Genetic Improvement: Taking real-world source code and improving it using computational search methods

Sæmundur Ó. Haraldsson, John R. Woodward, Alexander Brownlee

UNIVERSITY of STIRLING

Loughborough University

Latest version of slides at https://cs.stir.ac.uk/~sbr/files/GI_tutorial_GECCO_2023.pdf

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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 Senior 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

Loughborough University

- John R. Woodward is Head of Department at Loughborough University. Previously he was Head of The Operational Research Group 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.

UKRI Engineering and Physical Sciences Research Council

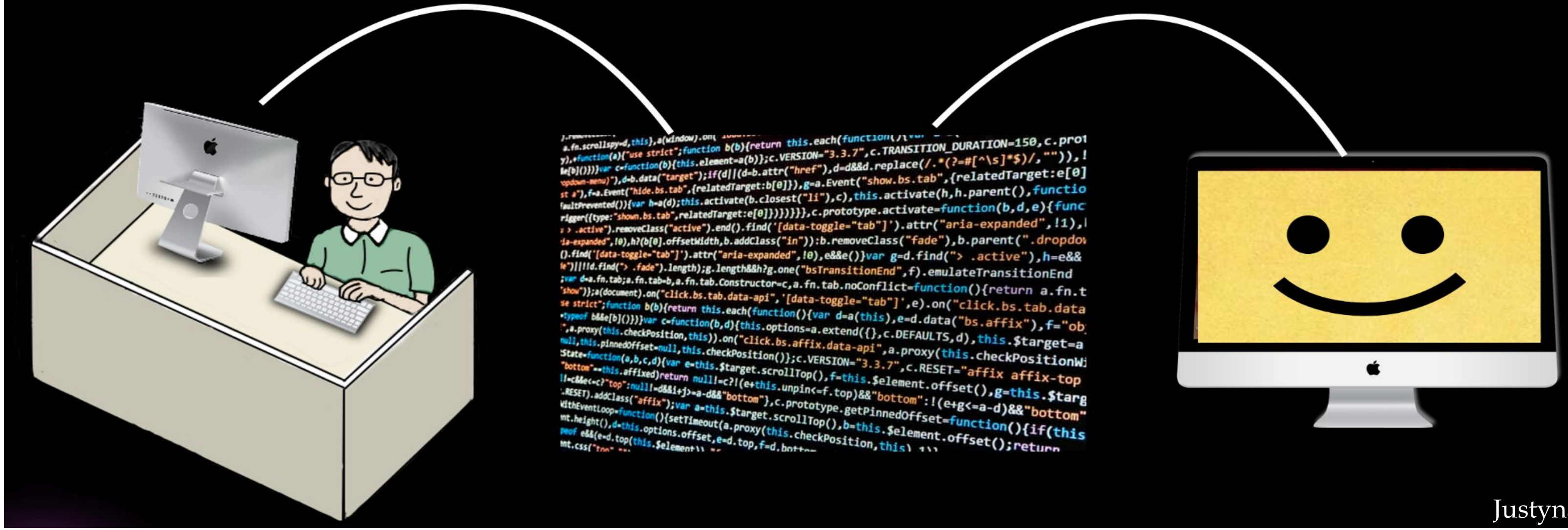
Overview

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

Genetic Improvement of Software

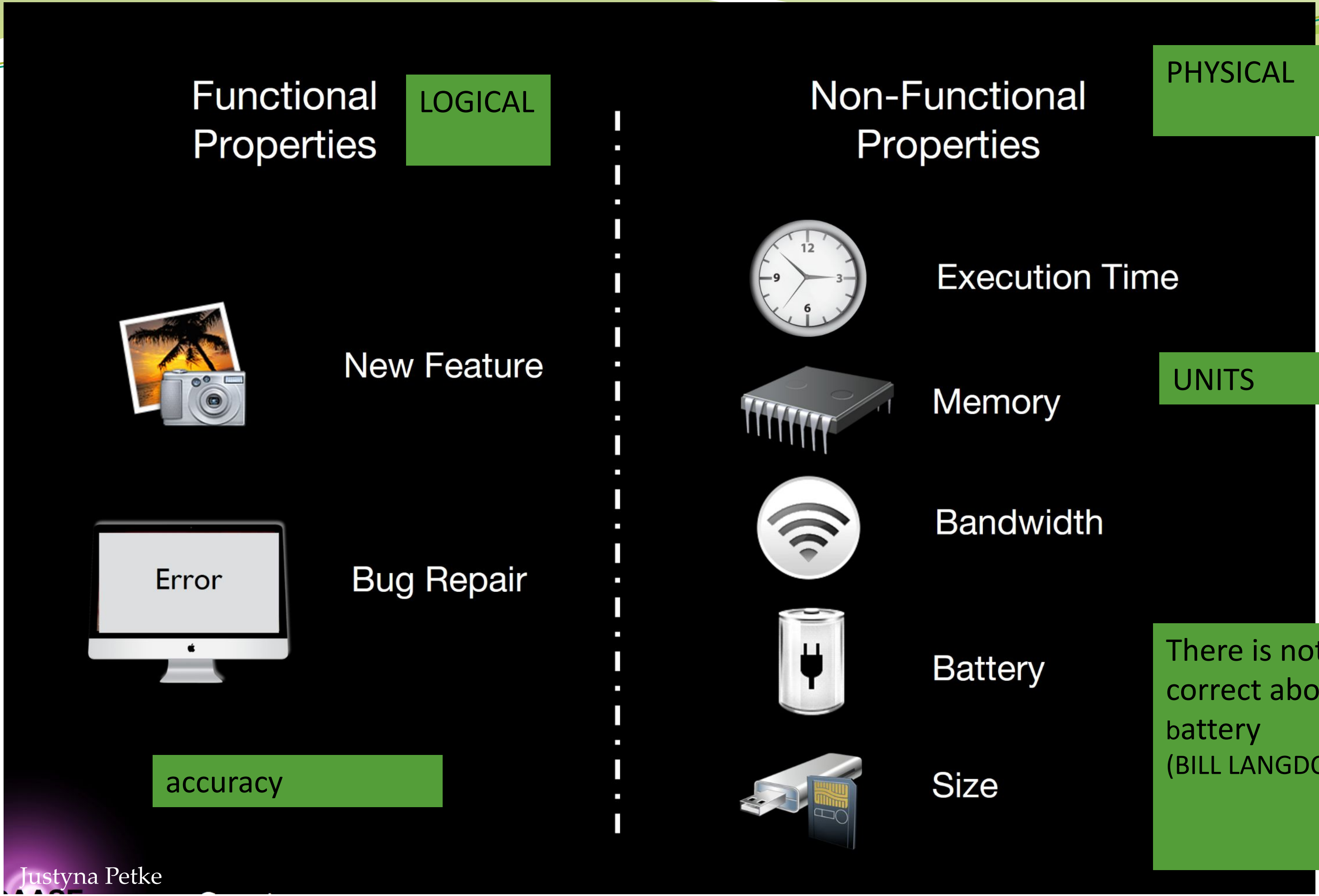
human writes code

computer improves it



```
a.fn.scrollspy=d,this},a(window).on(
y),+function(a){"use strict";function b(b){return this.each(function(){var
e[b]()}))}var c=function(b){this.element=a(b)};c.VERSION="3.3.7",c.TRANSITION_DURATION=150,c.prot
opdown-menu)"),d=b.data("target");if(d||(d=b.attr("href"),d=d&&d.replace(/.*(?=#[^\s]*$)/,"")),!
st a"),f=a.Event("hide.bs.tab",{relatedTarget:b[0]}),g=a.Event("show.bs.tab",{relatedTarget:e[0]
faultPrevented()){var h=a(d);this.activate(b.closest("li"),c),this.activate(h,h.parent(),functio
rigger({type:"shown.bs.tab",relatedTarget:e[0]})})}}},c.prototype.activate=function(b,d,e){func
> .active").removeClass("active").end().find('[data-toggle="tab"]').attr("aria-expanded",!1),
ia-expanded",!0),h?(b[0].offsetWidth,b.addClass("in")):b.removeClass("fade"),b.parent(".dropdow
