# 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

1 Evolutionary Computation

2 Why Byetocde and Assembly?

3 Java Bytecode and the JVM

4 FINCH:Evolving Java Bytecode

5 Using Instruction-level Code to Automate Bug Repair

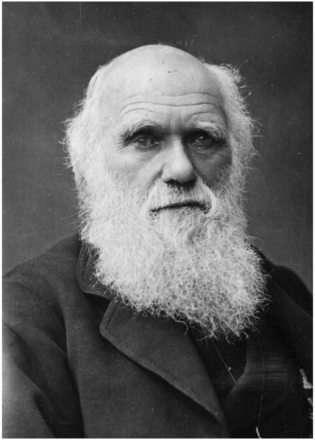
6 Conclusions

# Outline

1. Evolutionary Computation
   - What is it?
   - How does it work?
   - Genetic Programming
2. Why Byetocde and Assembly?
3. Java Bytecode and the JVM
4. FINCH:Evolving Java Bytecode
5. Using Instruction-level Code to Automate Bug Repair

# What is Evolutionary Computation?

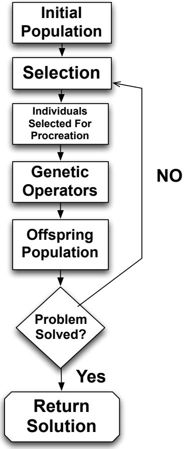
- Evolutionary Computation (EC) is a a technique that is used to automate computer problem solving.
- Loosely emulates evolutionary biology.



Charles Darwin
http://tinyurl.com/lqwj3wt

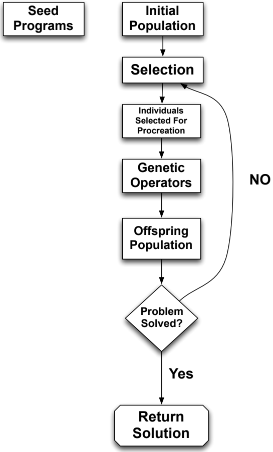
# How does it work?

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



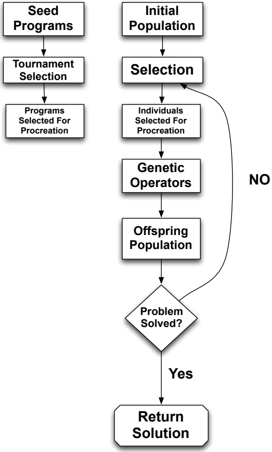
# Genetic Programming

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



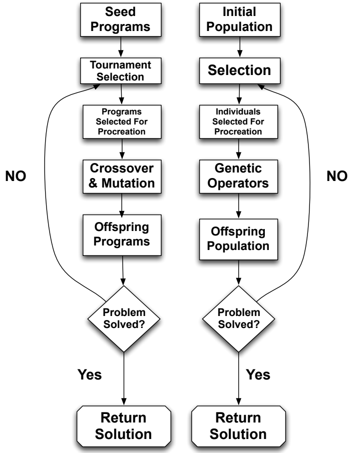
# Genetic Programming

- 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



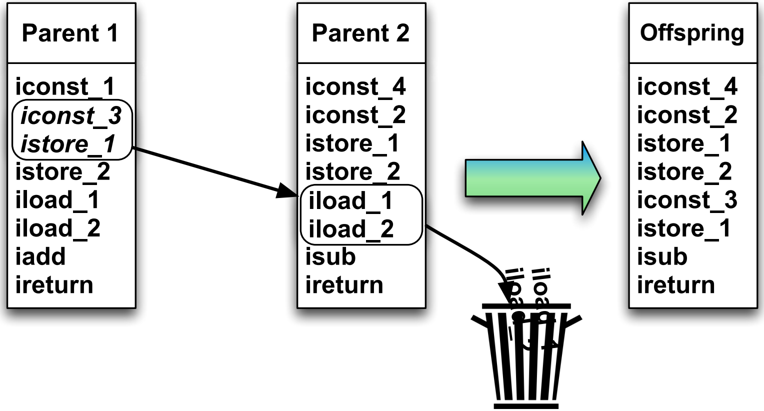
# Genetic Programming

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



The Evolutionary Computation Process

# Crossover



**Parent 1**

iconst_1
*iconst_3*
*istore_1*
istore_2
iload_1
iload_2
iadd
ireturn

**Parent 2**

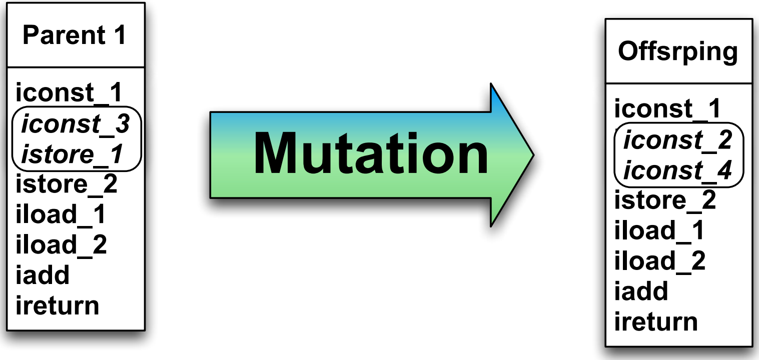
iconst_4
iconst_2
istore_1
istore_2
iload_1
iload_2
isub
ireturn

