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Evolutionary Computation

Part of COMP4660/8420:
Neural Networks, Deep Learning and Bio-inspired Computing

3. Genetic Programming

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Human Centered Computing (HCC) Laboratory
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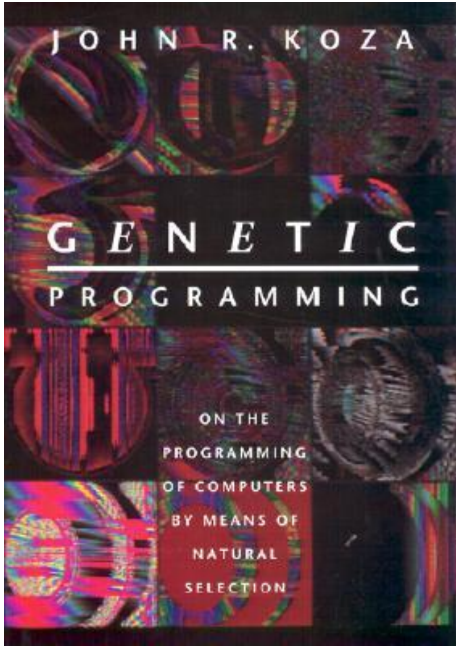
GP Quick Overview

- Developed: USA in the 1990's
- Early names: John Koza, Stanford University
- Typically applied to:
  - machine learning tasks (prediction, classification…)
- Attributed features:
  - competes with neural nets and alike
  - needs huge populations (thousands)
  - slow
- Special:
  - non-linear chromosomes: trees, graphs
  - mutation possible but not necessary (disputed!)



GP Technical Summary Tableau

Representation	Tree structures
Recombination	Exchange of subtrees
Mutation	Random change in trees
Parent selection	Fitness proportional

Introductory example: credit scoring

- Bank wants to distinguish good from bad loan applicants
- Model needed that matches historical data

ID	No of children	Salary	Marital status	OK?
ID-1	2	45000	Married	0
ID-2	0	30000	Single	1
ID-3	1	40000	Divorced	1
…				

Introductory Example: Credit Scoring

- A possible model:

  IF (NOC = 2) AND (S > 80000) THEN good ELSE bad

- In general:

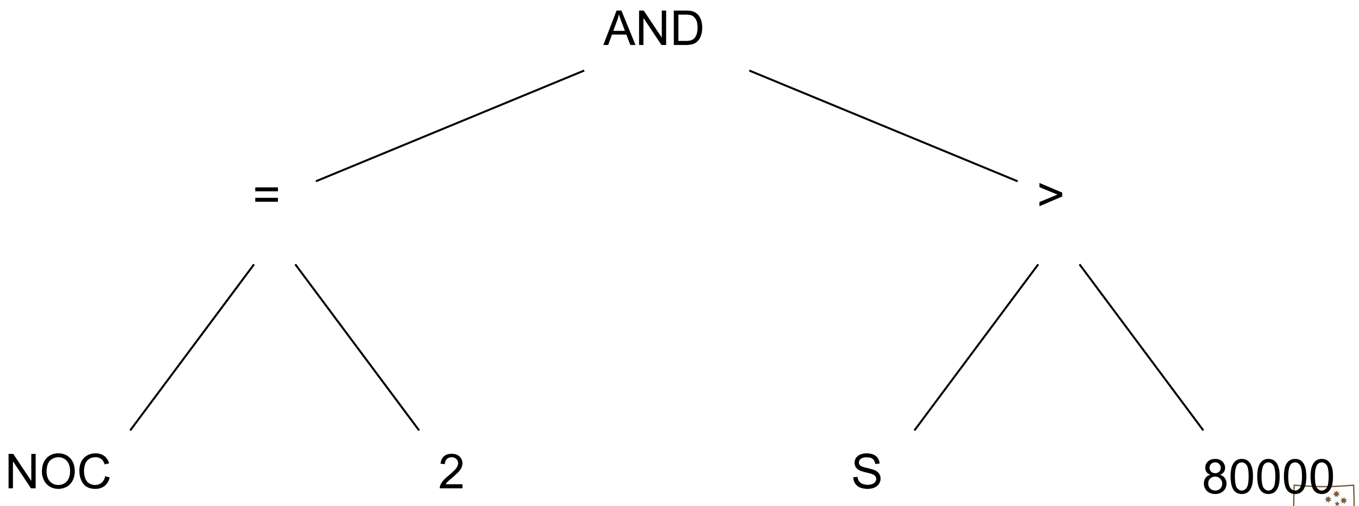
  IF formula THEN good ELSE bad

- Only unknown is the right formula, hence
- Our search space (phenotypes) is the set of formulas
- Natural fitness of a formula: percentage of well classified cases of the model it stands for
- Natural representation of formulas (genotypes) is: parse trees