().find('[data-toggle="tab"]').attr("aria-expanded",!0),e&&e()}var g=d.find("> .active"),h=e&&
e")||!!d.find("> .fade").length);g.length&&h?g.one("bsTransitionEnd",f).emulateTransitionEnd
;var d=a.fn.tab;a.fn.tab=b,a.fn.tab.Constructor=c,a.fn.tab.noConflict=function(){return a.fn.t
"show")};a(document).on("click.bs.tab.data-api",'[data-toggle="tab"]',e).on("click.bs.tab.data
se strict";function b(b){return this.each(function(){var d=a(this),e=d.data("bs.affix"),f="ob
typeof b&&e[b]()}))}var c=function(b,d){this.options=a.extend({},c.DEFAULTS,d),this.$target=a
",a.proxy(this.checkPosition,this)).on("click.bs.affix.data-api",a.proxy(this.checkPositionWi
null,this.pinnedOffset=null,this.checkPosition()};c.VERSION="3.3.7",c.RESET="affix affix-top
State=function(a,b,c,d){var e=this.$target.scrollTop(),f=this.$element.offset(),g=this.$targ
"bottom"==this.affixed)return null!=c?!(e+this.unpin<=f.top)&&"bottom":!(e+g<=a-d)&&"bottom"
!=c&&e<=c?"top":null!=d&&i+j>=a-d&&"bottom"},c.prototype.getPinnedOffset=function(){if(this
.RESET).addClass("affix");var a=this.$target.scrollTop(),b=this.$element.offset();return
WithEventLoop=function(){setTimeout(a.proxy(this.checkPosition,this),1)}
nt.height(),d=this.options.offset,e=d.top,f=d.botto
eof e&&(e=d.top(this.$element))
```

Justyna Petke



Functional Properties

LOGICAL

Non-Functional Properties

PHYSICAL

New Feature

Bug Repair

accuracy

Execution Time

Memory

UNITS

Bandwidth

Battery

Size

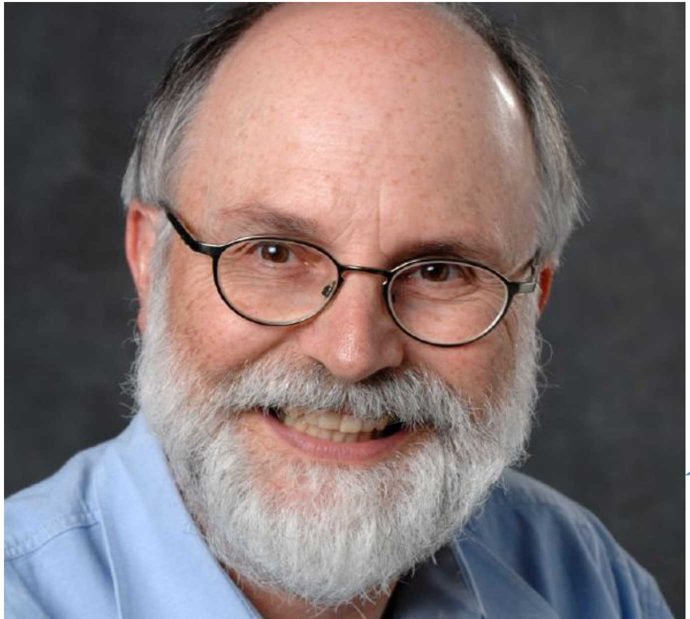
There is nothing correct about a flat battery
(BILL LANGDON)

Justyna Petke

What is Genetic Improvement

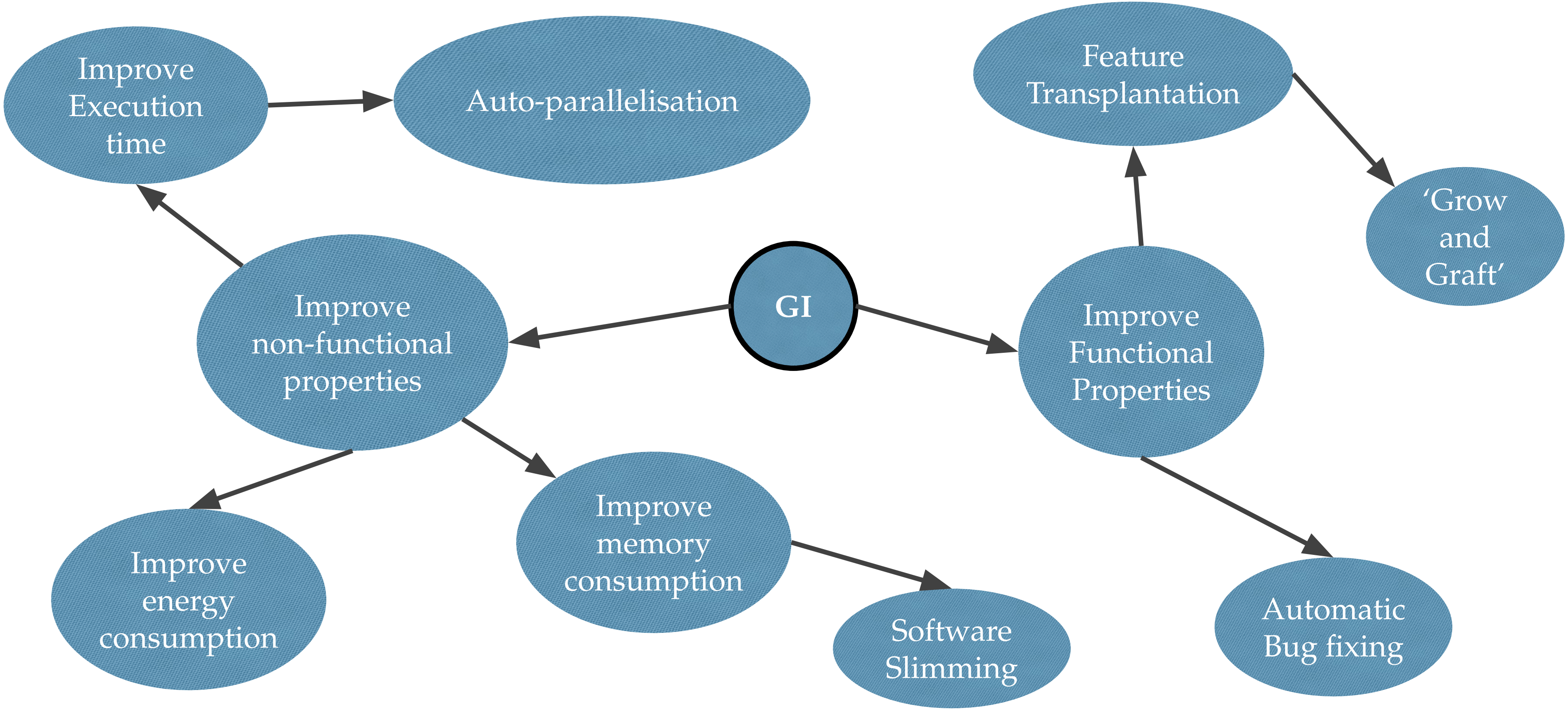
A wordy definition:

