Genetic Algorithms and Genetic Programming

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Evolutionary Computation

- Genetic Algorithms and Genetic Programming are prototypical examples of what is called *Evolutionary Computation*
- Evolutionary computation characterized by
  - Population consisting of multiple "individuals"
  - Fitness function evaluating individuals
  - Reproduction strategy for generating new generations of individuals
  - Ideally, fitness increases (on average) over successive generations
- Ultimately just a focused random search strategy for finding maximum-fitness individuals

Pseudo-code

```
Initialize generation counter
Initialize a (usually random) population of individuals
Evaluate fitness of all individuals of population
While not done (based on fitness, # generations, etc.)
    Increment the generation counter
    Select a sub-population for generating new offspring
    Generate new individuals using
        • replication of individuals
        • crossover using 2 parents
        • mutation of resulting individuals
    Evaluate fitness of all new individuals
```

Genetic Algorithms

- Prototypical representation: fixed length bit strings
  - "chromosomes"
- To create new individuals, select 2 "parents"
- Combine the bit strings of the 2 parents in some way to create one or more (often 2) new individuals
  - Crossover
- Also, apply small random perturbations to the "children"
  - Mutation

Crossover Operators

- Single-point

11101001000 → 11101010101
00001010101 → 00001001000

- Two-point

11101001000 → 00101000101
00001010101 → 11001011000

- Uniform

11101001000 → 10001000100
00001010101 → 01101011001

Mutation Operator

11101001000 → 11101011000

With some probability, a bit is flipped.

GA Representations

- Bit strings
  - Fixed length
  - Variable length
- Strings of more general kinds of data
  - Integers
  - Reals

Representation Issues

- What if some chromosomes don’t represent valid objects in the domain of the search space? Possible approaches:
  - Give meaningless chromosomes very low fitness
  - Limit crossover or other operators so that only valid chromosomes generated
  - Follow generation of any new chromosome with a step that modifies it to make it valid

Selecting Most Fit Individuals

- Fitness proportionate selection

$$P(x_i) = \frac{Fitness(x_i)}{\sum_j Fitness(x_j)}$$

- Tournament selection
  - Pick a random subset of individuals (often 2)
  - With fixed probability *p*, select the most fit
- Rank selection
  - Sort individuals by fitness
  - Prob. of selection based on rank

Selecting Most Fit Individuals

Another interesting way

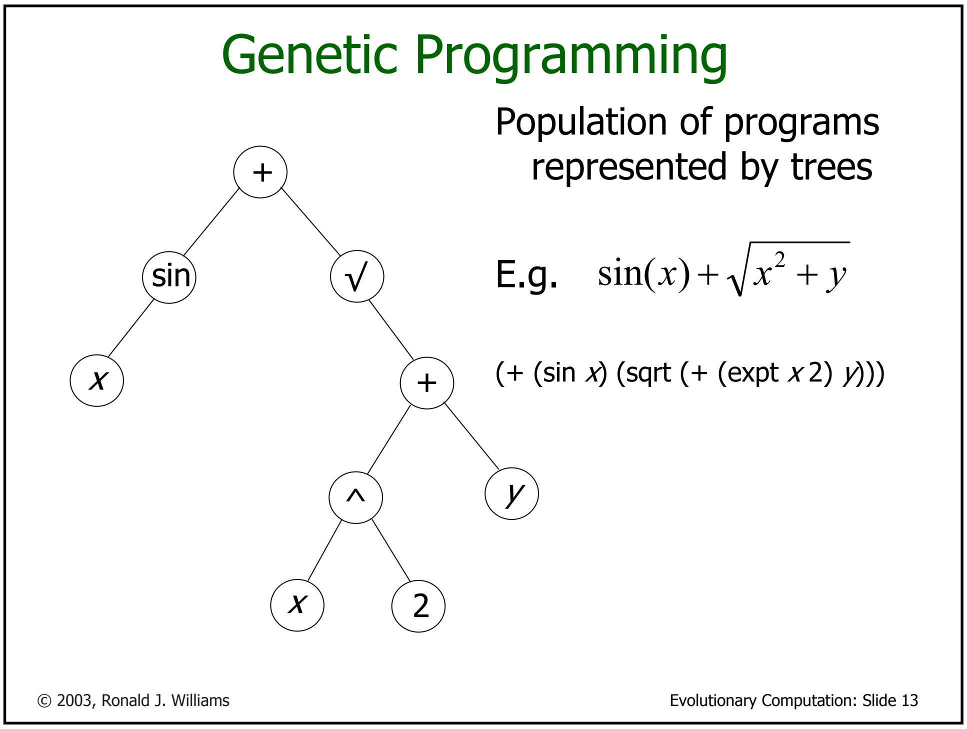
- Have individuals compete head-to-head
- Appropriate where fitness defined in terms of competitive ability
- Used to evolve neural networks for evaluating checkers board positions (Fogel)