Introductory Example: Credit Scoring

IF (NOC = 2) AND (S > 80000) THEN good ELSE bad

can be represented by the following tree



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Tree Based Representation

- Trees are a universal form, e.g., consider
- Arithmetic formula

$$2 \cdot \pi + \left((x+3) - \frac{y}{5+1} \right)$$

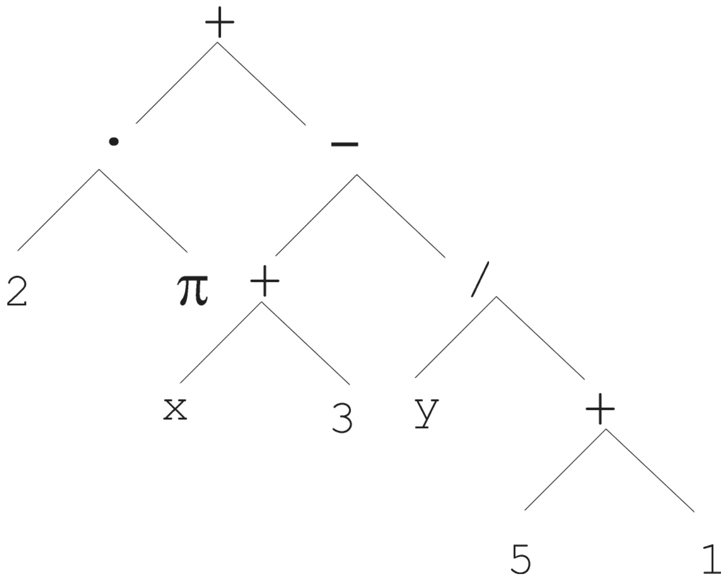
- Logical formula

$$(x \wedge \text{true}) \rightarrow ((x \vee y) \vee (z \leftrightarrow (x \wedge y)))$$

- Program

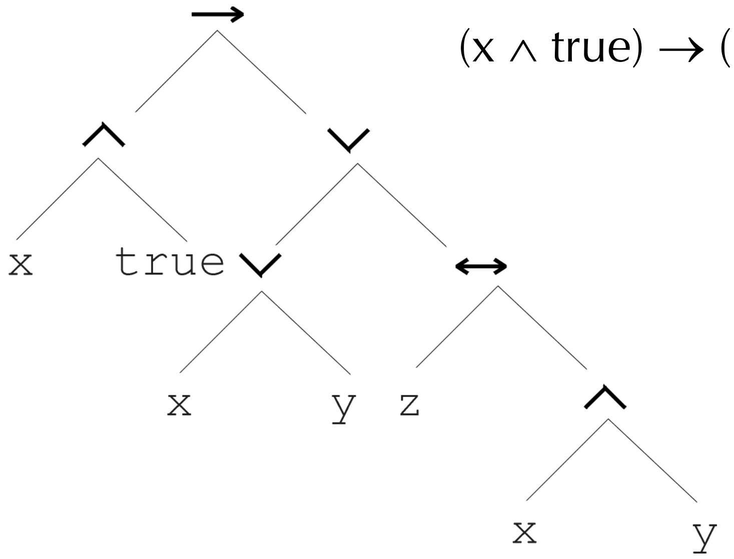
```
i =1;
while (i < 20)
{
        i = i +1
}
```

Tree Based Representation



$$2 \cdot \pi + \left((x+3) - \frac{y}{5+1} \right)$$

Tree Based Representation



$(x \wedge \text{true}) \rightarrow ((x \vee y) \vee (z \leftrightarrow (x \wedge y)))$

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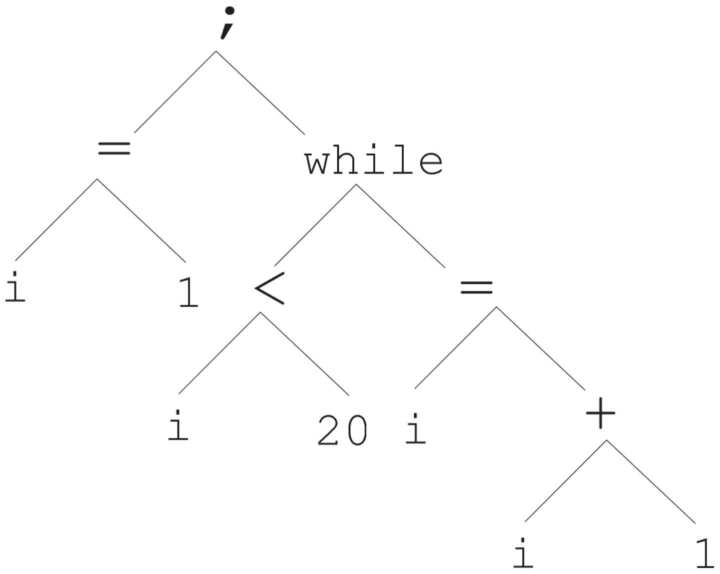
Tree Based Representation




```
i =1;
while (i < 20)
{
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}
```