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



GI

Improve non-functional properties

Improve Execution time

Auto-parallelisation

Improve energy consumption

Improve memory consumption

Software Slimming

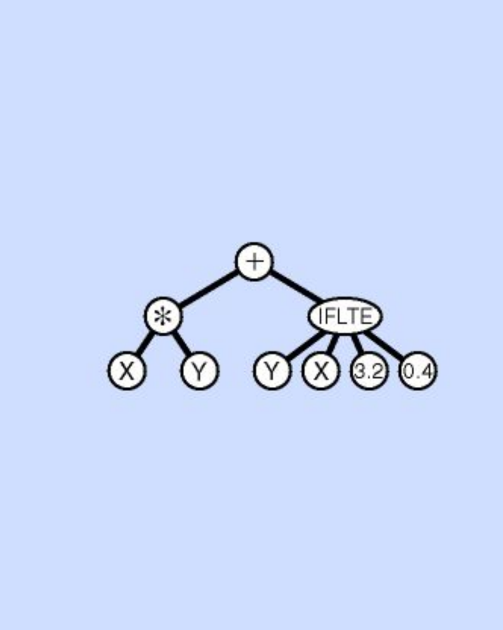
Improve Functional Properties

Feature Transplantation

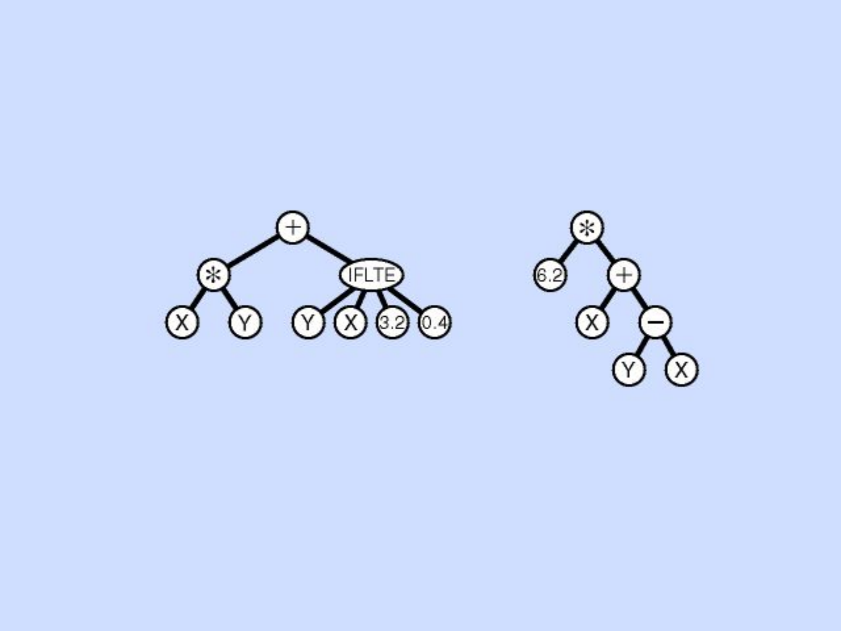
'Grow and Graft'

Automatic Bug fixing

Genetic Programming overview



mutation

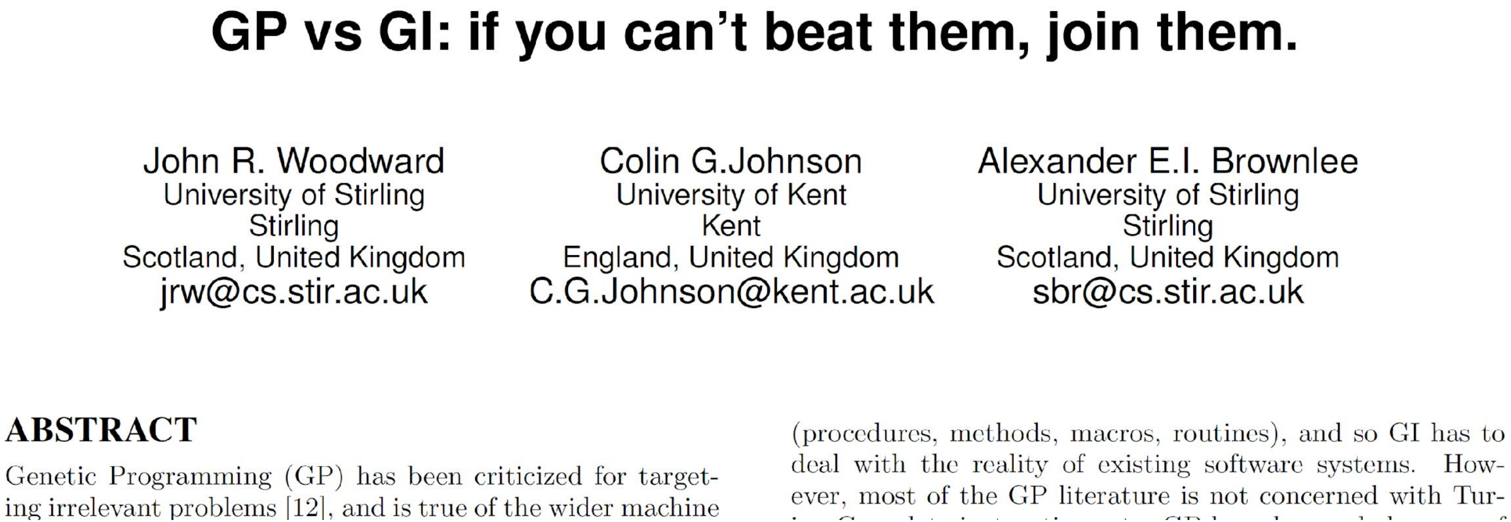


crossover

Genetic Programming: GI's ROOTS

1. **Aim** – *to discover new programs by telling the computer what we want it to do, but not how 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-