Applications

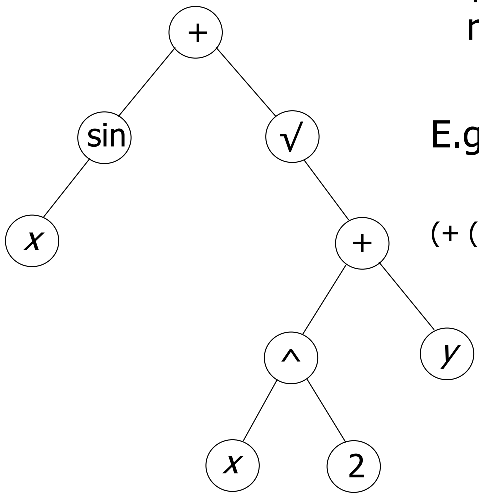
- Timetabling (e.g., exam scheduling)
- Discovering successful policies in simple dynamical systems (e.g., pole-balancing)
- Neural networks
  - Finding weights
  - Finding topology
- Other combinatorial optimization problems
  - Traveling salesman

Where do GAs fit?

- Perhaps more of a *machine discovery* method
  - A way to search spaces for "fit" individuals
  - Can be used to search for good hypotheses in more traditional machine learning applications
    - Weights/topology in neural networks
    - Rules
    - Decision trees