Tree Based Representation

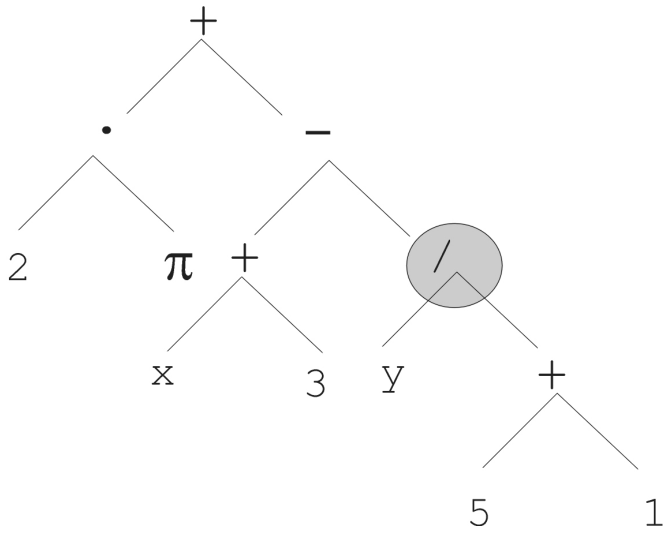
- In GA, chromosomes are linear structures (bit strings, integer string, real-valued vectors, permutations)
- Tree shaped chromosomes are non-linear structures
- In GA, the size of the chromosomes is fixed
- Trees in GP may vary in depth and width

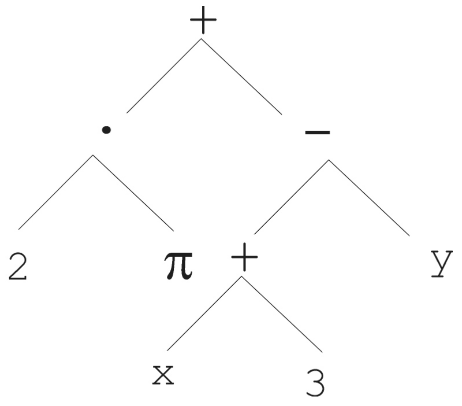
Tree Based Representation

- Symbolic expressions can be defined by
  - Terminal set T
  - Function set F (with the arities of function symbols)
- Adopting the following general recursive definition:
  1. Every $t \in T$ is a correct expression
  2. $f(e_1, \ldots, e_n)$ is a correct expression if $f \in F$, arity(f)=n and $e_1, \ldots, e_n$ are correct expressions
  3. There are no other forms of correct expressions
- In general, expressions in GP are not typed (closure property: any $f \in F$ can take any $g \in F$ as argument)

Mutation

- Most common mutation: replace randomly chosen subtree by randomly generated tree



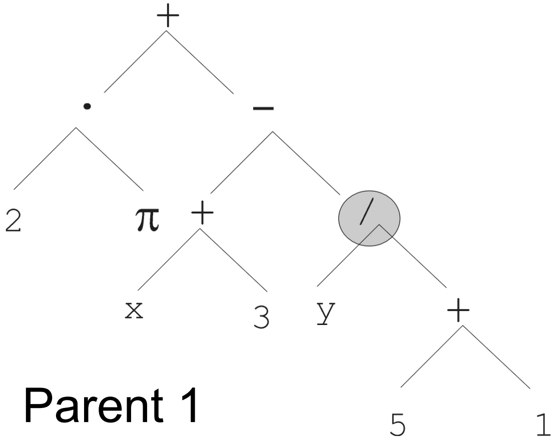


Mutation (cont.)

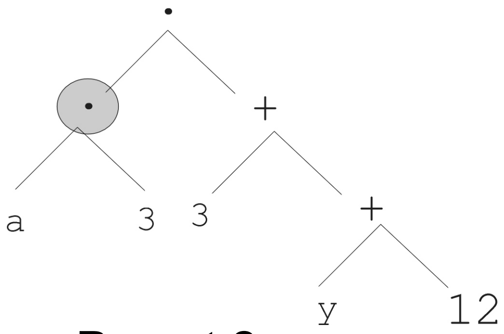
- We need:
  - Probability to chose an internal point as the root of the subtree to be replaced
- The size of the child can exceed the size of the parent