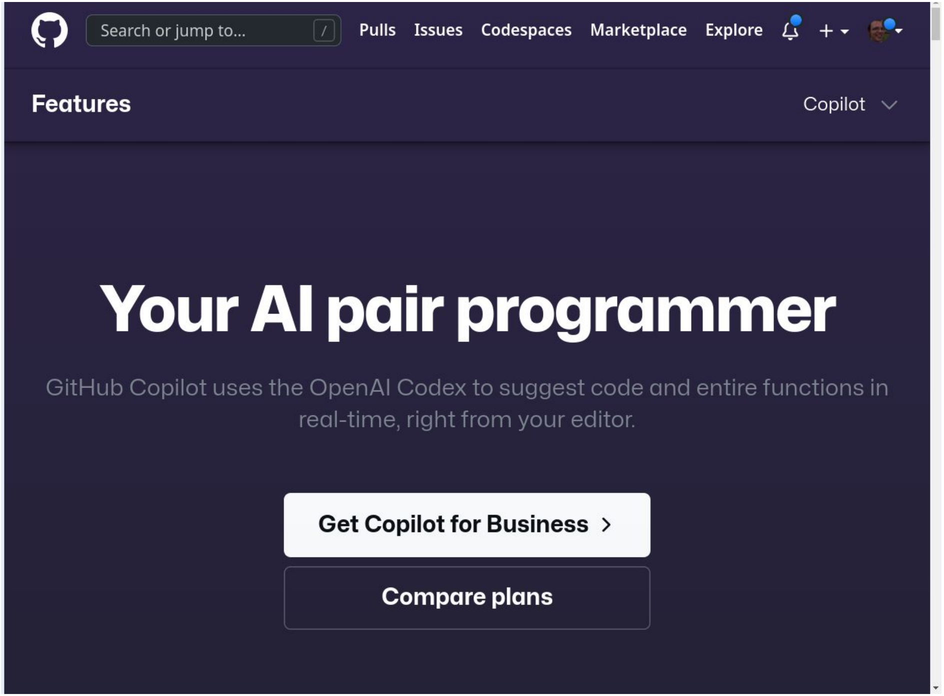
What about Copilot/ChatGPT…?

Large language models generate code!

Replicate patterns given some prompt

Can lead to errors![*] Related-but-incorrect solutions

GI search tests the code as it goes, so can be constrained to only produce variants that (probably) work



Your AI pair programmer

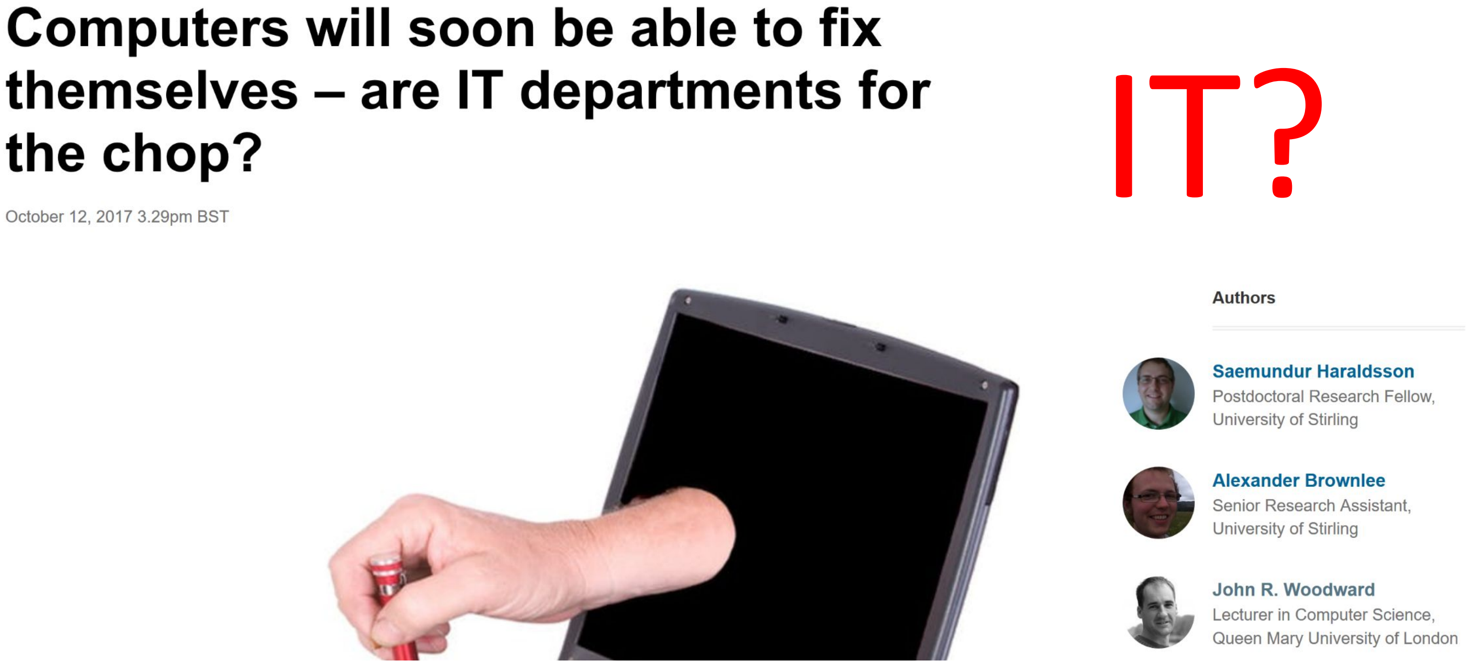
GitHub Copilot uses the OpenAI Codex to suggest code and entire functions in real-time, right from your editor.

