUMIES"** AWARDS
FOR HUMAN-COMPETITIVE RESULTS
PRODUCED BY GENETIC AND EVOLUTIONARY COMPUTATION
HELD AT THE
ANNUAL GENETIC AND EVOLUTIONARY COMPUTATION CONFERENCE



2009 Humies 2008 Humies 2007 Humies 2006 Humies 2005 Humies 2004 Humies

www.human-competitive.org

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Humie Example: Antenna Design

- NASA Space Technology 5 Mission
  - Three micro-satellites exploring Earth's magnetic fields
  - Requirements:
    - wide beam width
    - circularly-polarized wave
    - wide bandwidth
  - Competitive bid selected human engineering team (contractor)
    - team created antenna design based on best engineering practices

Humie Example: Antenna Design

- NASA Space Technology 5 Mission
  - *In addition*, different team used evolutionary computation methods
    - Evolvable Systems Group at NASA Ames Research Center
    - genetic algorithms
    - genetic programming

Humie Example: Antenna Design

- NASA Space Technology 5 Mission
  - Conventional design
    - did *not* meet mission requirements
    - required 5 person-months to complete
  - Evolved designs
    - *did* meet mission requirements
    - required 3 person-months to complete

Questions?