Genetic improvement: Taking real-world source code and improving it using genetic programming

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Instructors

UNIVERSITY of STIRLING

- Saemundur O. Haraldsson is a Lecturer at the University of Stirling. He co-organised every version of this tutorial. He has multiple publications on Genetic Improvement, including two that have received best paper awards. Additionally, he co-authored the first comprehensive survey on GI 1 which was published in 2017. He has been invited to give talks on the subject in two Crest Open Workshops and for an industrial audience in Iceland. His PhD thesis (submitted in May 2017) details his work on the world's first live GI integration in an industrial application.
- Alexander (Sandy) Brownlee is a Lecturer in the Division of Computing Science and Mathematics at the University of Stirling. His main topics of interest are in search-based optimisation methods and machine learning, with applications in civil engineering, transportation and SBSE. Within SBSE, he is interested in automated bug-fixing and improvement of non-functional properties such as run-time and energy consumption; how these different objectives interact with each other; and novel approaches to mutating code. He is also one of the developers of Gin, an open-source toolkit for experimentation with Genetic Improvement on real-world software projects.

Instructors

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- John R. Woodward is a lecturer at the Queen Mary University of London. Formerly he was a lecturer at the University of Stirling, and was employed on the DAASE project (http://daase.cs.ucl.ac.uk/). Before that he was a lecturer for four years at the University of Nottingham. He holds a BSc in Theoretical Physics, an MSc in Cognitive Science and a PhD in Computer Science, all from the University of Birmingham. His research interests include Automated Software Engineering, particularly Search Based Software Engineering, Artificial Intelligence/Machine Learning and in particular Genetic Programming. He has over 50 publications in Computer Science, Operations Research and Engineering which include both theoretical and empirical contributions, and given over 50 talks at International Conferences and as an invited speaker at Universities. He has worked in industrial, military, educational and academic settings, and been employed by EDS, CERN and RAF and three UK Universities.

Engineering and Physical Sciences Research Council

Exploiting Defect Prediction for Automatic Software Repair (Fixie), grant EP/S005803/1

Instructors

THE UNIVERSITY of ADELAIDE

- Markus Wagner is a Senior Lecturer at the School of Computer Science, University of Adelaide, Australia. He has done his PhD studies at the Max Planck Institute for Informatics in Saarbruecken, Germany and at the University of Adelaide, Australia. For the outcomes of his studies, he has received the university's Doctoral Research Medal - the first for his school - and three best paper awards. His research topics range from mathematical runtime analysis of heuristic optimisation algorithms and theory-guided algorithm design to applications of heuristic methods to renewable energy production, professional team cycling and software engineering. So far, he has been a program committee member 60+ times, and he has written 150+ articles with 150+ different co-authors. He is on SIGEVO's Executive Board and serves as the first ever Sustainability Officer. He has contributed to GECCOs as Workshop Chair and Competition Chair, and he has chaired several education-related committees within the IEEE CIS.
- Bradley (Brad) Alexander is a Senior Lecturer and Director of Teaching at the School of Computer Science, University of Adelaide, Australia. Brad's research interests include program optimisation, rewriting, genetic-programming (GP) - especially the discovery of recurrences and search-based-software-engineering. He has also supervised successful projects in the evolution of control algorithms for robots, the evolution of three-dimensional geological models, and the synthesis of artificial water distribution networks, and using background optimisation to improve the performance of instruction set simulators (ISS)'s. He has also worked on improving algorithms for the analysis of water distribution networks.

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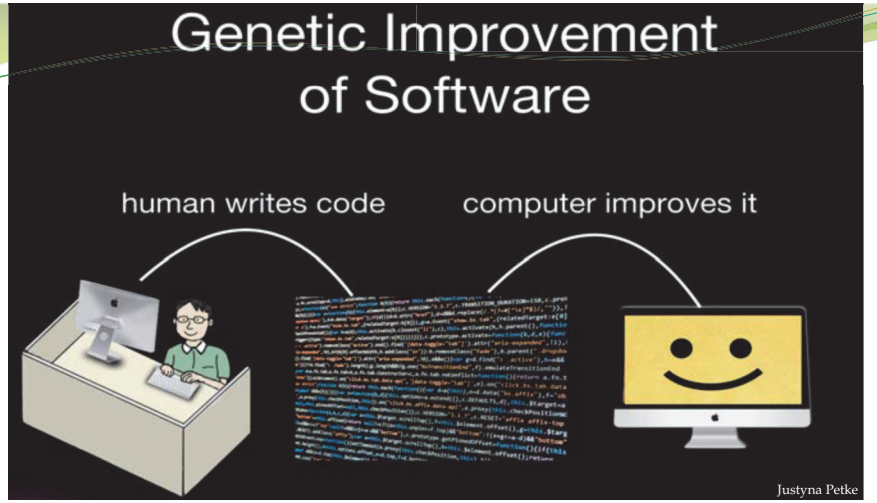
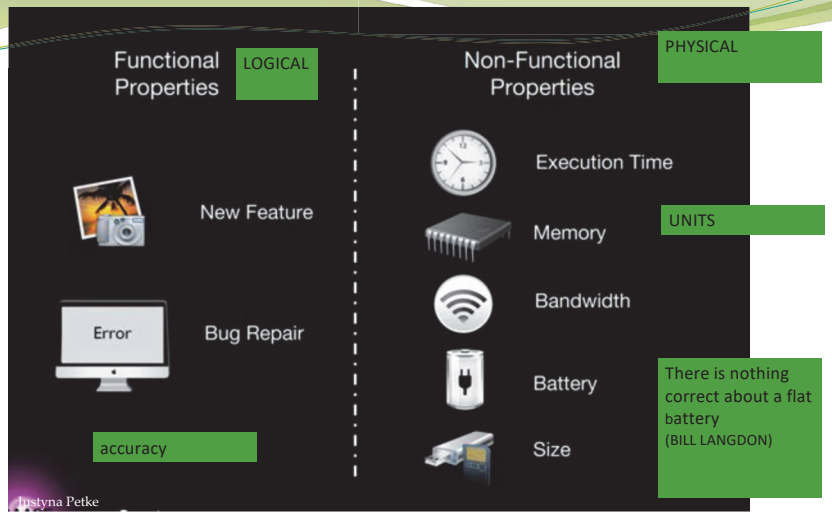
DE160100850. http://purl.org/au-research/grants/arc/DE160100850

Overview

- **Introduction**
- **Fixing Bugs and other examples**
- **Noteworthy papers and issues**
- **Getting involved**
- **Summary and Q&A**

5





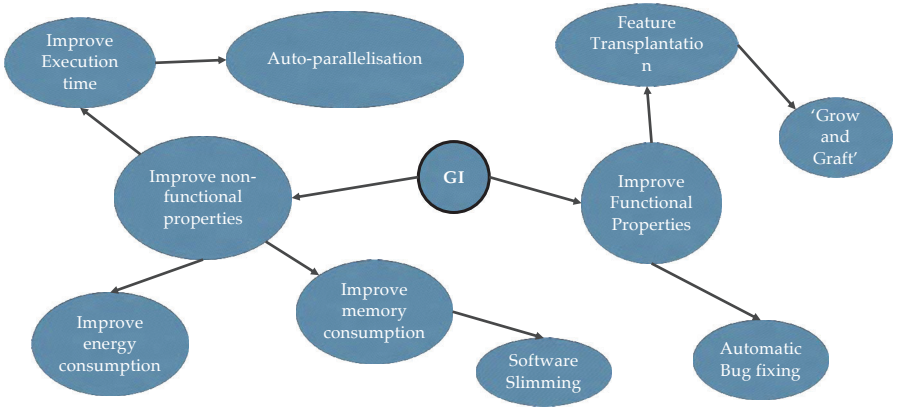
What is Genetic Improvement

A wordy definition:

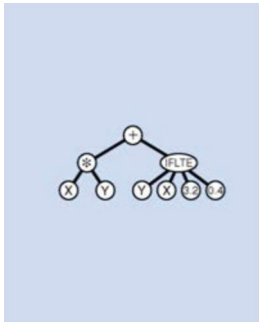
Genetic Improvement is the application of search-based (typically evolutionary) techniques to modify software with respect to some user-defined fitness measure.

It's just GP - BUT starting with a **nearly complete** program
[Wolfgang Banzhaf]

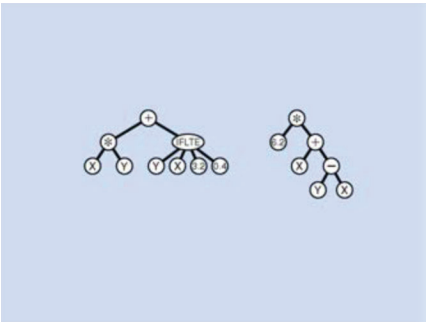
What is Genetic Improvement



Genetic Programming overview



mutation



crossover

Genetic Programming: GI's ROOTS

1. **Aim** – *to discover new programs by telling the computer <u>what</u> we want it to do, but <u>not how</u> we want it to do it* – John Koza
2. **How** – we evolve computer programs using natural selection.
3. **Starts** from scratch (empty program)
4. Choose **primitives** (terminal set/FEATURES and function set)
5. Choose **representation** (tree based, graph based, linear e.g. CGP)
6. **Choose** *fitness function, parameters, genetic operators.*

GI forces "the full capabilities of programming languages"- side effects, ADFs, LOOPS

GP vs GI: if you can't beat them, join them.

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ABSTRACT

Genetic Programming (GP) has been criticized for targeting irrelevant problems [12], and is true of the wider machine (procedures, methods, macros, routines), and so GI has to deal with the reality of existing software systems. However, most of the GP literature is not concerned with Tur-

Popular Science

- easy to digest articles for non-specialists.

https://theconversation.com/computers-will-soon-be-able-to-fix-themselves-are-it-departments-for-the-chop-85632

Computers will soon be able to fix themselves – are IT departments for the chop?

October 12, 2017 3.29pm BST

IT?

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https://theconversation.com/how-computers-are-learning-to-make-human-software-work-more-efficiently-43798

How computers are learning to make human software work more efficiently

June 25, 2015 10.08am BST

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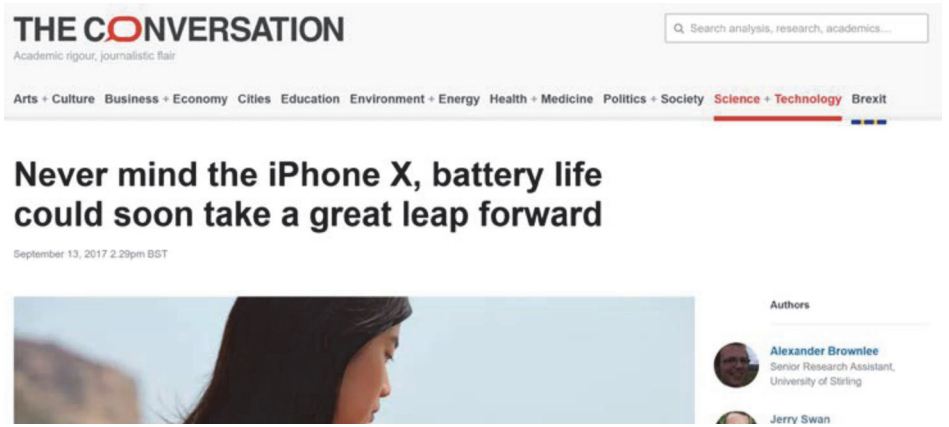
http://www.davidrwhite.co.uk/2014/11/27/genetic-programming-has-gone-backwards/

Genetic Programming has gone Backwards

When Genetic Programming (GP) first arose in the late 80s and early 90s, there was one very defining characteristic of its application, which was so widely accepted as to be left unsaid:

GP always starts from scratch

http://www.davidrwhite.co.uk/tag/genetic-programming/



Competent Programmers Hypothesis

1. programmers write programs that are <u>almost</u> perfect.
1. program faults are syntactically small (slip of finger, T/F)
1. corrected with a few keystrokes. (e.g. < for <=)
1. **GI can find small patches.**
1. Small changes are non-unique (write 7 lines code, or utter 7 words **before they're unique)**

Plastic Surgery Hypothesis.

the content of new code can often be assembled
out of fragments of code that already exist.