**Offspring**

iconst_4
iconst_2
istore_1
istore_2
iconst_3
istore_1
isub
ireturn

Crossover with Java Bytecode

# Mutation



**Parent 1**

**iconst_1**
***iconst_3***
***istore_1***
**istore_2**
**iload_1**
**iload_2**
**iadd**
**ireturn**

**Mutation**

**Offsrping**

**iconst_1**
***iconst_2***
***iconst_4***
**istore_2**
**iload_1**
**iload_2**
**iadd**
**ireturn**

Crossover with Java Bytecode

# Outline

1 Evolutionary Computation

2 Why Byetocde and Assembly?

- Difficulties in Source Code

3 Java Bytecode and the JVM

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6 Conclusions

# Source Code Semantic Constraints

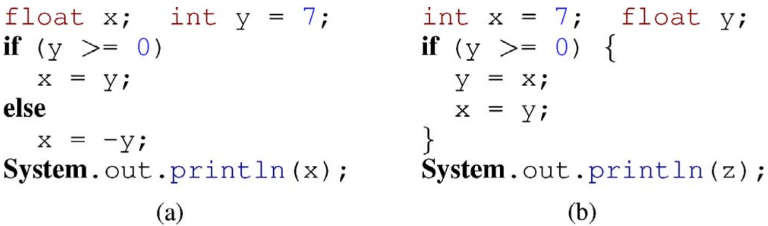
- It is difficult to apply evolution to an entire program in source code
    - Source code is made to simplify reading and writing programs
    - Source code does not represent the semantic constraints of the program.

# 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.

# Instruction-Level Code Constraints

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

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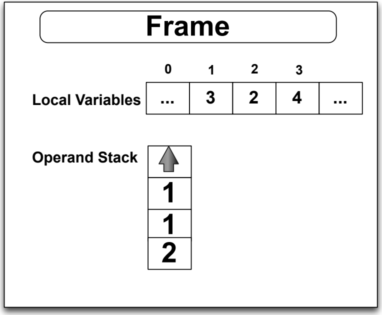
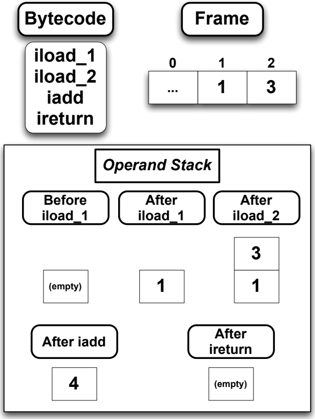
## Java Virtual Machine

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



## Java Bytcode and Frames

- Opcodes
- The prefix indicates type



Bytecode

```
iload_1
iload_2
iadd
ireturn
```

Frame

| 0 | 1 | 2 |
|---|---|---|
| ... | 1 | 3 |

*Operand Stack*

Before iload_1: (empty)

After iload_1: 1

After iload_2: 3, 1

After iadd: 4

After ireturn: (empty)

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4 FINCH:Evolving Java Bytecode
- How it Works
- The Array Sum Problem

5 Using Instruction-level Code to Automate Bug Repair

# 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

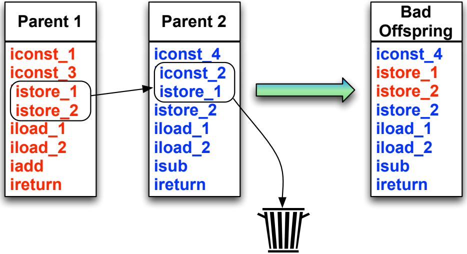
The semantic constraints that are checked for are

- Stack and Frame Depth
- Variable Types
- Control Flow

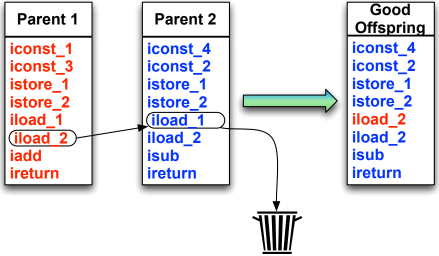
# Dealing With Semantic Constraints

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



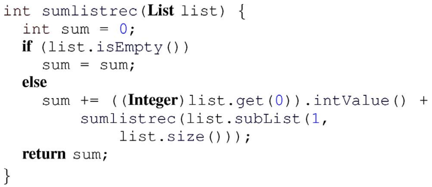
# Array Sum

- 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;
}
```

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   - How it Works
   - Results

# 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

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## Conclusions

# References

M. Orlov and M. Sipper.
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