[*]Jones E & Steinhardt J. Capturing failures of large language models via human cognitive biases. In AH Oh, A Agarwal, D Belgrave & K Cho, eds., Advances in Neural Information Processing Systems. 2022

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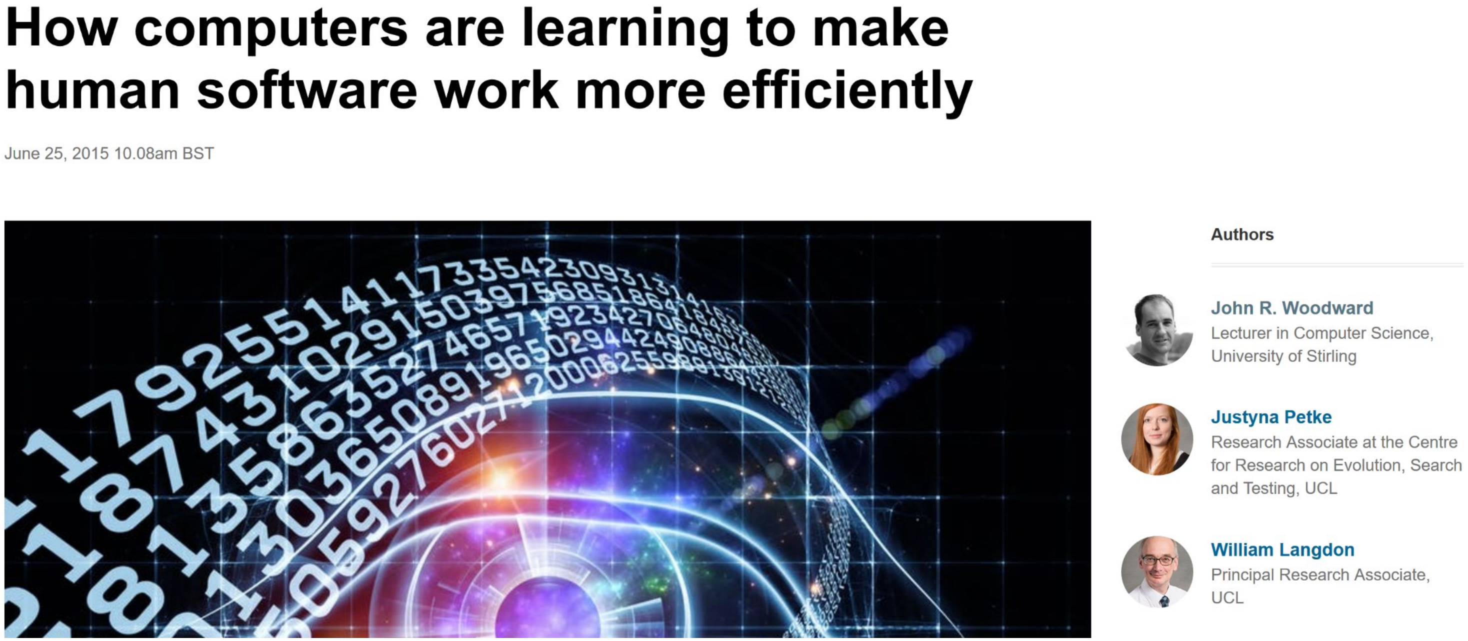
https://theconversation.com/how-computers-are-learning-to-make-human-software-work-more-efficiently-43798



How computers are learning to make human software work more efficiently

June 25, 2015 10.08am BST

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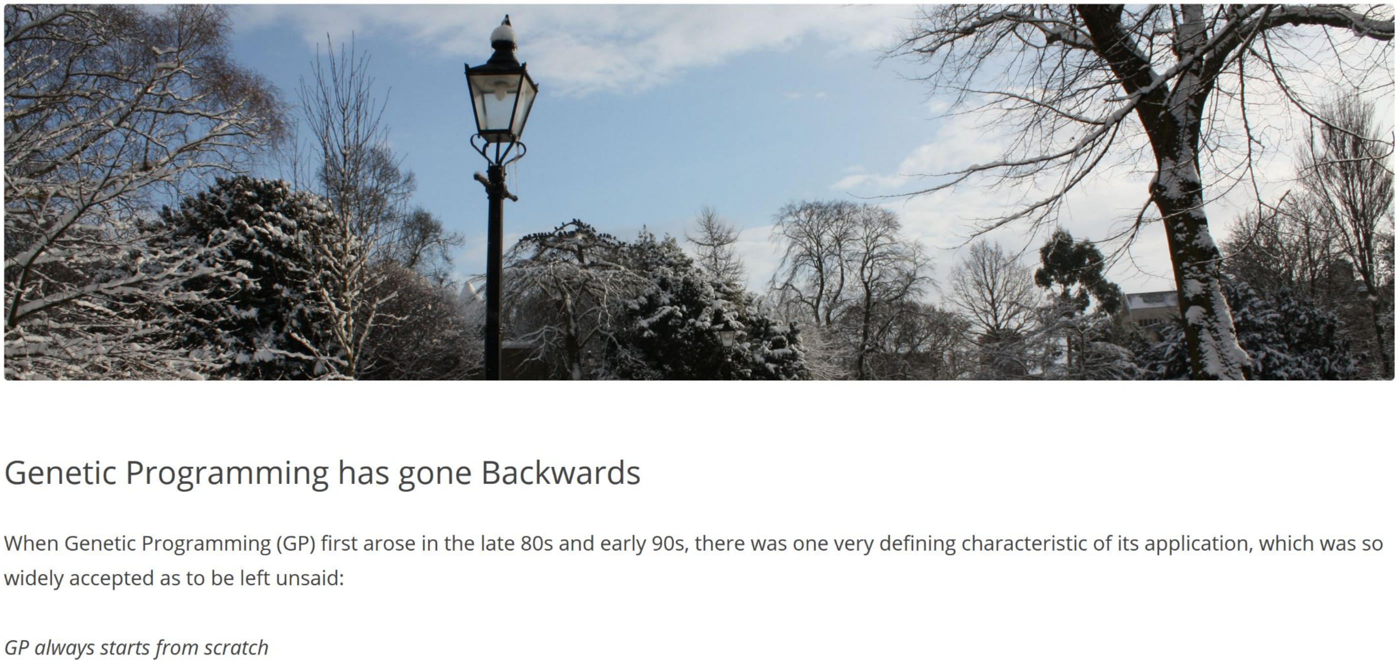
http://www.davidrwhite.co.uk/2014/11/27/genetic-programming-has-gone-backwards/



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/

has genetic programming gone backwards

About 2,440,000 results (0.46 seconds)