Barr et al. [71] showed that changes are 43% graftable from the exact version of the software being changed.

The Plastic Surgery Hypothesis: Changes to a codebase contain snippets that already exist in the codebase at the time of the change, and these snippets can be efficiently found and exploited.

THE CODE CONTAINS SOLUTIONS – CANDIDATE PATCHES

Representations of PROGRAMS

Natural Representation of CODE

1. Text files e.g. Program.java is a text file. Saemi.
2. Abstract syntax tree (AST) – Genprog, Genofix.
3. Java byte code (also C binaries) [102]

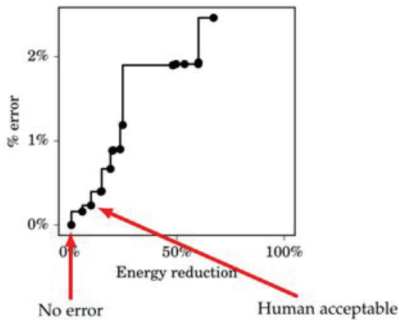
1. Errors, compile, halting (Langdon - discard)

Objectives

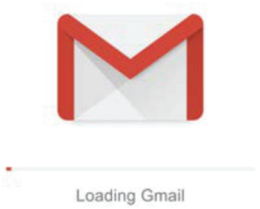
- Functional (**logical properties**)
  - Accuracy e.g. as in machine learning - FLOAT
  - Number of bugs – as measured against a set of test cases. BOOLEAN
  - New functionality – e.g.
- Non-functional (***physical* properties**)
  - Execution time
  - Energy (power consumption – peak/average)
  - Memory
  - Bandwidth
- Multi-objective
  - Trade-offs, convex, a set of programs = a single tuneable program

Multi-Objective

- Seems be convex
- – simple argument (see pic)
- Can provide a set of programs
- weighted sum of objectives?
- weight has meaning to user.
- *Will there be elbow/knee points?*



Slow connections.



Loading standard view | Load basic HTML (for slow connections)

GISMOE

The GISMOE challenge:

to create an automated program development environment in which the Pareto program surface is automatically constructed to support dialog with and decision making by the software designer concerning the trade offs present in the solution space of programs for a specific programming problem.

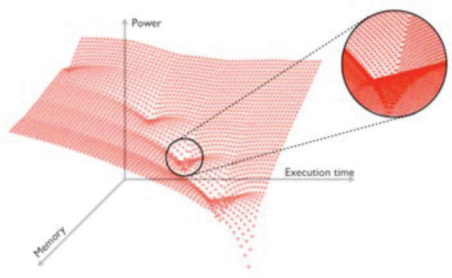


Figure 1: The GISMOE Pareto Program Surface

EDIT Operators – changes to programs

- Line level
- Single Character level
- Function/module level.
- AST – GIN, Gen-0-fix, genprog,
- Java – machine code – java byte code.

- LIST OF EDITS IS A PATCH.

GI: An example of execution time optimisation

```
static final int INVALID = 0;
static final int SCALENE = 1;
static final int EQUALATERAL = 2;
static final int ISOCELES = 3;

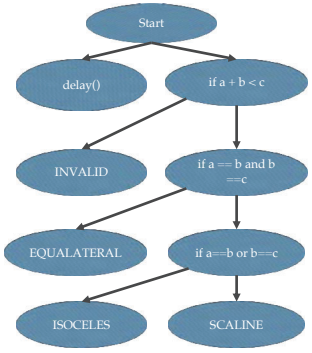
public static int classifyTriangle(int a, int b, int c) {

    delay();

    assert(a <= b && b <= c);
    if (a + b <= c) {
        return INVALID;
    } else if (a == b && b == c) {
        return EQUALATERAL;
    } else if (a == b || b == c) {
        return ISOCELES;
    } else {
        return SCALENE;
    }

}

private static void delay() {
    try {
        Thread.sleep(100);
    } catch (InterruptedException e) {
        // do nothing
    }
}
```



GI: An example of automated bug fixing

```
static final int INVALID = 0;
static final int SCALENE = 1;
static final int EQUALATERAL = 2;
static final int ISOCELES = 3;

public static int classifyTriangle(int a, int b, int c) {

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    } else {
        return SCALENE;
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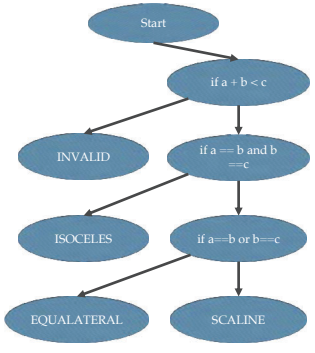
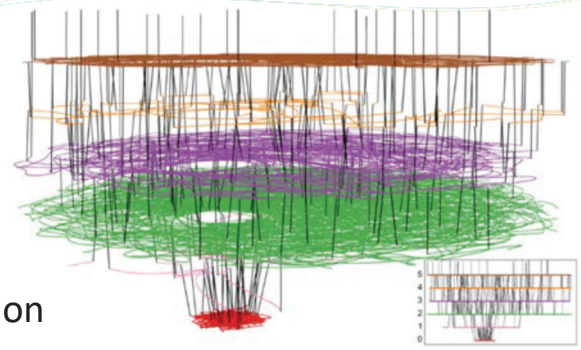


Neutral networks Graceful degradation

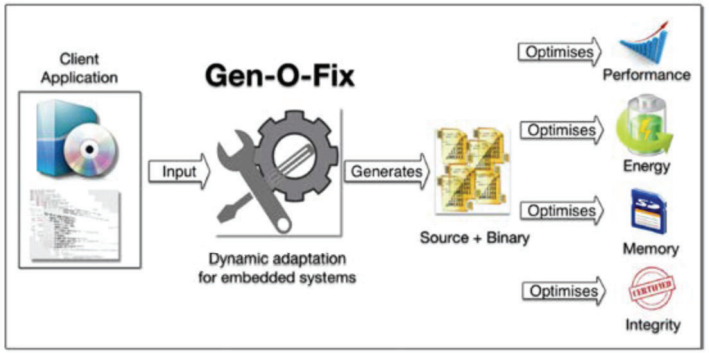


structure

Hill climber

Fig. 1. Local optima network of the Triangle Program using 100 random starts (see Section 4.4). Edges are coloured if they start and end at the same fitness. Insert shows fitness levels edge on. Best (bottom) red 0 (pass all tests), pink 1 (fail only one test), green 2, purple 3, orange 4, brown 5.

System Diagram for Gen-O-Fix



Gen-O-Fix: Abstract Syntax Trees

Main features of framework are

1. **Embedded** adaptively.
2. Minimal end-user requirements.
   1. Initial source code: **location** of Scala source code file containing a function
   2. Fitness function: providing a means of **evaluating the quality** of system
3. **Source to source transformations**
4. Operates on **ASTs** (i.e. arbitrarily fine).

AST - scala

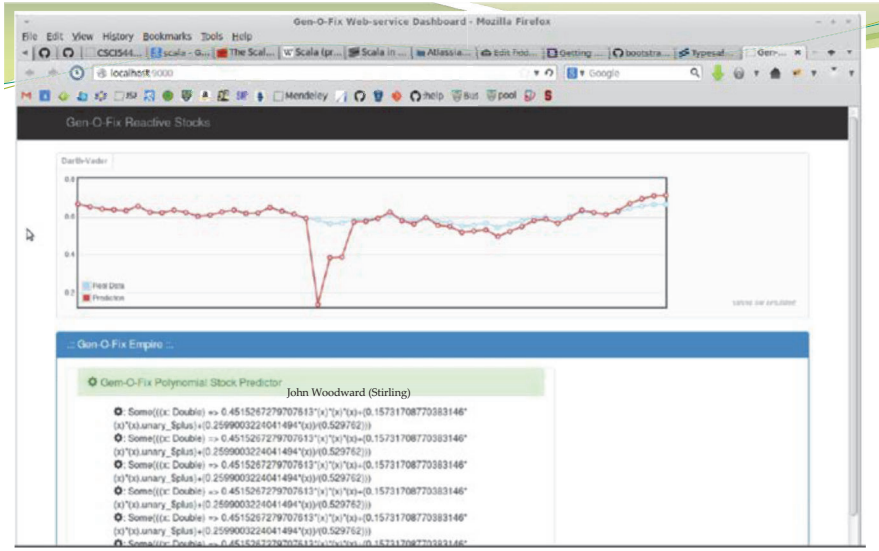
Code as data, data as code.

