Applying Genetic Programming to Bytecode and Assembly

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The big picture

- Evolving whole programs is hard to do with source code.
- Evolving whole programs with bytecode and assembly is not as hard.

Outline

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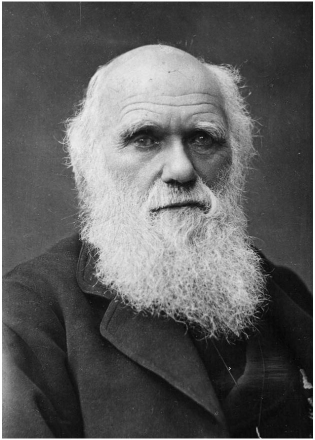
What is Evolutionary Computation?

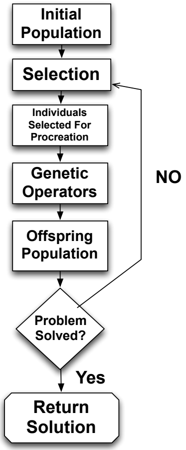
- Evolutionary Computation (EC) is a a technique that is used to automate computer problem solving.
- Loosely emulates evolutionary biology.



Charles Darwin
http://tinyurl.com/lqwj3wt

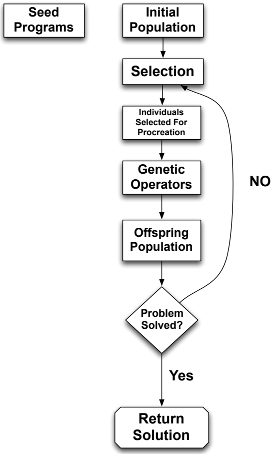
How does it work?

- Continuous optimization
- Selection is driven by the *fitness* of individuals
- Genetic operators mimic sexual reproduction and mutation



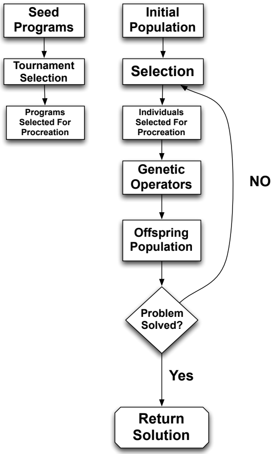
Genetic Programming

- Genetic programming (GP) uses the EC process to evolve **programs**
- This done by using an Evolutionary Algorithm (EA)



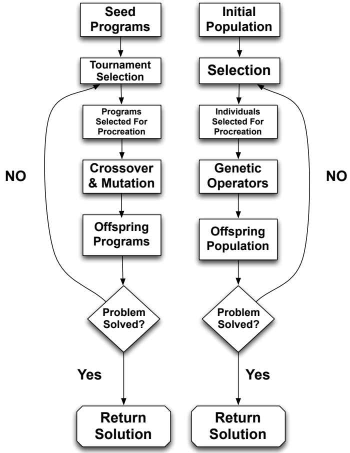
Genetic Programming

- Tournament Selection
  1. Randomly select a specified number of programs
  2. Pick the program with the highest fitness
  3. That program then is selected for reproduction



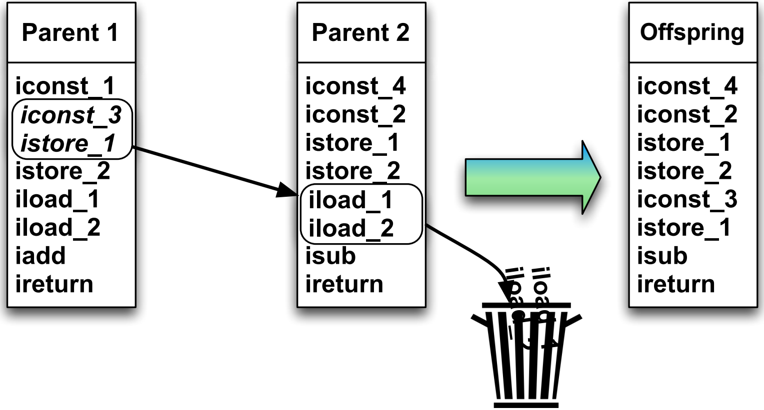
Genetic Programming

Two genetic operators used in GP are *crossover* and *mutation*



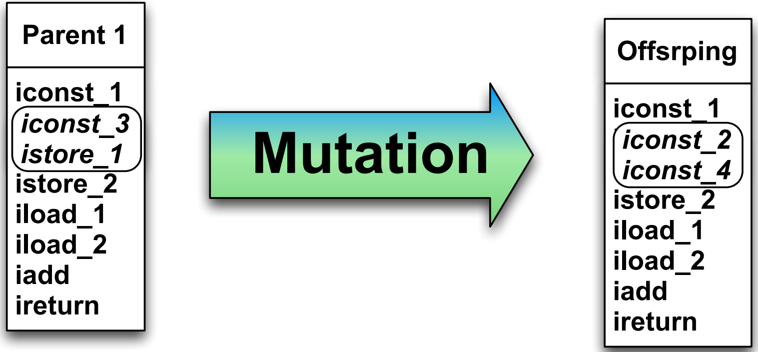
The Evolutionary Computation Process

Crossover



Crossover with Java Bytecode

Mutation



Crossover with Java Bytecode

Outline

Source Code Semantic Constraints

- It is difficult to apply evolution to an entire program in source code
  - Source code is made to simplify reading and writing programs
  - Source code does not represent the semantic constraints of the program.