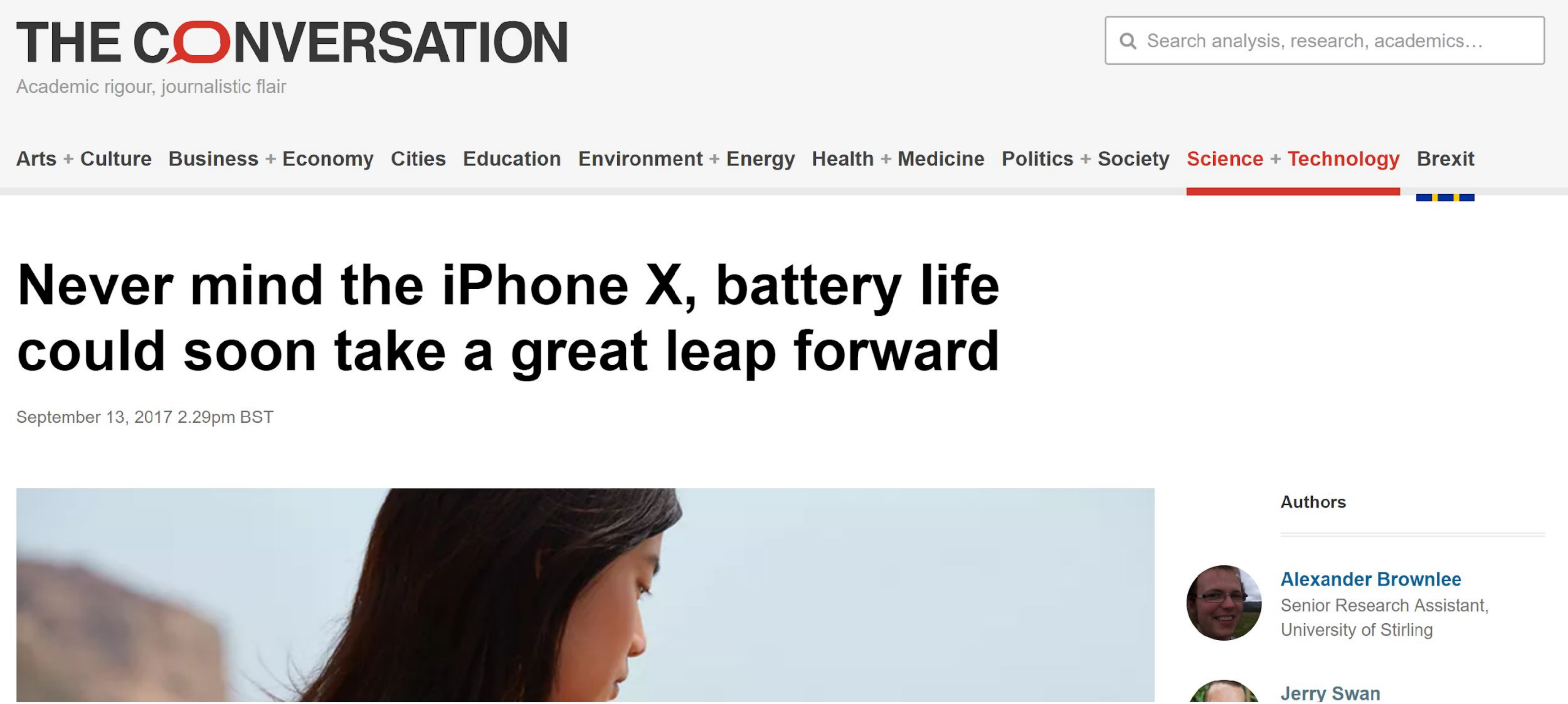
Genetic Programming has gone Backwards | David R. White

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

TAG ARCHIVES: GEN

Genetic Improvement: the Story so far

This blog post is based on a seminar given to the Department of Computer Science at the University of Manchester in April 2016; it also builds on the ideas and talks of many fellow academics, who I acknowledge at the end of the article.



THE CONVERSATION

Academic rigour, journalistic flair

Never mind the iPhone X, battery life could soon take a great leap forward

September 13, 2017 2.29pm BST

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Jerry Swan

Competent Programmers Hypothesis

1. programmers write programs that are almost perfect.
2. program faults are syntactically small (slip of finger, T/F)
3. corrected with a few keystrokes. (e.g. < for <=)
4. **GI can find small patches.**
5. 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]

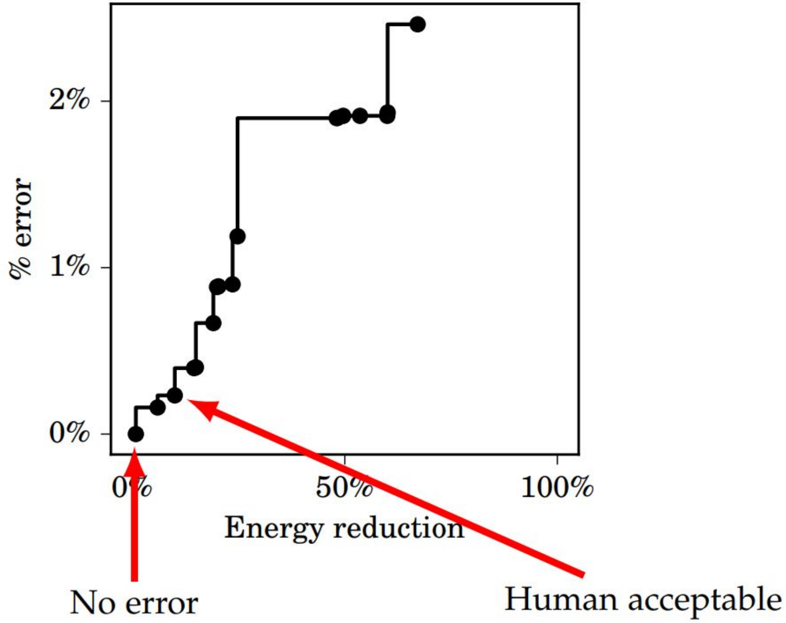
4. Errors, compile, halting (Langdon - discard)

Objectives

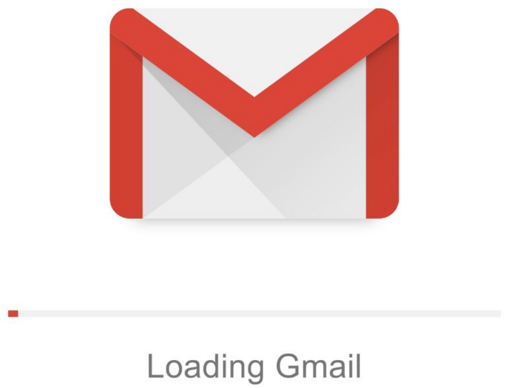
- Functional (**logical properties**)
  - Accuracy e.g. as in machine learning - FLOAT
  - Number of bugs – as measured against a set of test cases. BOOLEAN
  - New functionality – e.g.
- Non-functional (***physical* properties**)
  - Execution time
  - Energy (power consumption – peak/average)
  - Memory
  - 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 Gmail

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 ir the solution space of programs for a specific programming problem.