```
// code to data:
var m = 2; var x = 3; var c = 4
val expr = reify( ( m * x ) + c )
println( "AST = " + showRaw( expr.tree ) )

// output:
AST = Apply(Select(Apply(Select(Select(Ident("m"),
"elem"),"$times"),List(Select(Ident("x")),
"elem"))),"$plus"),List(Select(Ident("c"),"elem")))
```

```
// run AST datatype as code:
println( "eval = " + expr.tree.eval() )

// output:
eval = 10
```



John Woodward (Stirling)

GI Hashcode tuning

1. **Hadoop** provides a mapReduce implementation in Java.
2. Equals method has to obey **contract** (Reflective, Symmetric, Transitive, …)
3. x.equals(y) **implies** hashCode(x)== hashCode(y).
4. hashCode method is an integer function of a subset of an object's fields

Some GP Settings

1. **Terminal set** is
   1. Field values
   2. Random integers [0, 100]
2. **Function set** is
   1. {+, *, XOR, AND}
3. **Fitness function**: close to uniform distribution of hashes (uniform distribution is the ideal), over 10,000 instances.

Distribution of Hashcodes

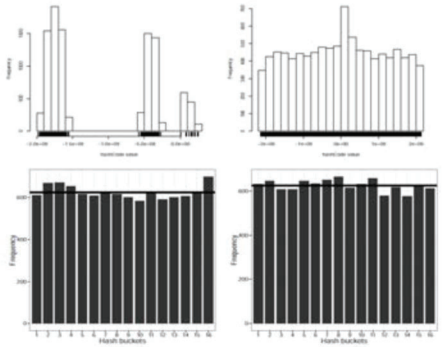


Fig. 1: The distribution of the hashcode values (top) and the distribution of the created objects in hash buckets (bottom), generated by the Apache commons (left) and the evolved function (right)

Overview

- Introduction
- Fixing Bugs and other examples
- Noteworthy papers and issues
- Getting involved
- Summary and Q&A

Fixing Bugs and other examples

Saemundur O. Haraldsson

- Fixing bugs
- Making software faster
- Making software more accurate

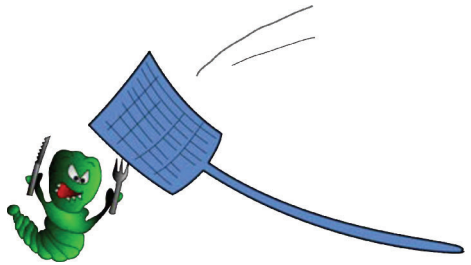
Fixing bugs

A real world example of GI in action

Saemundur O. Haraldsson, John R. Woodward, Alexander E. I. Brownlee, and Kristin Siggeirsdottir. 2017. Fixing bugs in your sleep: how genetic improvement became an overnight success. In Proceedings of the Genetic and Evolutionary Computation Conference Companion (GECCO '17). ACM, New York, NY, USA, 1513-1520. DOI: https://doi.org/10.1145/3067695.3082517

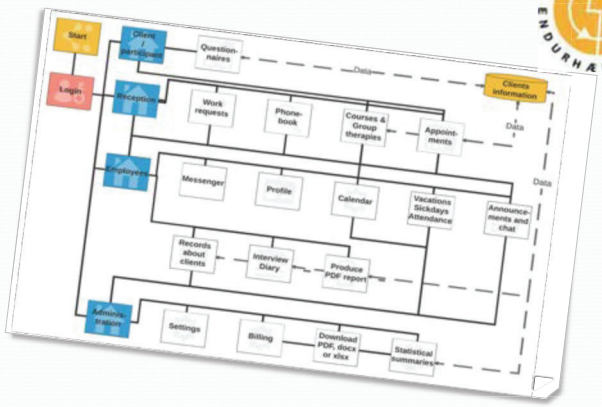
S. O. Haraldsson, J. R. Woodward and A. I. E. Brownlee, "The Use of Automatic Test Data Generation for Genetic Improvement in a Live System," 2017 IEEE/ACM 10th International Workshop on Search-Based Software Testing (SBST), Buenos Aires, 2017, pp. 28-31. DOI: https://10.1109/SBST.2017.10

S.O. Haraldsson, 2017. 'Genetic Improvement of Software: From Program Landscapes to the Automatic Improvement of a Live System', PhD thesis, University of Stirling, Stirling. http://hdl.handle.net/1893/26007



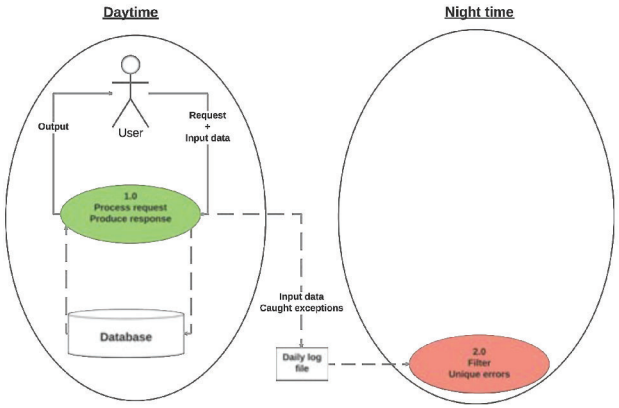
Janus Manager

- Management system for rehabilitation
- Web application
  - Python source code
  - >25K LOC
- ~200 users
  - ~40 specialists
  - 150-160 patients
- In use since March 2016
- 47 bugs automatically fixed to date



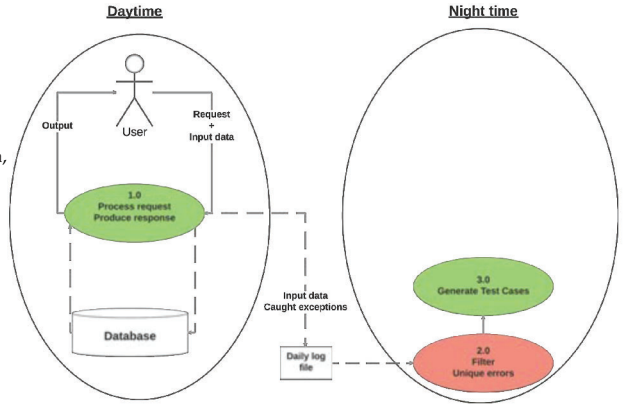
When last user logs out

1. Procedure 2.0
   - Sorts and filters the day's exceptions



When last user logs out

1. Procedure 2.0 started
   - Sorts and filters the day's exceptions
2. Procedure 3.0
   - Emulates input data, type, size and structure.
   - Produces test cases



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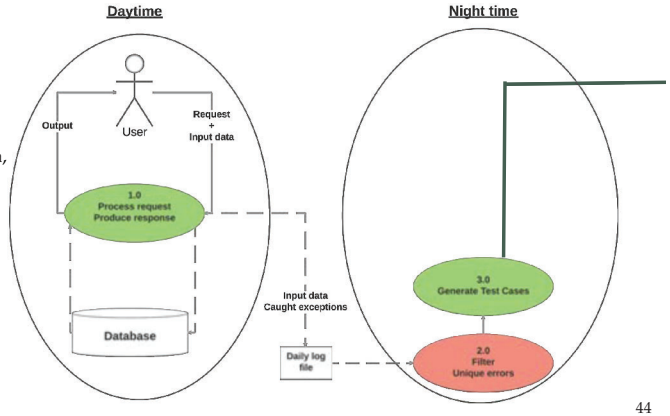
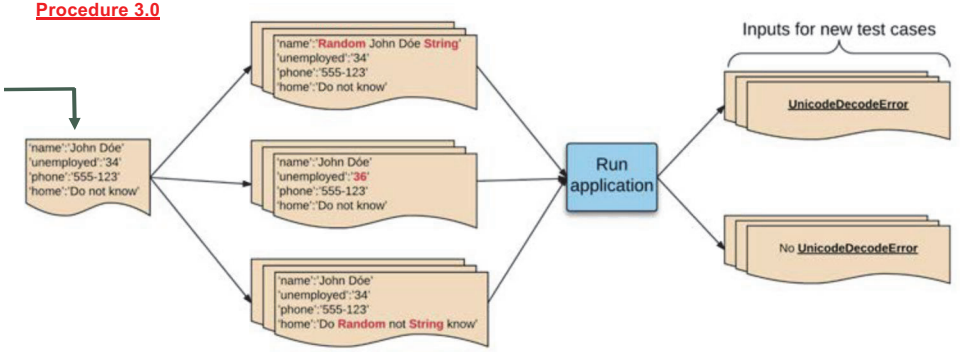
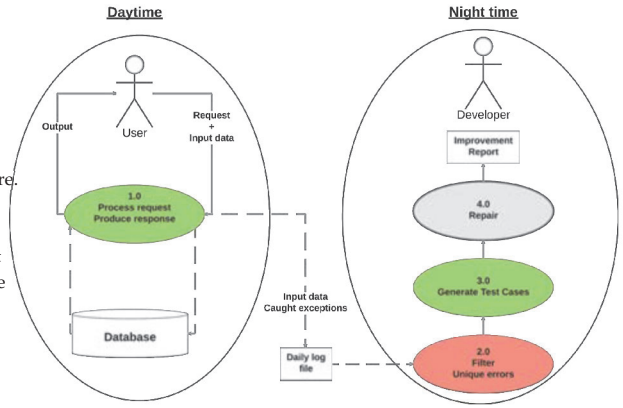


Procedure 3.0

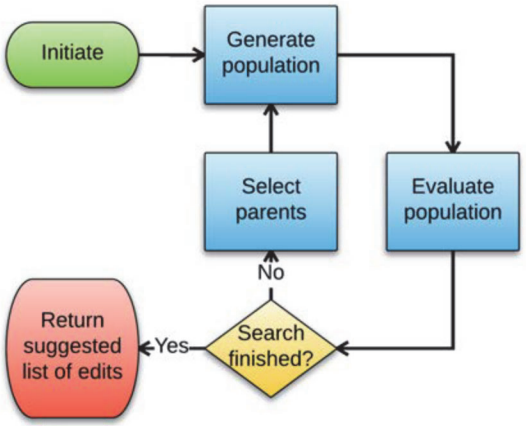


When last user logs out

1. Procedure 2.0 started
   - Sorts and filters the day's exceptions
2. Procedure 3.0
   - Emulates input data, type, size and structure.
   - Produces test cases
3. Procedure 4.0
   - Genetic Improvement
   - Parallel process on the server
   - Outputs report for developer



- Procedure 4.0
- Genetic Improvement
  - Pop.= 50 patches
  - fit.= #passed tests
  - select= ½ pop by fitness
  - Output= report



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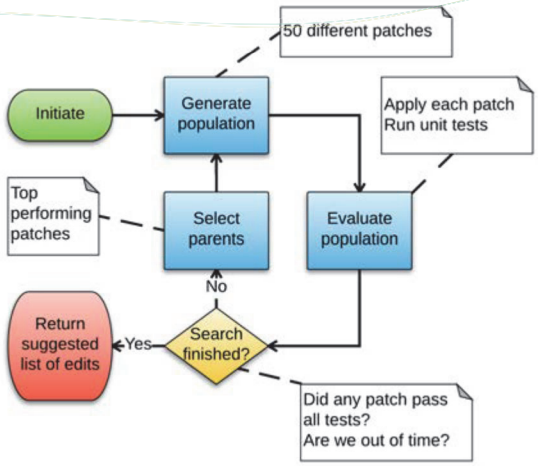


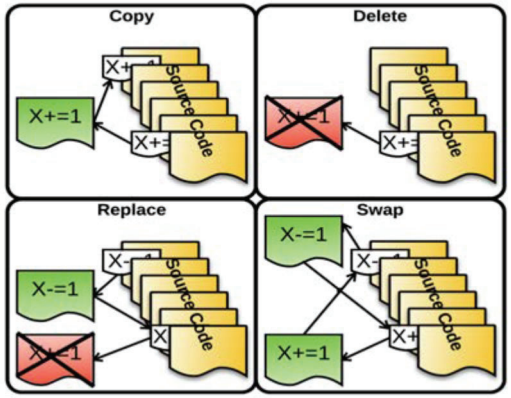
4 different types of implemented **Edits**

Primitive types:

- **Copy**
  - Equivalent to: CTRL+C -> CTRL+V
- **Delete**
  - Almost what you think

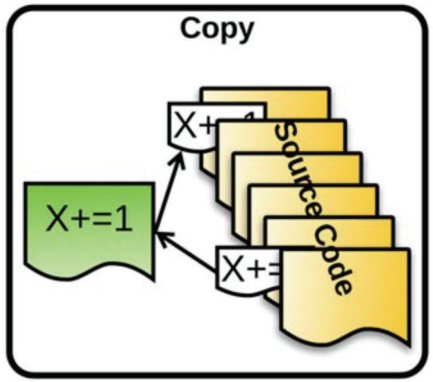
Composite types:

- **Replace**
  - Copy + Delete
- **Swap**
  - 2x Copy + 2x Delete



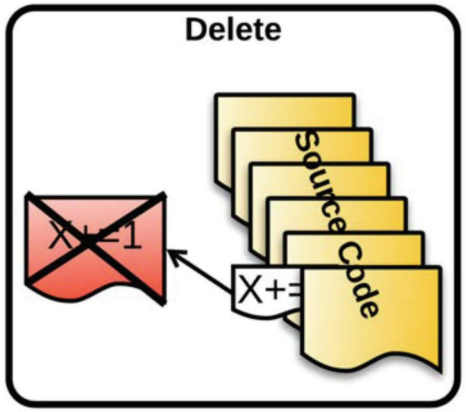
Copy

- CTRL+C => CTRL+V
- Applied to whole lines
- Some restrictions on what lines can be copied
  - Identified with regular expressions



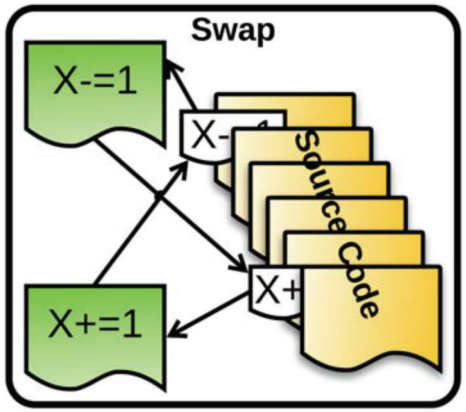
Delete

- Adds "#" to beginning of line