Recombination

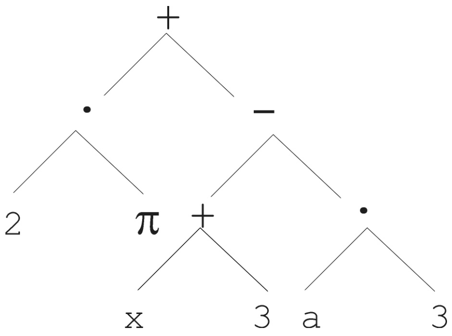
- Most common recombination: exchange two randomly chosen subtrees among the parents
- We need:
  - Probability to chose an internal point within each parent as crossover point
- The size of offspring can exceed that of the parents



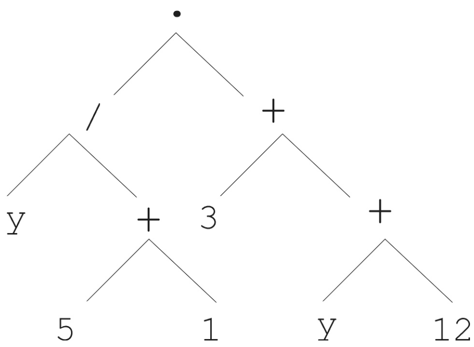
Parent 1



Parent 2



Child 1



Child 2

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Selection

- Parent selection typically fitness proportionate
- Over-selection in very large populations
  - rank population by fitness and divide it into two groups:
  - group 1: best x% of population, group 2 other (100-x)%
  - 80% of selection operations chooses from group 1, 20% from group 2
  - for pop. size = 1000, 2000, 4000, 8000 x = 32%, 16%, 8%, 4%
  - motivation: to increase efficiency, %'s come from rule of thumb

Initialization

- Maximum initial depth of trees D_{max} is set
- Full method (each branch has depth = D_{max}):
  - nodes at depth $d < D_{max}$ randomly chosen from function set F
  - nodes at depth $d = D_{max}$ randomly chosen from terminal set T
- Grow method (each branch has depth $\leq D_{max}$):
  - nodes at depth $d < D_{max}$ randomly chosen from $F \cup T$
  - nodes at depth $d = D_{max}$ randomly chosen from T
- Common GP initialization: ramped half-and-half, where grow & full method each deliver half of initial population

Example Application: Symbolic Regression

- Given some points in $\mathbf{R}^2$, $(x_1, y_1), \ldots, (x_n, y_n)$
- Find function $f(x)$ s.t. $\forall i = 1, \ldots, n : f(x_i) = y_i$
- Possible GP solution:
  - Representation by $F = \{+, -, /, \sin, \cos\}$, $T = \mathbf{R} \cup \{x\}$
  - Fitness is the error:

$$err(f) = \sum_{i=1}^{n} (f(x_i) - y_i)^2$$

  - All operators standard
  - pop.size = 1000, ramped half-half initialisation
  - Termination: n "hits" or 50000 fitness evaluations reached
    - (where "hit" is if for any i $| f(x_i) - y_i | < 0.0001$)

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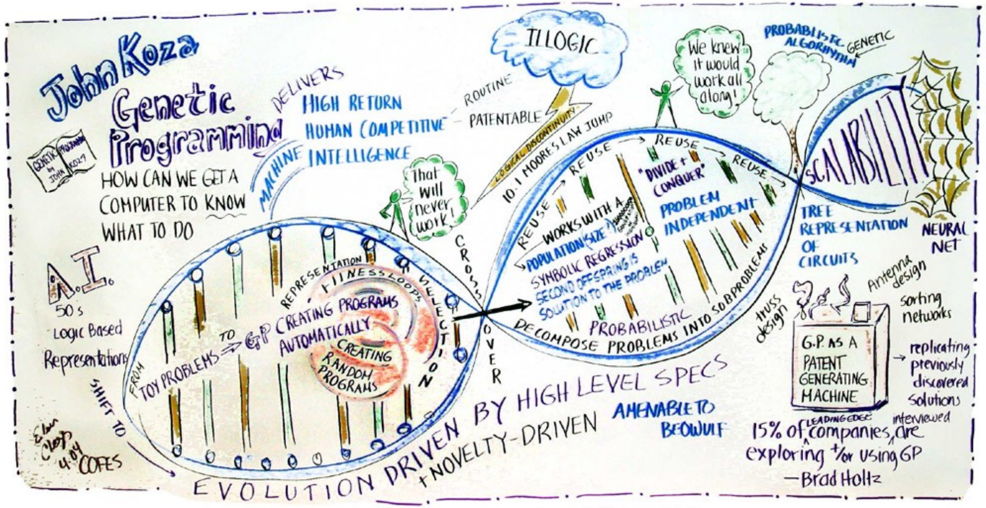
Discussion

Is GP:

The art of evolving computer programs ?

Means to automated programming of computers?

GA with another representation?



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