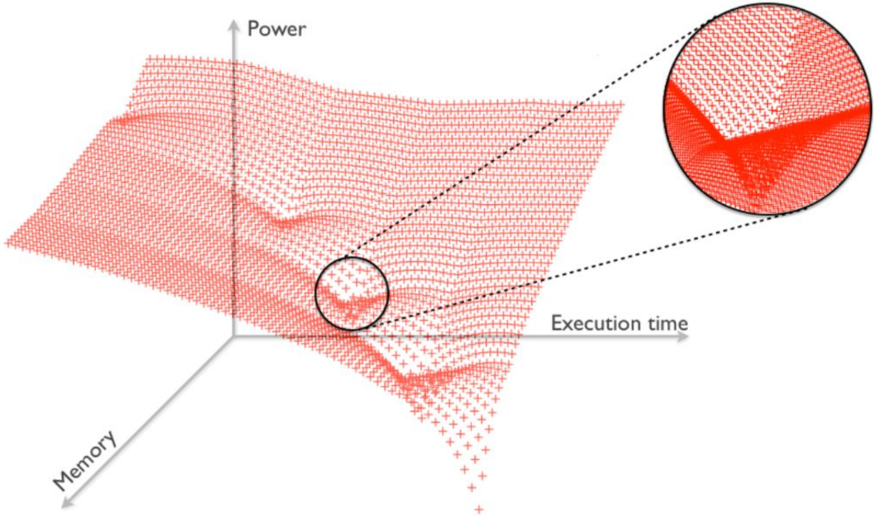


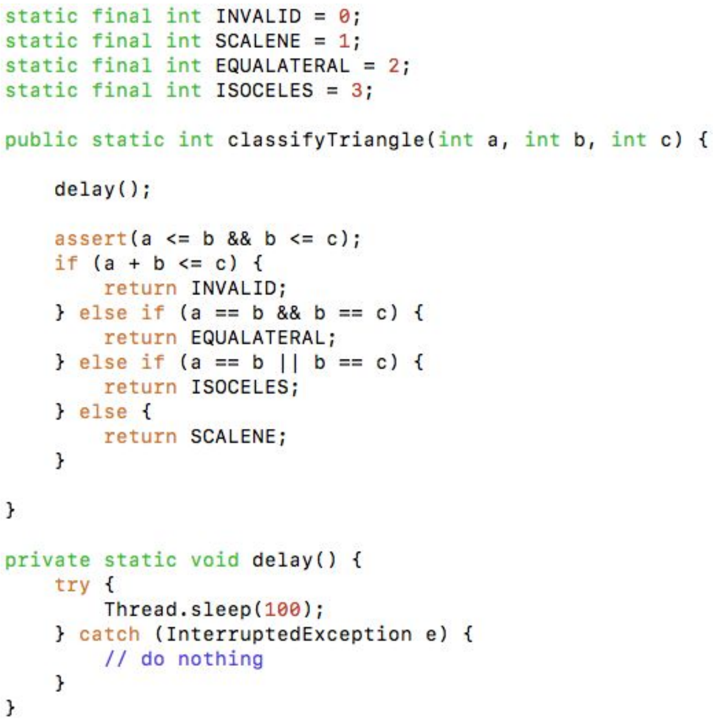
Figure 1: The GISMOE Pareto Program Surface

EDIT Operators – changes to programs

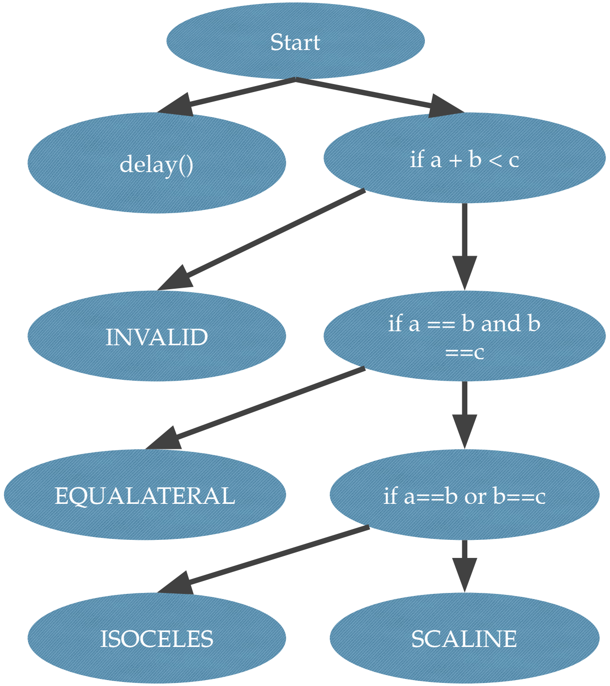
- Line level
- Single Character level
- Function/module level.
- AST – GIN, Gen-0-fix, genprog,
- Java – machine code – java byte code.

- LIST OF EDITS IS A PATCH.