  - "Comment"
- Applied to whole lines
- Some restrictions on what lines can be commented out
  - Identified with regular expressions
- Can be reversed for previously deleted lines
  - "Uncomment"



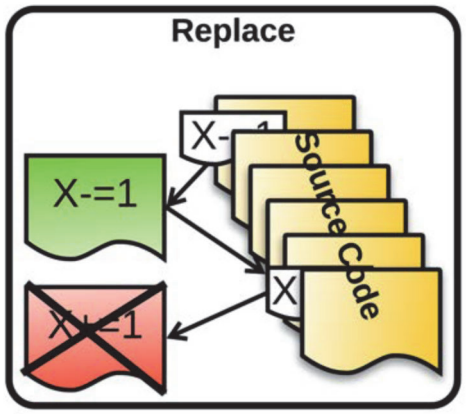
Swap

- Copies both lines above each other
- Then deletes the originals
- Applied to whole lines
  - Like for like



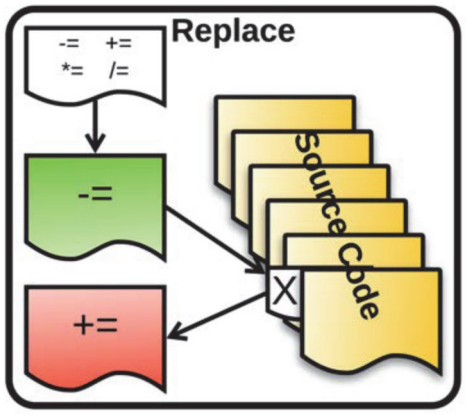
Replace

- Copies one line above another
- Then deletes that line



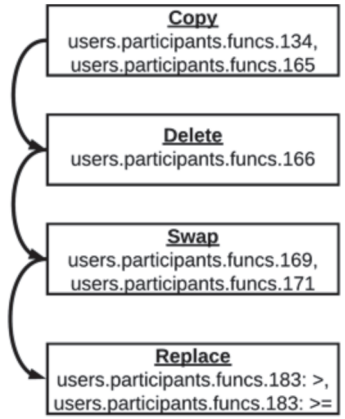
Replace -- extra

- Deep parameter tuning
- Operator specific replacement
  - and numbers too
- From a list of equivalent operators.



A list of edits makes a suggestion

- Reads like a recipe
  - Step-by-step
- Automatically reduced
  - Delta debugging
- Scrutinised by the developer
  - Might change the recipe



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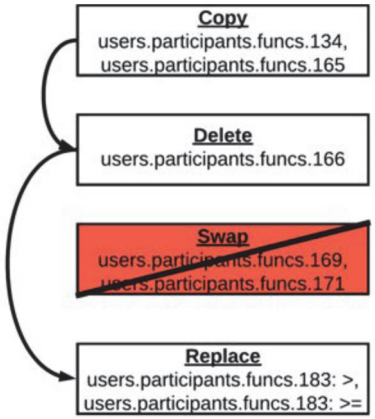

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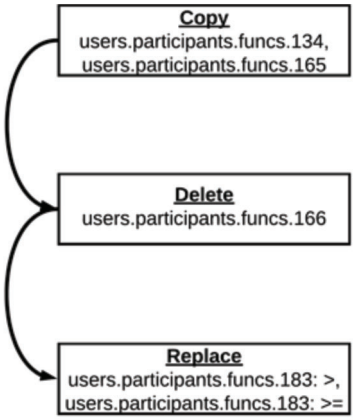

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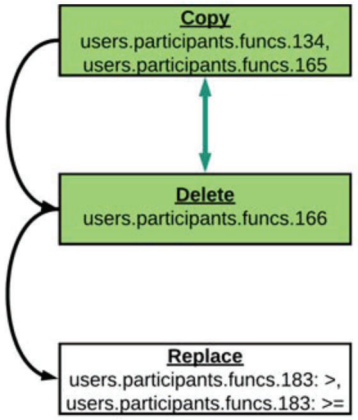

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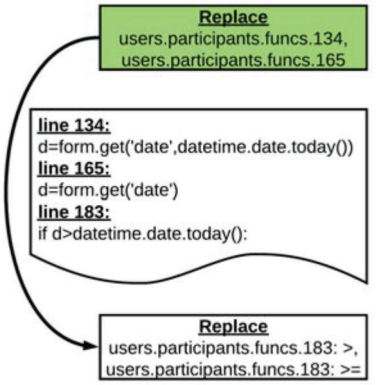
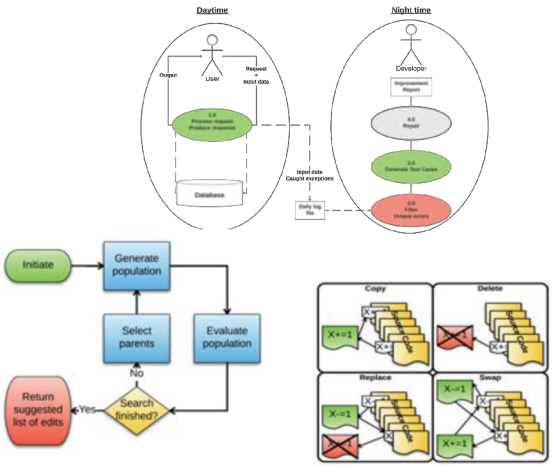


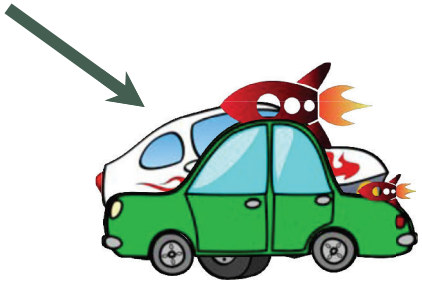
Summary

- Real-world example
- Catches inputs that produce crashes
- Line(-ish) based GI
  - 4 types of edits
- Overnight repair
- Developers are the gatekeepers



Faster

Another example of GI in action



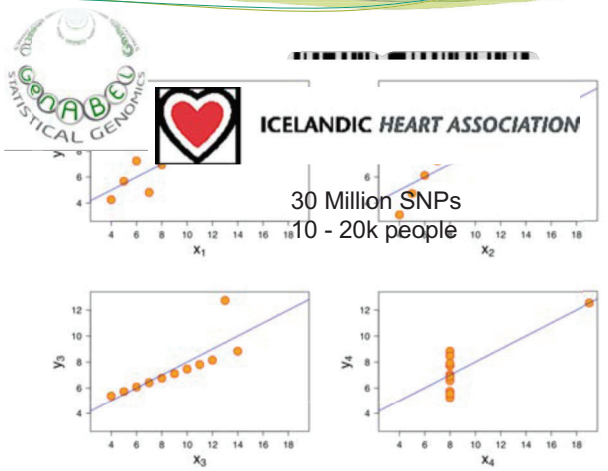
Saemundur O. Haraldsson, John R. Woodward, Alexander E. I. Brownlee, Albert V. Smith, and Vilmundur Gudnason. 2017. Genetic improvement of runtime and its fitness landscape in a bioinformatics application. In Proceedings of the Genetic and Evolutionary Computation Conference Companion (GECCO '17). ACM, New York, NY, USA, 1521-1528. DOI: https://doi.org/10.1145/3067695.3082526

S.O. Haraldsson, 2017. 'Genetic Improvement of Software: From Program Landscapes to the Automatic Improvement of a Live System', PhD thesis, University of Stirling, Stirling. http://hdl.handle.net/1893/26007

The software

ProbABEL

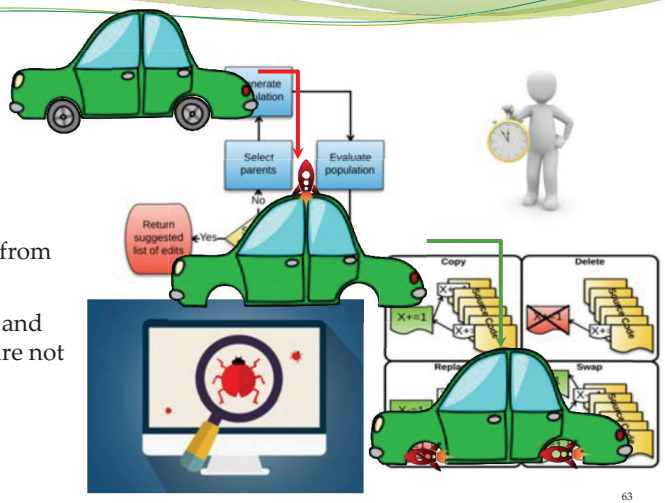
- A tool for Genome Wide Association studies.
- Collection of functions for regression models
- Written in C and C++
  - 8k LOC
  - 31 files
- Typical execution time around 8-12 hours



http://www.genabel.org/packages/ProbABEL

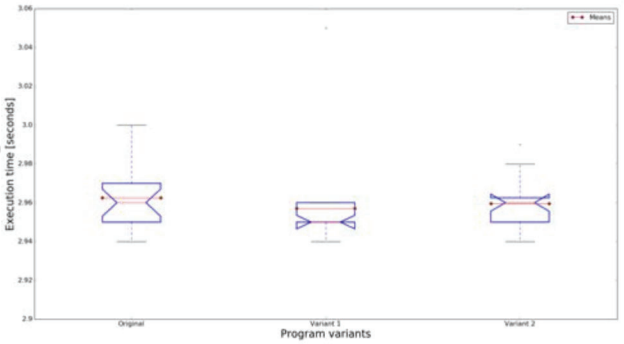
The GI setup

- Same as before
- Except for the evaluation
- Mean CPU time from 20 executions
- None compiling and failing variants are not discarded



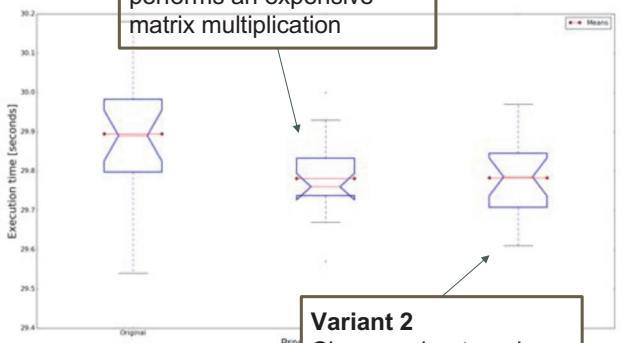
Results

- 2 good variants found early on
  - < a second faster
  - Generations 5 and 10
- **Not** statistically significant on training dataset



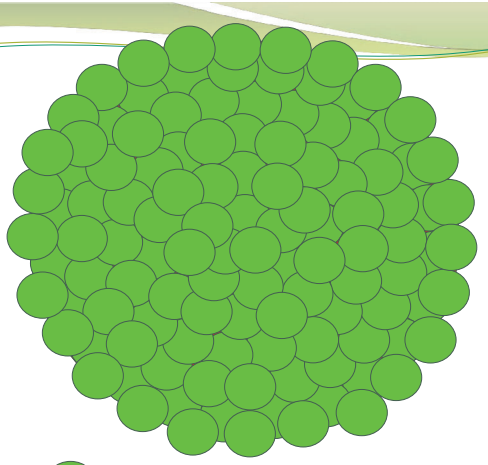
Results

- 2 good variants found early on
  - < a second faster
  - Generations 5 and 10
- Not statistically significant on training dataset
- **Significant on a larger dataset**
  - Still, only about 1 sec faster



Variant 1
Deletes a single line that performs an expensive matrix multiplication

Variant 2
Changes: i++ to ++i



Gained improvement per execution

66

Overview

- **Introduction**
- **Fixing Bugs and other examples**
- **Noteworthy papers and issues**
- **Getting involved**
- **Summary and Q&A**

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Improving CUDA DNA Analysis Software with Genetic Programming (2015)
W.B. Langdon , B.Y.H. Lam , J. Petke & M. Harman

1. DNA sequencing
2. consisting of **8,000+** lines of code.
3. improved version is up to **3x** faster
4. downloaded **1,000** times.
5. **Ported by IBM** to one of their super computers

BOW TIE

A 50,000 line system

Optimising Existing Software with Genetic Programming

William B. Langdon and Mark Harman

- Bowtie2, a **DNA sequence** alignment/sequence analysis tool
- Using Genetic Improvement, Harman and Langdon were capable of increasing performance 70x.

A Systematic Study of Automated Program Repair: Fixing 55 out of 105 Bugs for $8 Each

(2012)
Cited ~400 times

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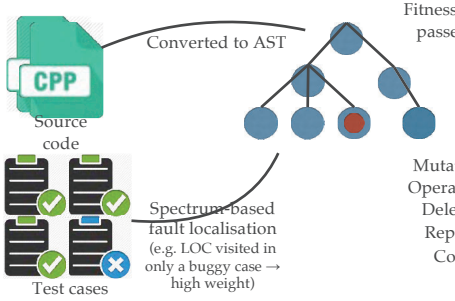
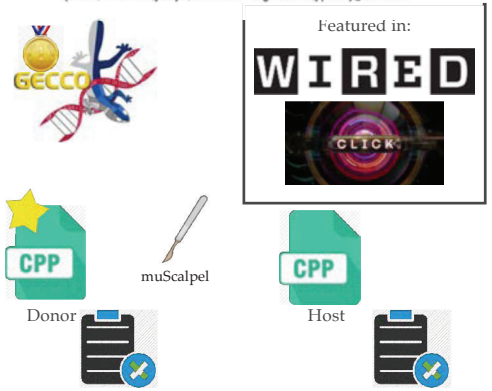


- Where an adequate test suite is provided, GenProg has been shown to fix **real-world bugs**
- It has **inspired a variety of alternative frameworks,** most of which claim to outperform GenProg