Syntax vs Semantics

- Syntax represents structure
- Semantics represent meaning

  Semantically Wrong: The sun rises in the West.
  Semantically Correct: The sun rises in the East.

Syntax vs Semantics

```
float x;  int y = 7;
if (y >= 0)
  x = y;
else
  x = -y;
System.out.println(x);
```

(a)

```
int x = 7;  float y;
if (y >= 0) {
  y = x;
  x = y;
}
System.out.println(z);
```

(b)

Both (a) and (b) are valid syntactically. However (b) is invalid semantically.

EAs and Source Code

- EAs that evolve source code are usually designed to avoid dealing with semantic constraints

```
class Robot{
...
  double robotSpeed(){
      double evolvedVariable = valueFromEA;
      return (robot.location + evolvedVariable)/2;
  }
...
}
```

Instruction-Level Code Constraints

- Consists of a smaller alphabets
- Simpler syntactically
- Less semantic constraints to violate

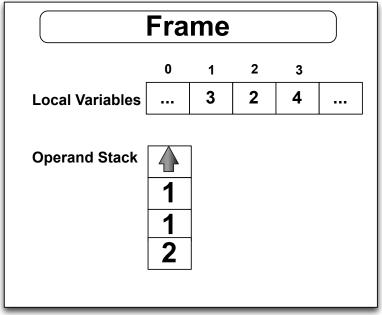
Instruction-level Code Benefits

- Do not need to understand the structure of the program being evolved
- Can evolve a lot from a little
- If there is a compiler for it we can evolve it

Outline

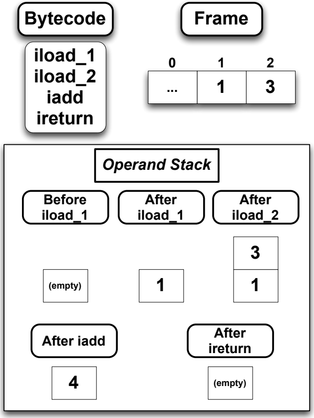
Java Virtual Machine

- A frame stores data and partial results as well as return values for methods



Java Bytcode and Frames

- Opcodes
- The prefix indicates type



Outline

What is FINCH?

- FINCH is an EA developed by M. Orlov and M. Sipper
- It evolves Java bytecode
- It deals with semantic constraints

Dealing With Semantic Constraints

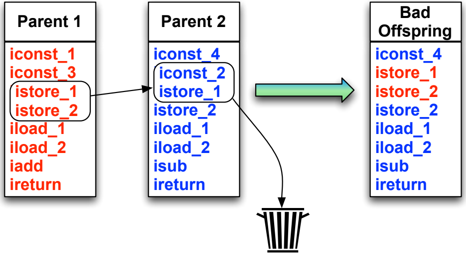
The semantic constraints that are checked for are

- Stack and Frame Depth
- Variable Types
- Control Flow

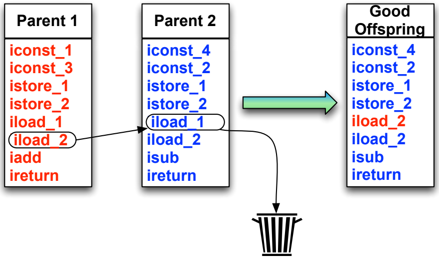
Dealing With Semantic Constraints

1. Apply crossover to two parents
2. Check if they comply to semantic constraints
3. If the program passes the constraint test then it proceeds to offspring generation
4. If it fails the constrain check then another attempt is made with the same parents

Bad Crossover



Good Crossover



Array Sum

- The array sum problem
  - Started with a zero fitness seed program
  - Counted function calls to check for a non-halting state

```
int sumlistrec(List list){
    int sum = 0;
    if(list.isEmpty())
        sum *= sumlistrec(list);
    else
        sum += list.get(0)/2 + sumlistrec(
              list.subList(1, list.size()));
    return sum;
}
```

Array Sum

Decompiled Solution

```
int sumlistrec(List list) {
  int sum = 0;
  if (list.isEmpty())
    sum = sum;
  else
    sum += ((Integer)list.get(0)).intValue() +
        sumlistrec(list.subList(1,
            list.size()));
  return sum;
}
```

Outline

Automating Bug Repair

- Schulte et al., automated bug repair by evolving Java bytecode and x86 assembly
- Does not check for semantic constraints

Tests and Fitness

- Fitness was determined by tests
- Test consisted of one *negative* test and multiple *positive* tests
- The negative test was used to check if the bug was fixed

How it Works

- Programs at times consist of thousands of lines of code
- Uses a weighted path due to size of programs
- The weighted path was determined by what tests execute that instruction

Instruction Weight

- Only executed by failing test: weight = 1.0
- Executed by negative test and one positive: weight = 0.1
- Not executed by negative test case: weight = 0

Outline

Conclusions

[1] [2]

References

M. Orlov and M. Sipper.
Flight of the FINCH Through the Java Wilderness.
Evolutionary Computation, IEEE Transactions on, 15(2):166–182, April 2011.

E. Schulte, S. Forrest, and W. Weimer.
Automated Program Repair Through the Evolution of Assembly Code.
In *Proceedings of the IEEE/ACM International Conference on Automated Software Engineering*, ASE '10, pages 313–316, New York, NY, USA, 2010. ACM.