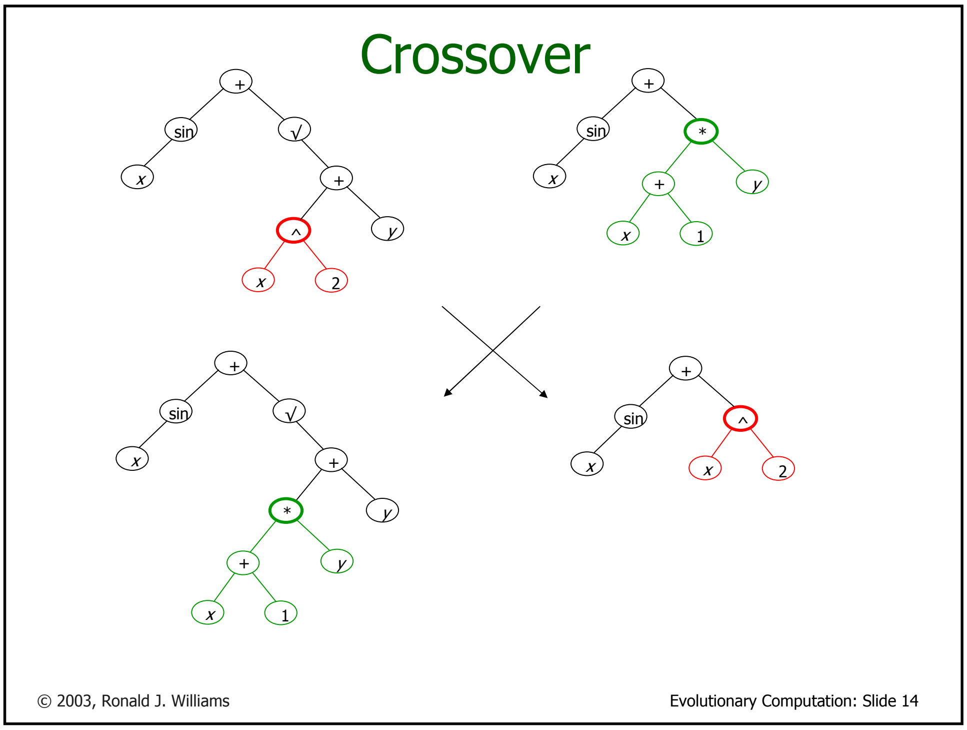
Genetic Programming



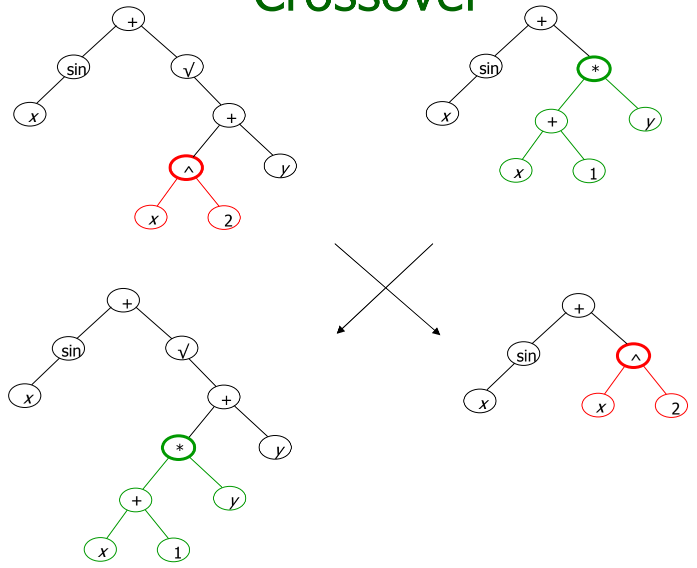
Population of programs represented by trees

E.g. $\sin(x) + \sqrt{x^2 + y}$

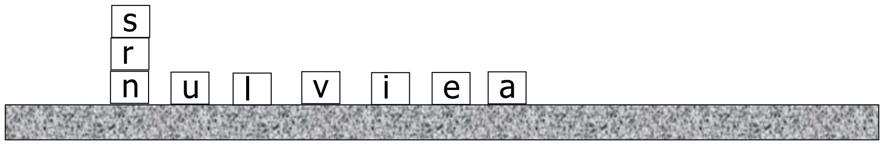
(+ (sin *x*) (sqrt (+ (expt *x* 2) *y*)))



Crossover



Block Stacking Problem (Koza)



Goal: Spell UNIVERSAL vertically

Terminals:

- CS ("current stack") = name of the top block on the stack, or F
- TB ("top correct block") = name of topmost correct block on stack
- NN ("next necessary") = name of the next block needed above TB in the stack

Block Stacking: Primitive Functions

- (MS x): ("move to stack"), if block x is on the table, moves x to the top of the stack and returns T. Otherwise, does nothing and returns F.
- (MT x): ("move to table"), if block x is somewhere in the stack, moves the block at the top of the stack to the table and returns T. Otherwise, returns F.
- (EQ x y): ("equal"), returns T if x equals y, and F otherwise.
- (NOT x): returns T if x = F and returns F if x=T
- (DU x y): ("do until"), executes x repeatedly until y returns T

Learned Program

- Trained to fit 166 test problems
- Using population of 300 programs, found this after 10 generations:

```
(EQ (DU (MT CS) (NOT CS))
    (DU (MS NN) (NOT NN)))
```

Use of EQ here just a syntactically valid way to perform sequential execution

Another Example: Electronic Circuit Design

(Koza)

- Individuals are programs that transform beginning circuit to final circuit by adding or subtracting components and connections
- Use population of 640,000, run on 64 node parallel processor
- Discovers filter circuits competitive with best human designs

Evolutionary Methods: Upside

- Simple to implement
- Easily parallelized
- Less subject to local optima than more local search techniques
- Very general-purpose framework

Evolutionary Methods: Downside

- Often extremely large search spaces
  - Need to carefully handcraft
    - Fitness function
    - Representation of individuals
    - Operators
  - Can be impractically slow
- Very little theory