Automated Software Transplantation

(2015)

Earl T. Barr Mark Harman Yue Jia Alexandru Marginean Justyna Petke
CREST, University College London, Malet Place, London, WC1E 6BT, UK
{e.barr,m.harman,yue.jia,alexandru.marginean.13,j.petke}@ucl.ac.uk



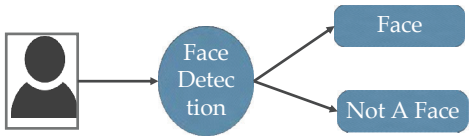
Babel Pidgin: SBSE Can Grow and Graft Entirely New Functionality into a Real World System

(2014)

Mark Harman, Yue Jia, and William B. Langdon
University College London, CREST centre, UK

Deep Parameter Optimisation for Face Detection Using the Viola-Jones Algorithm in OpenCV

Bobby R. Bruce[1(✉)], Jonathan M. Aitken[2(✉)], and Justyna Petke[1(✉)]



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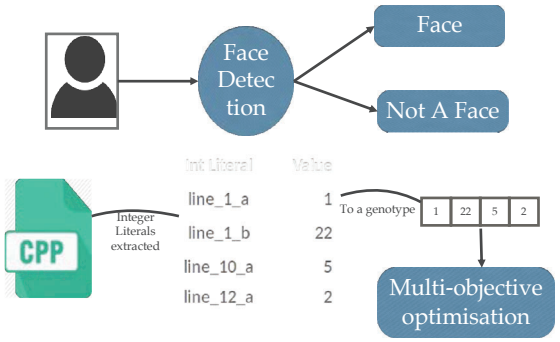

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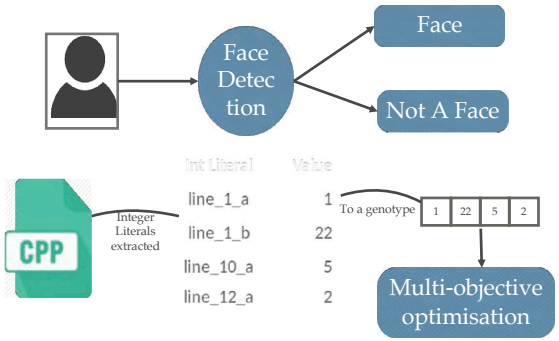
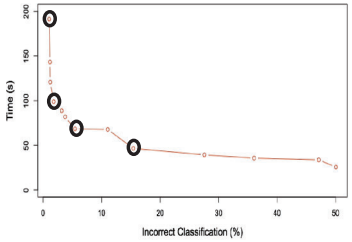


Original: 191s, 1.04% inaccuracy
99s (48% decrease), 1.8% inaccuracy
68s (64% decrease), 5.4% inaccuracy
46s (76% decrease), 15.4% inaccuracy

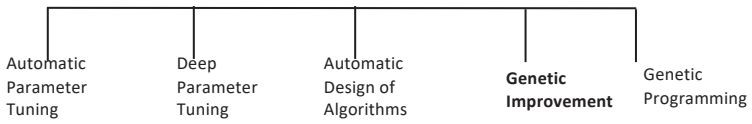


PhD Theses

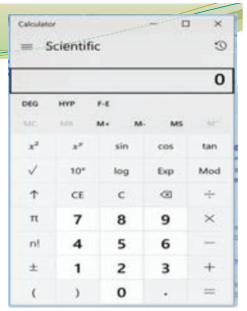
- David R. White
- Andrea Accuri
- Bobby R. Bruce
- Sæmundur Ó. Haraldsson
- Mahmoud R. Bokhari
- And many more to come...

Relationship to other fields

- Optimization/machine learning - OVERFITTING (or: specialisation?) ("Is the cure worse than the disease?" Smith et al. FSE 2015)
- Genetic Programming and Metaheuristics
- the automatic design of algorithms
- Automatic parameter tuning/deep parameter tuning/GI

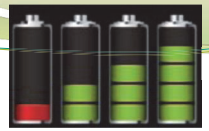


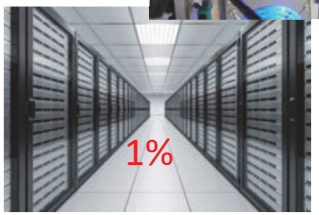
GI & Benchmarking



1. GP suffered a "midlife crisis"
2. Toy problem e.g. lawnmower
3. Genetic Programming Needs Better Benchmarks [White et al.]
4. Machine Learning that Matter [Wagstaff 2012] what is 1% meaning
5. *Is Software Engineering the best benchmark for GP?*
6. Do we have a stable set of benchmarks for GI? (for program repair: http://program-repair.org/benchmarks.html)
7. Benchmarking is more complex (noise, hardware, prog lang, …)

Measuring Energy





- **computational energy consumption growing importance, particularly at the extremes (i.e., mobile devices and datacentres).**

one line = one unit

simulate (runtime/system calls/) Tools Opacitor, PowerGauge

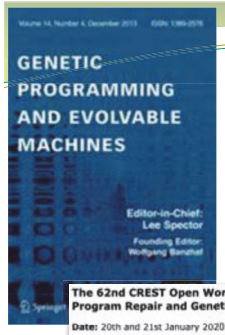
read battery indicator

physically measure and validate(e.g. see Bokhari et al.)

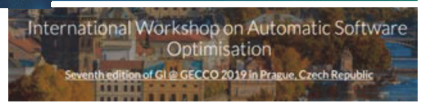
GI@GECCO'17 **Deep Parameter Optimisation on Android Smartphones for Energy Minimisation - A Tale of Woe and a Proof-of-Concept**

GECCO '20 Towards Rigorous Validation of Energy Optimisation Experiments

CEC 2019 Mind the gap - a distributed framework for enabling energy optimisation on modern smart-phones in the presence of noise, drift, and statistical insignificance [#19776]



activities

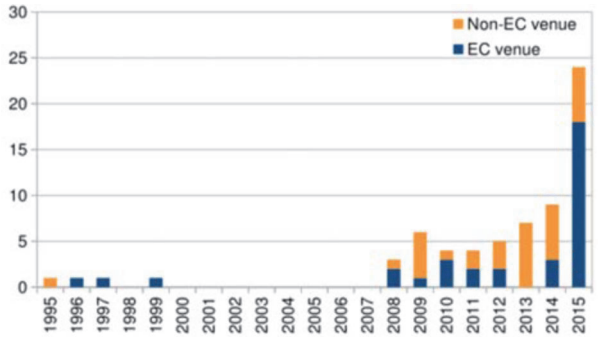


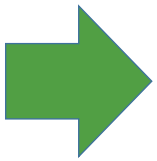
The 6th International Workshop on Genetic Improvement @ICSE 2019

January 2018

SCHLOSS DAGSTUHL
Leibniz-Zentrum für Informatik

Growth of Papers





SOURCE CODE WILL ALWAYS BE IMPORTANT

How will it continue…???

Source of Genetic Material

1. the program being improved,
1. a different program written in the same language (Petke: MiniSAT competition),
1. a piece of code generated from scratch (GP),
1. different programming language other than the software to be improved.

J. Petke, M. Harman, W. B. Langdon, and W. Weimer, "Using genetic improvement and code transplants to specialise a C++ program to a problem class," in *European Conf. on Genetic Programming EuroGP*, ser. LNCS, vol. 8599. Springer, 2014, pp. 137–149.

Theory

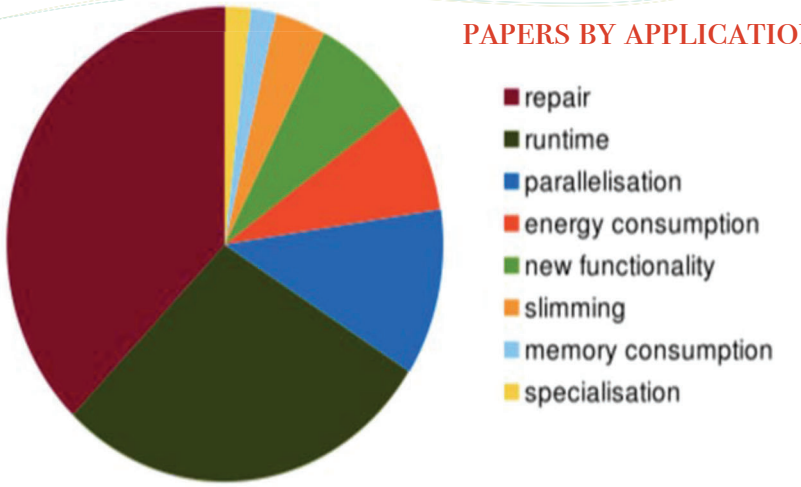
- Hard!

- NFL not really valid for GP, and therefore GI.
  - Why – because many programs share same functionality.

=> GI will remain empirical for years to come

Breakdown

Papers by application



Grant Writing

- A grant about GP (0%)

VS

- A grant about GI. (100%)

Websites

Genetic Improvement Workshop

An International Workshop on the Repair and Optimisation of Software using Computational Search

- http://geneticimprovementofsoftware.com/
- https://en.wikipedia.org/wiki/Genetic_improvement_(computer_science)
- http://www.davidrwhite.co.uk/
- http://daase.cs.ucl.ac.uk/
- http://crest.cs.ucl.ac.uk/publications/
- https://clairelegoues.com/blog/
- https://cs.adelaide.edu.au/~optlog/research/software.php

Google Scholar label:genetic_improvement

CREST

Starting point – POP science, GIN, Survey

IEEE TRANSACTIONS ON EVOLUTIONARY COMPUTATION

Genetic Improvement of Software: a Comprehensive Survey

(2017)

Justyna Petke, Saemundur O. Haraldsson, Mark Harman, William B. Langdon, David R. White, and John R. Woodward

GI@GECCO'19

A Survey of Genetic Improvement Search Spaces

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Overview

- **Introduction**
- **Fixing Bugs and other examples**
- **Noteworthy papers and issues**
- **Getting involved**
- **Summary and Q&A**

Get involved with GI in No time - or GIN

Available at
https://github.com/gintool/gin

http://www.davidrwhite.co.uk/

v2.0 published in June 2019
"Gin: Genetic Improvement Research Made Easy" (GECCO 2019)

GI in No Time

David R. White
UCL, London, UK
david.r.white@ucl.ac.uk

(Inaugural paper at GI@GECCO 2017)

The inaugural paper

official V2.0 released on 12 June 2019:
https://github.com/gintool/gin/releases

Gin: Genetic Improvement Research Made Easy

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ABSTRACT

Genetic improvement (GI) is a young field of research on the cusp of transforming software development. GI uses search to improve existing software. Researchers have already shown that GI can improve human-written code, ranging from program repair to optimising run-time, from reducing energy-consumption to the transplantation of new functionality. Much remains to be done. The cost of re-implementing GI to investigate new approaches is hindering progress. Therefore, we present Gin, an extensible *and* modifiable

1 INTRODUCTION

Genetic improvement (GI) is a young field of software engineering research that uses search to improve existing software. GI aims to improve both functional, notably bug fixing, and non-functional properties of software, such as runtime or energy consumption. The intersection of automated program repair (APR) and GI has had the greatest impact to date, from the release of the GI-based tool GenProg [27] to successful integration of APR into commercial development processes [19, 20]. Non-functional improvement (NFI) is

Bradley Alexander

Earl T. Barr

Sandy Brownlee

Justyna Petke

Markus Wagner

Also uses GIN in teaching since 2017

https://tinyurl.com/giassignment

David R. White

"Stupidly simple"

GIN

ECJ

https://cs.gmu.edu/~eclab/projects/ecj/

Genetic Improvement

- Many success stories
- …however, these typically need at GI expert in the loop
- What's needed is a more systematic approach
- A toolkit to enable experimentation

Gin's Goals

- Remove *incidental* difficulties of GI for research and teaching
- Enable focus on general questions
- Provide a central tool for the community
- Support more than bug-fixing: non-functional properties
- Work on open-source software projects out-of-the-box

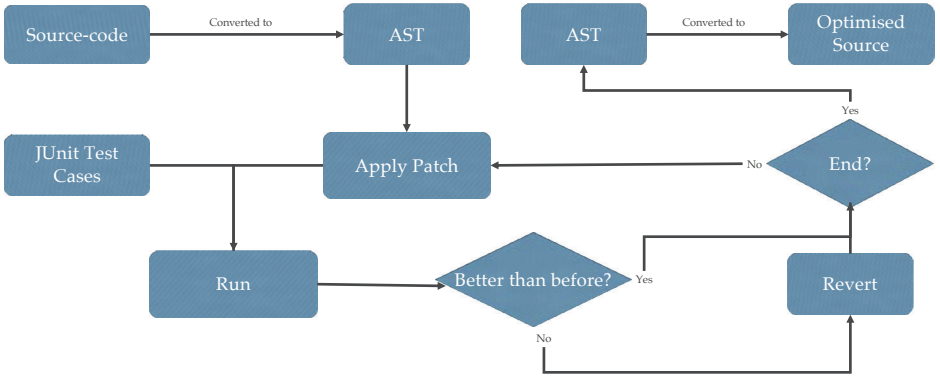
Gin Design

What's in Gin?

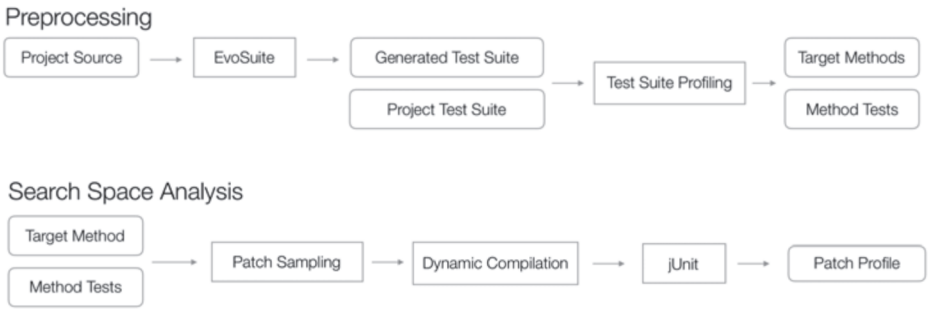
- Implementations of edits for source code
- Evaluate edits: compile and run JUnit tests
- Searches and Samplers
- Test generation (EvoSuite)
- Profiler to identify hot methods (hprof)
- Build tool integration (Maven, Gradle)

Let's see those in more detail...

Vanilla GIN: Neighbourhood search



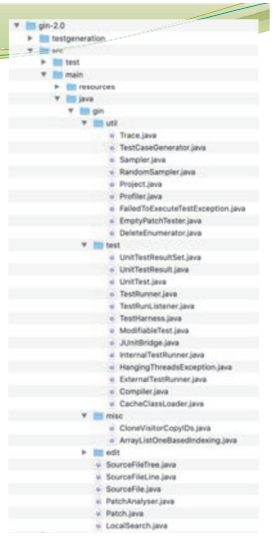
Gin Pipelines



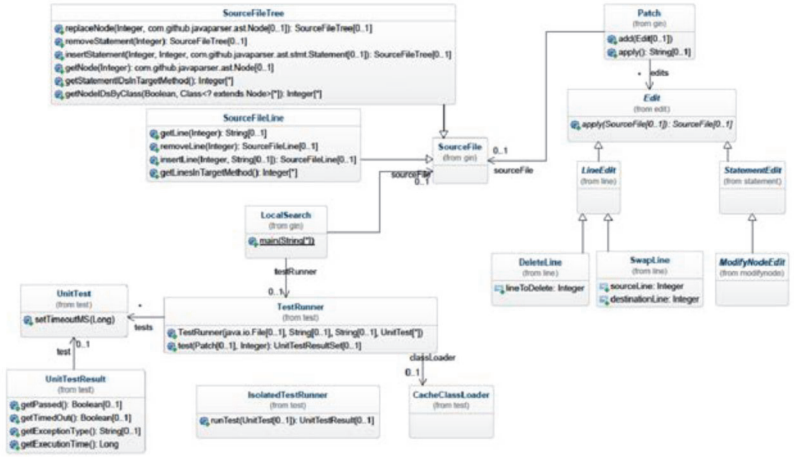
Vanilla GIN Version 1.0

Vanilla GIN Version 2.0:

gradle/maven support,
various types of edits,
profiler to find "hot" methods,
various samplers, …



Gin v2 Core Classes



Edits

- Edits are single changes to source code
  - Building blocks of a repair
  - Combined into Patches
  - Question: actually, what scale might an *edit* be?
- Gin supports edits at:
  - line level (Langdon) - delete/replace/copy/swap/move
  - statement level (GenProg) - delete/replace/copy/swap/move
  - constrained (matched) statement - replace/swap
  - micro edits
    - binary & unary operator replacement (OR ⇔ AND) (++ ⇔ --)
    - reorder Boolean expressions (X && Y ⇔ Y && X)
  - loop and method shortcuts (insert return/break/continue)

Edits

- We provide many wrappers to make your life easier, so that you can focus on higher-level tasks:
  - "Tell me which lines are eligible for deletion in this method"
  - "Delete this line"
  - "Give me all the for loop conditions in this method"
  - And many more...

Example edits

```
1 public class ReplaceStatement extends StatementEdit {
2
3   public int sourceID;
4   public int destinationID;
5
6   public ReplaceStatement(SourceFileTree sf, Random r) {
7     sourceID = sf.getRandomStatementID(false, r);
8     destinationID = sf.getRandomStatementID(true, r);
9   }
10
11  public SourceFile apply(SourceFileTree sf) {
12    Statement source = sf.getStatement(sourceID);
13    Statement dest = sf.getStatement(destinationID);
14    return sf.replaceNode(dest, source.clone());
15  }
16
17 }
```

Disclaimer: this was an old version. Today, it is a little bit longer, e.g., to prevent us from replacing statements within the same parent node.

Patch Evaluation

Gin invokes test cases via Junit…

Tracks:

- compile success;
- run-time errors, exception types
- actual & expected outcomes
- timing: wall-clock and CPU time

```
UnitTest[] ut = {
    new UnitTest("TriangleTest", "testInvalidTriangles"),
    new UnitTest("TriangleTest", "testEqualateralTriangles"),
    new UnitTest("TriangleTest", "testIsocelesTriangles"),
    new UnitTest("TriangleTest", "testScaleneTriangles")
};

UnitTest.defaultTimeoutMS = 10000;
int reps = 1;

SourceFileTree sf = new SourceFileTree("examples/triangle/Triangle.java",
          Collections.singletonList("classifyTriangle(int,int,int)"));

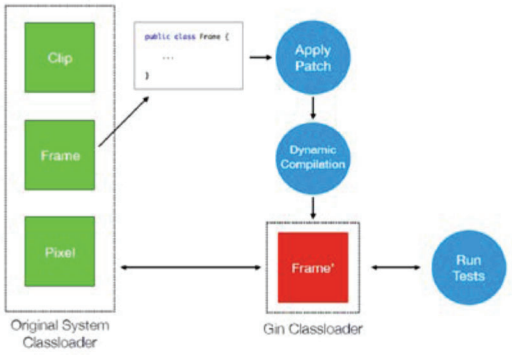
InternalTestRunner tr = new InternalTestRunner("TriangleTest",
          "examples/triangle", Arrays.asList(ut));

// Start with the empty patch
Patch patch = new Patch(sf);

// Run empty patch and log
UnitTestResultSet rs = tr.runTests(patch, reps);

boolean compiled = rs.getCleanCompile();
boolean test0TimedOut = rs.getResults().get(0).getTimedOut();
long test0ExecutionTime = rs.getResults().get(0).getExecutionTime();
String test0ExceptionMessage = rs.getResults().get(0).getExceptionMessage();
```

An analogy: video editing. Here: Gin Compiles and Reloads on-the-fly



Note: If you prefer to use the more "traditional" way of writing the file to disk first - e.g., due to integration of Gin into other pipelines - then you can use a command-line flag to do so.

Sampling and Searching

- Included samplers:
  - EmptyPatchTester
  - RandomSampler
  - DeleteEnumerator
- Searches: LocalSearch, GP

- Possible Questions:
  - What is the effectiveness of a given edit type for fixing a category of bug?
  - How robust is the space of single-line edits, modulo the given test suite?
  - ...

DeleteEnumerator

```
1 public static void main(String[] args) {
2
3   UnitTest[] ut = {
4     new UnitTest("TriangleTest","testInvalidTriangles"),
5     ...
6   };
7
8   int reps = 1;
9
10  SourceFileTree sf = new SourceFileTree(
11      "examples/simple/Triangle.java",
12      Collections.singletonList(
13          "classifyTriangle(int,int,int)"));
14
15  TestRunner tr = new TestRunner(
16      new File("examples/simple"), "Triangle",
17      "examples/simple", Arrays.asList(ut));
18
19  // Start with the empty patch
20  Patch patch = new Patch(sf);
21
22  // Run empty patch and log
23  UnitTestResultSet rs = tr.test(patch, reps);
24  writeResults(rs, 0);
25
26  int patchCount = 0;
27  for (int id : sf.getStatementIDsInTargetMethod()) {
28    patchCount++;
29    patch = new Patch(sf);
30    patch.add(new DeleteStatement(sf.getFilename(),id));
31
32    rs = tr.test(patch, reps);
33    writeResults(rs, patchCount);
34  }
35 }
```

Sampling

The following is one really wide output file - here of RandomSampler:

PatchIndex	PatchSize	Patch
1	1	gin.edit.statement.SwapStatement ./src/main/java/org/jcodec/codecs/vpx/VPXBitstream.java:752 <-> ./src/main/java/org/jcodec/codecs/vpx/VPXBitstream.java:884 |
2	1	gin.edit.statement.ReplaceStatement ./src/main/java/org/jcodec/codecs/prores/ProresEncoder.java:2310 -> ./src/main/java/org/jcodec/codecs/prores/ProresEncoder.java:1185 |
3	1	gin.edit.statement.CopyStatement ./src/main/java/org/jcodec/containers/mp4/boxes/Box.java:514 -> ./src/main/java/org/jcodec/containers/mp4/boxes/Box.java:110:110 |

TestTimedOut	TestExceptionType	TestExceptionMessage	AssertionExpectedValue	AssertionActualValue
FALSE	java.lang.AssertionError	expected:<255> but was:<207>	255	207
FALSE	N/A	N/A	N/A	N/A
FALSE	N/A	N/A	N/A	N/A

MethodIndex	TestIndex	UnitTest	RepNumber	PatchValid	PatchCompiled	TestPassed	TestExecutionTime(ns)	TestCPUTime(ns)
152	1	org.jcodec.codecs.vpx.TestCoeffEncoder.testCoeffDCTU []	0	TRUE	TRUE	FALSE	2853708	1535633
189	1	org.jcodec.codecs.prores.ProresEncoderTest.testWholeThing []	0	TRUE	FALSE	FALSE	0	0
184	1	org.jcodec.containers.mp4.boxes.TrunBoxTest.testReadWriteCreate []	0	TRUE	FALSE	FALSE	0	0

Local search

```
1  private Patch search() {
2      // start with the empty patch
3      Patch bestPatch = new Patch(sourceFile);
4      long bestTime = testRunner.test(bestPatch, 10).
           totalExecutionTime();
5
6      for (int step = 1; step <= NUM_STEPS; step++) {
7          Patch neighbour = neighbour(bestPatch, rng);
8          UnitTestResultSet rs = testRunner.test(neighbour
               ,10);
9          if (rs.getValidPatch() && rs.getCleanCompile() &&
10             rs.allTestsSuccessful() &&
11             rs.totalExecutionTime() < bestTime) {
12         bestPatch = neighbour;
13         bestTime = rs.totalExecutionTime();
14         }
15     }
16
17     return bestPatch;
18 }
19
20 public Patch neighbour(Patch patch, Random rng) {
21     Patch neighbour = patch.clone();
22
23     if (neighbour.size() > 0 && rng.nextFloat() > 0.5) {
24         neighbour.remove(rng.nextInt(neighbour.size()));
25     } else {
26         neighbour.addRandomEdit(rng, allowableEditTypes);
27     }
28
29     return neighbour;
30 }
```

Local search, output

```
~bash-4.1$ java -jar build/gin.jar gin.LocalSearch -filename examples/triangle/Triangle.java -m "classifyTriangle(int, int, int)"
```

Local search, output

```
~bash-4.1$ java -jar build/gin.jar gin.LocalSearch -filename examples/triangle/Triangle.java -m "classifyTriangle(int, int, int)"
2020-04-10 04:36:41 gin.LocalSearch.search() INFO: Localsearch on file: examples/triangle/Triangle.java method: classifyTriangle(int, int, int)
2020-04-10 04:36:44 gin.test.InternalTestRunner.runSingleTest() WARNING: Possible hanging threads remain after test
2020-04-10 04:36:59 gin.LocalSearch.search() INFO: Original execution time: 1646971219ns
```

Local search, output

```
~bash-4.1$ java -jar build/gin.jar gin.LocalSearch -filename examples/triangle/Triangle.java -m "classifyTriangle(int, int, int)"
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2020-04-10 04:36:59 gin.LocalSearch.search() INFO: Original execution time: 1646971219ns
2020-04-10 04:36:59 gin.LocalSearch.search() INFO: Step: 1, Patch: | gin.edit.line.ReplaceLine examples/triangle/Triangle.java:5 ->
examples/triangle/Triangle.java:23 |, Failed to compile
```

Local search, output

```
~bash-4.1$ java -jar build/gin.jar gin.LocalSearch -filename examples/triangle/Triangle.java -m "classifyTriangle(int, int, int)"
2020-04-10 04:36:41 gin.LocalSearch.search() INFO: Localsearch on file: examples/triangle/Triangle.java method: classifyTriangle(int, int, int)
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2020-04-10 04:36:59 gin.LocalSearch.search() INFO: Step: 1, Patch: | gin.edit.line.ReplaceLine examples/triangle/Triangle.java:5 ->
examples/triangle/Triangle.java:23 |, Failed to compile
2020-04-10 04:36:59 gin.LocalSearch.search() INFO: Step: 2, Patch: | gin.edit.line.DeleteLine examples/triangle/Triangle.java:36 |, Failed to compile
2020-04-10 04:36:59 gin.LocalSearch.search() INFO: Step: 3, Patch: | gin.edit.line.DeleteLine examples/triangle/Triangle.java:19 |, Failed to compile
2020-04-10 04:36:59 gin.LocalSearch.search() INFO: Step: 4, Patch: | gin.edit.line.DeleteLine examples/triangle/Triangle.java:28 |, Failed to pass all tests
2020-04-10 04:36:59 gin.LocalSearch.search() INFO: Step: 5, Patch: | gin.edit.line.ReplaceLine examples/triangle/Triangle.java:38 ->
examples/triangle/Triangle.java:35 |, Failed to compile
2020-04-10 04:36:59 gin.LocalSearch.search() INFO: Step: 6, Patch: | gin.edit.line.DeleteLine examples/triangle/Triangle.java:17 |, Failed to compile
2020-04-10 04:37:00 gin.LocalSearch.search() INFO: Step: 7, Patch: | gin.edit.line.CopyLine examples/triangle/Triangle.java:34 ->
examples/triangle/Triangle.java:13 |, Failed to compile
2020-04-10 04:37:00 gin.test.InternalTestRunner.runSingleTest() WARNING: Possible hanging threads remain after test
2020-04-10 04:37:00 gin.test.InternalTestRunner.runSingleTest() WARNING: Possible hanging threads remain after test
2020-04-10 04:37:00 gin.LocalSearch.search() INFO: Step: 8, Patch: | gin.edit.line.SwapLine examples/triangle/Triangle.java:27 <->
examples/triangle/Triangle.java:10 |, Failed to pass all tests

...

2020-04-10 04:36:26 gin.LocalSearch.search() INFO: Step: 96, Patch: | gin.edit.line.DeleteLine examples/triangle/Triangle.java:10 | gin.edit.line.SwapLine
examples/triangle/Triangle.java:8 <-> examples/triangle/Triangle.java:14 |, Failed to compile
2020-04-10 04:36:28 gin.LocalSearch.search() INFO: Step: 97, Patch: |, Time: 1647522167ns
2020-04-10 04:36:28 gin.LocalSearch.search() INFO: Step: 98, Patch: | gin.edit.line.DeleteLine examples/triangle/Triangle.java:10 | gin.edit.line.CopyLine
examples/triangle/Triangle.java:51 -> examples/triangle/Triangle.java:26 |, Failed to compile
2020-04-10 04:36:29 gin.LocalSearch.search() INFO: Step: 99, Patch: |, Time: 1648831018ns
2020-04-10 04:36:29 gin.LocalSearch.search() INFO: Step: 100, Patch: | gin.edit.line.DeleteLine examples/triangle/Triangle.java:10 | gin.edit.line.SwapLine
examples/triangle/Triangle.java:39 <-> examples/triangle/Triangle.java:29 |, New best time: 38744892(ns)
```

Local search, output

```
~bash-4.1$ java -jar build/gin.jar gin.LocalSearch -filename examples/triangle/Triangle.java -m "classifyTriangle(int, int, int)"
2020-04-10 04:36:41 gin.LocalSearch.search() INFO: Localsearch on file: examples/triangle/Triangle.java method: classifyTriangle(int, int, int)
2020-04-10 04:36:44 gin.test.InternalTestRunner.runSingleTest() WARNING: Possible hanging threads remain after test
2020-04-10 04:36:59 gin.LocalSearch.search() INFO: Original execution time: 1646971219ns
2020-04-10 04:36:59 gin.LocalSearch.search() INFO: Step: 1, Patch: | gin.edit.line.ReplaceLine examples/triangle/Triangle.java:5 ->
examples/triangle/Triangle.java:23 |, Failed to compile
2020-04-10 04:36:59 gin.LocalSearch.search() INFO: Step: 2, Patch: | gin.edit.line.DeleteLine examples/triangle/Triangle.java:36 |, Failed to compile
2020-04-10 04:36:59 gin.LocalSearch.search() INFO: Step: 3, Patch: | gin.edit.line.DeleteLine examples/triangle/Triangle.java:19 |, Failed to compile
2020-04-10 04:36:59 gin.LocalSearch.search() INFO: Step: 4, Patch: | gin.edit.line.DeleteLine examples/triangle/Triangle.java:28 |, Failed to pass all tests
2020-04-10 04:36:59 gin.LocalSearch.search() INFO: Step: 5, Patch: | gin.edit.line.ReplaceLine examples/triangle/Triangle.java:38 ->
examples/triangle/Triangle.java:35 |, Failed to compile
2020-04-10 04:36:59 gin.LocalSearch.search() INFO: Step: 6, Patch: | gin.edit.line.DeleteLine examples/triangle/Triangle.java:17 |, Failed to compile
2020-04-10 04:37:00 gin.LocalSearch.search() INFO: Step: 7, Patch: | gin.edit.line.CopyLine examples/triangle/Triangle.java:34 ->
examples/triangle/Triangle.java:13 |, Failed to compile
2020-04-10 04:37:00 gin.test.InternalTestRunner.runSingleTest() WARNING: Possible hanging threads remain after test
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2020-04-10 04:37:00 gin.LocalSearch.search() INFO: Step: 8, Patch: | gin.edit.line.SwapLine examples/triangle/Triangle.java:27 <->
examples/triangle/Triangle.java:10 |, Failed to pass all tests

...

2020-04-10 04:36:26 gin.LocalSearch.search() INFO: Step: 96, Patch: | gin.edit.line.DeleteLine examples/triangle/Triangle.java:10 | gin.edit.line.SwapLine
examples/triangle/Triangle.java:8 <-> examples/triangle/Triangle.java:14 |, Failed to compile
2020-04-10 04:36:28 gin.LocalSearch.search() INFO: Step: 97, Patch: |, Time: 1647522167ns
2020-04-10 04:36:28 gin.LocalSearch.search() INFO: Step: 98, Patch: | gin.edit.line.DeleteLine examples/triangle/Triangle.java:10 | gin.edit.line.CopyLine
examples/triangle/Triangle.java:51 -> examples/triangle/Triangle.java:26 |, Failed to compile
2020-04-10 04:36:29 gin.LocalSearch.search() INFO: Step: 99, Patch: |, Time: 1648831018ns
2020-04-10 04:36:29 gin.LocalSearch.search() INFO: Step: 100, Patch: | gin.edit.line.DeleteLine examples/triangle/Triangle.java:10 | gin.edit.line.SwapLine
examples/triangle/Triangle.java:39 <-> examples/triangle/Triangle.java:29 |, New best time: 38744892(ns)
2020-04-10 04:36:29 gin.LocalSearch.search() INFO: Finished. Best time: 38744892 (ns), Speedup (%): 97.64, Patch: | gin.edit.line.DeleteLine
examples/triangle/Triangle.java:10 |
```

Local search: What did we actually optimise here?

```
~bash-4.1$ cat examples/triangle/Triangle.java
public class Triangle {

                    static final int INVALID = 0;
                    static final int SCALENE = 1;
                    static final int EQUALATERAL = 2;
                    static final int ISOCELES = 3;

                    public static int classifyTriangle(int a, int b,
int c) {

                    delay();

                    // Sort the sides so that a <= b <= c
                    if (a > b) {
                    int tmp = a;
                    a = b;
                    b = tmp;
                    }

                    if (a > c) {
                    int tmp = a;
                    a = c;
                    c = tmp;
                    }

                    if (b > c) {
                    int tmp = b;
                    b = c;
                    c = tmp;
                    }

                    if (a + b <= c) {
                    return INVALID;
                    } else if (a == b && b == c) {
                    return EQUALATERAL;
                    } else if (a == b || b == c) {
                    return ISOCELES;
                    } else {
                    return SCALENE;
                    }

                    }

                    private static void delay() {
                    try {
                    Thread.sleep(100);
                    } catch (InterruptedException e) {

                    }
                    }

}
```

The problematic line was deleted.

```
~bash-4.1$ cat examples/triangle/Triangle.java.optimised
public class Triangle {

                    static final int INVALID = 0;
                    static final int SCALENE = 1;
                    static final int EQUALATERAL = 2;
                    static final int ISOCELES = 3;

                    public static int classifyTriangle(int a, int b,
int c) {


                    // Sort the sides so that a <= b <= c
                    if (a > b) {
                    int tmp = a;
                    a = b;
                    b = tmp;
                    }

                    if (a > c) {
                    int tmp = a;
                    a = c;
                    c = tmp;
                    }

                    if (b > c) {
                    int tmp = b;
                    b = c;
                    c = tmp;
                    }

                    if (a + b <= c) {
                    return INVALID;
                    } else if (a == b && b == c) {
                    return EQUALATERAL;
                    } else if (a == b || b == c) {
                    return ISOCELES;
                    } else {
                    return SCALENE;
                    }


                    }

                    private static void delay() {
                    try {
                    Thread.sleep(100);
                    } catch (InterruptedException e) {

                    }
                    }

}
```

Generating tests and Profiling

Generate new test cases

```
java -cp build/gin.jar gin.util.TestCaseGenerator
-projectDir examples/maven-simple -projectName my-app
-classNames com.mycompany.app.App -generateTests
```

Profile a test suite

```
java -cp build/gin.jar gin.util.Profiler -p my-app
-d examples/maven-simple/ .
```

Results written to `profiler_output.csv`.

Build tool integration

- Maven and Gradle API documentation is sparse!
  - And many projects seem to break conventions about paths, resources etc.
- Project class wraps most of what we have learned
  - provide the classpath for a project
  - find a particular source file within a project's file hierarchy
  - provide a standard method signature for a given method
  - provide a list of project tests
  - run a unit test given its name
- Gin can infer the necessary classpath and dependencies for running unit tests from a Maven or Gradle project, or these can be specified manually
- Maven projects can be updated automatically with new unit tests from *EvoSuite*

Examples with jCodec (maven project)

- Profiler

```
projectnameforgin='jcodec';
java -Dtinylog.level=trace -cp ../../ginfork/build/gin.jar gin.util.Profiler
-h ~/.sdkman/candidates/maven/current/ -p $projectnameforgin -d .
-o $projectnameforgin.Profiler_output.csv -r 1
```

Examples with jCodec (maven project)

- Profiler

```
projectnameforgin='jcodec';
java -Dtinylog.level=trace -cp ../../ginfork/build/gin.jar gin.util.Profiler
-h ~/.sdkman/candidates/maven/current/ -p $projectnameforgin -d .
-o $projectnameforgin.Profiler_output.csv -r 1
```

Examples with jCodec (maven project)

- Profiler

projectnameforgin='jcodec';

java -Dtinylog.level=trace -cp ../../ginfork/build/gin.jar gin.util.Profiler -h ~/.sdkman/candidates/maven/current/ -p $projectnameforgin -d . -o $projectnameforgin.Profiler_output.csv -r 1

- EmptyPatchTester

projectnameforgin='jcodec';

java -Dtinylog.level=trace -cp ../../ginfork/build/gin.jar gin.util.EmptyPatchTester -h ~/.sdkman/candidates/maven/current/ -p $projectnameforgin -d . -m $projectnameforgin.Profiler_output.csv -o $projectnameforgin.EmptyPatchTester_output.csv

Examples with jCodec (maven project)

- Profiler

projectnameforgin='jcodec';

java -Dtinylog.level=trace -cp ../../ginfork/build/gin.jar gin.util.Profiler -h ~/.sdkman/candidates/maven/current/ -p $projectnameforgin -d . -o $projectnameforgin.Profiler_output.csv -r 1

- EmptyPatchTester

projectnameforgin='jcodec';

java -Dtinylog.level=trace -cp ../../ginfork/build/gin.jar gin.util.EmptyPatchTester -h ~/.sdkman/candidates/maven/current/ -p $projectnameforgin -d . -m $projectnameforgin.Profiler_output.csv -o $projectnameforgin.EmptyPatchTester_output.csv

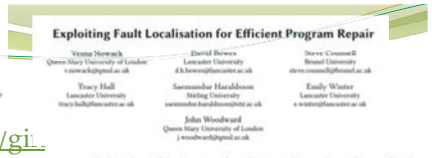
- PatchSampler

projectnameforgin='jcodec';

java -Dtinylog.level=trace -cp ../../ginfork/build/gin.jar gin.util.PatchSampler -h ~/.sdkman/candidates/maven/current/ -p $projectnameforgin -d . -m $projectnameforgin.Profiler_output.csv -o $projectnameforgin.PatchSampler_LINE_output.csv -editType LINE -patchNo 100

Gin


Gin: Genetic Improvement Research Made Easy

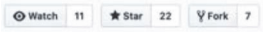

Exploiting Fault Localisation for Efficient Program Repair


Injecting Shortcuts for Faster Running Java Code


Analysing Program Transformation Spaces for Genetic Improvement using Gin


Software Improvement with Gin: A Case Study

- Available at https://github.com/gintool/gi...
- The team actively uses Gin to push the GI boundaries, and quite a few papers are in the works.
- Open for contributions!
  - Particularly new edits and tools
  - https://github.com/gintool/gin
  - we'd like this to become the MiniSAT of GI



Comments/questions: Sandy (Alexander E.I. Brownlee) sbr@cs.stir.ac.uk

Overview

- **Introduction**
- **Fixing Bugs and other examples**
- **Noteworthy papers and issues**
- **Getting involved**
- **Summary and Q&A**

Genetic Improvement vs Genetic Programming

1. Start from an existing program
2. BLOAT? – interpretation?
3. NO function / terminal set
4. Improvement of non-functional properties.
5. Easier to write grants
6. Different benchmarks.
7. Population of edits **NOT programs**.

PUTTING IT ALL TOGETHER

- Let's start with **existing programs**. Not like standard GP.
- Python vs C vs Java? Amenable to GI? Most popular
- Benchmarking ???
- Population of edits, not programs
- GP applied to real software
  - Large, loops, side-effect, modules,…
  - Non functional properties

Questions?

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Brad Alexander <bradley.alexander@adelaide.edu.au>

Bibliography

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