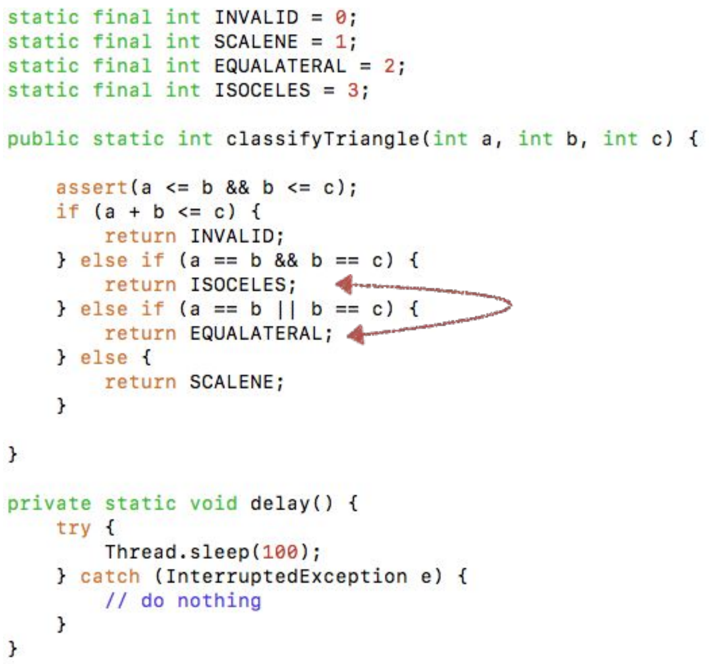
GI: An example of execution time optimisation



```java
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



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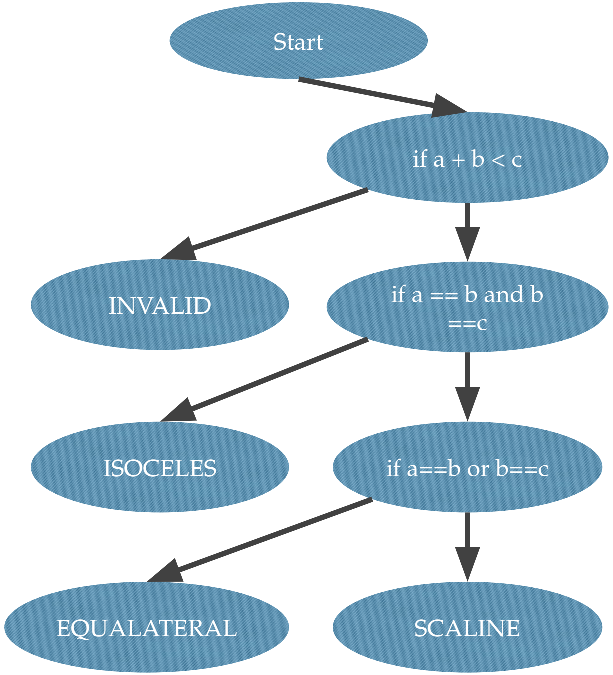
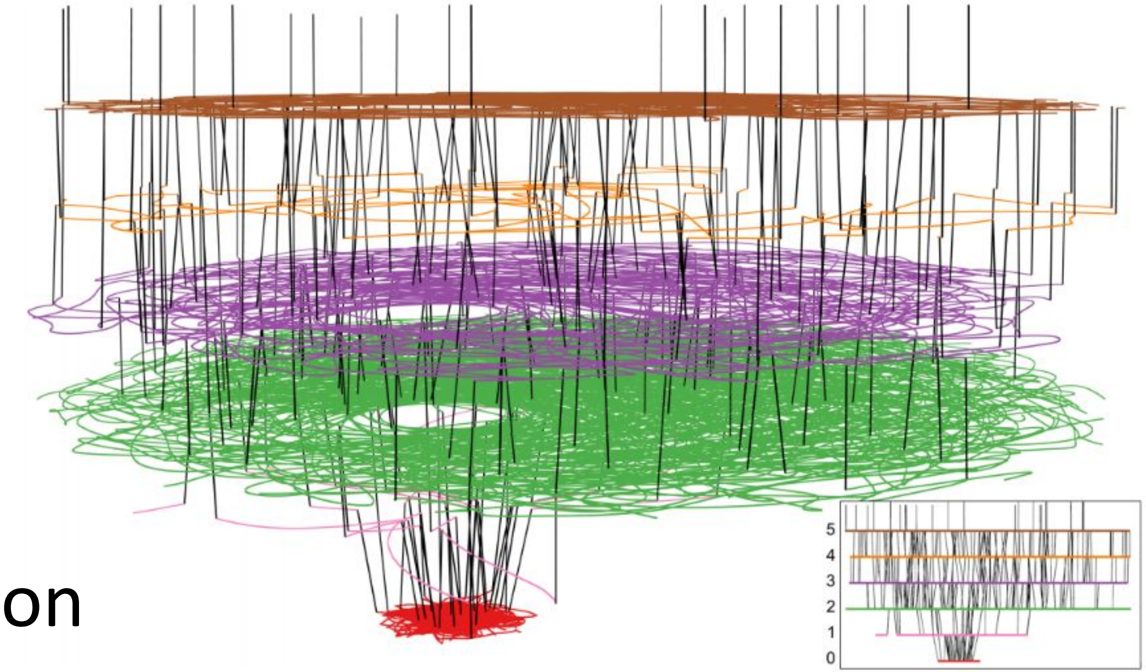


Neutral networks

Graceful degradation

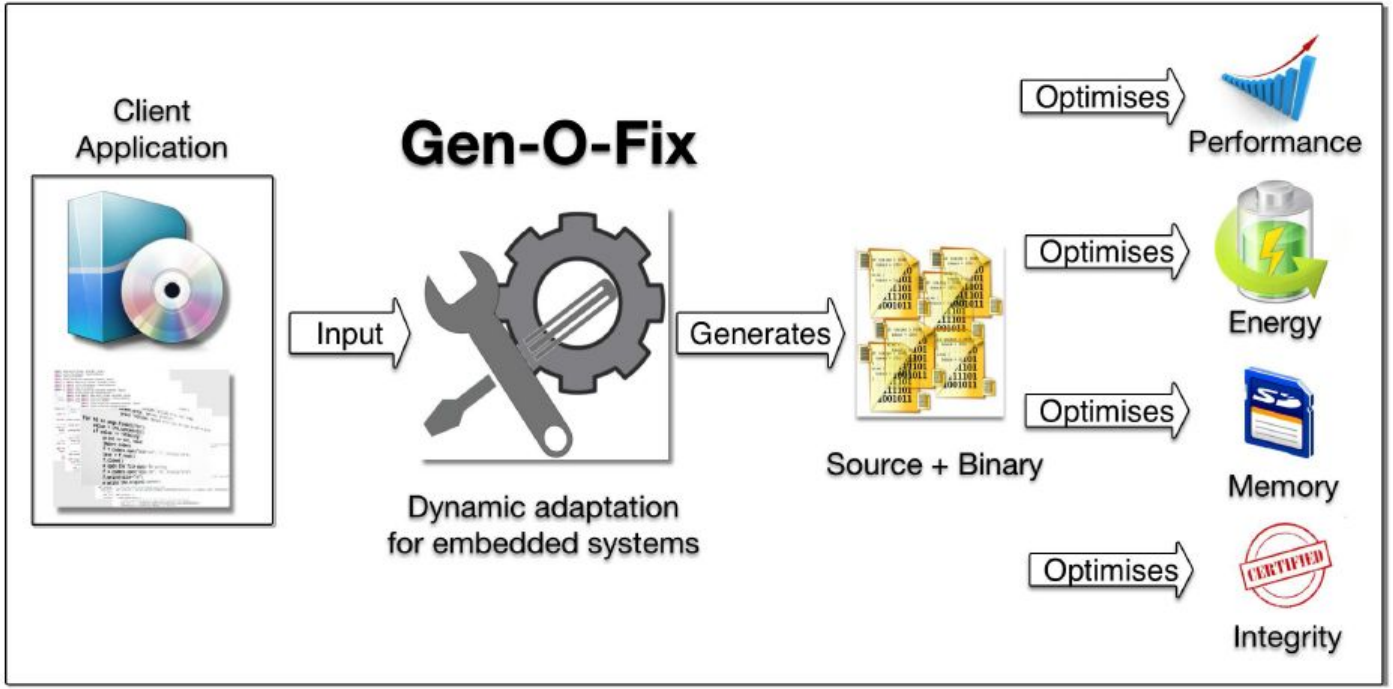


structure

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

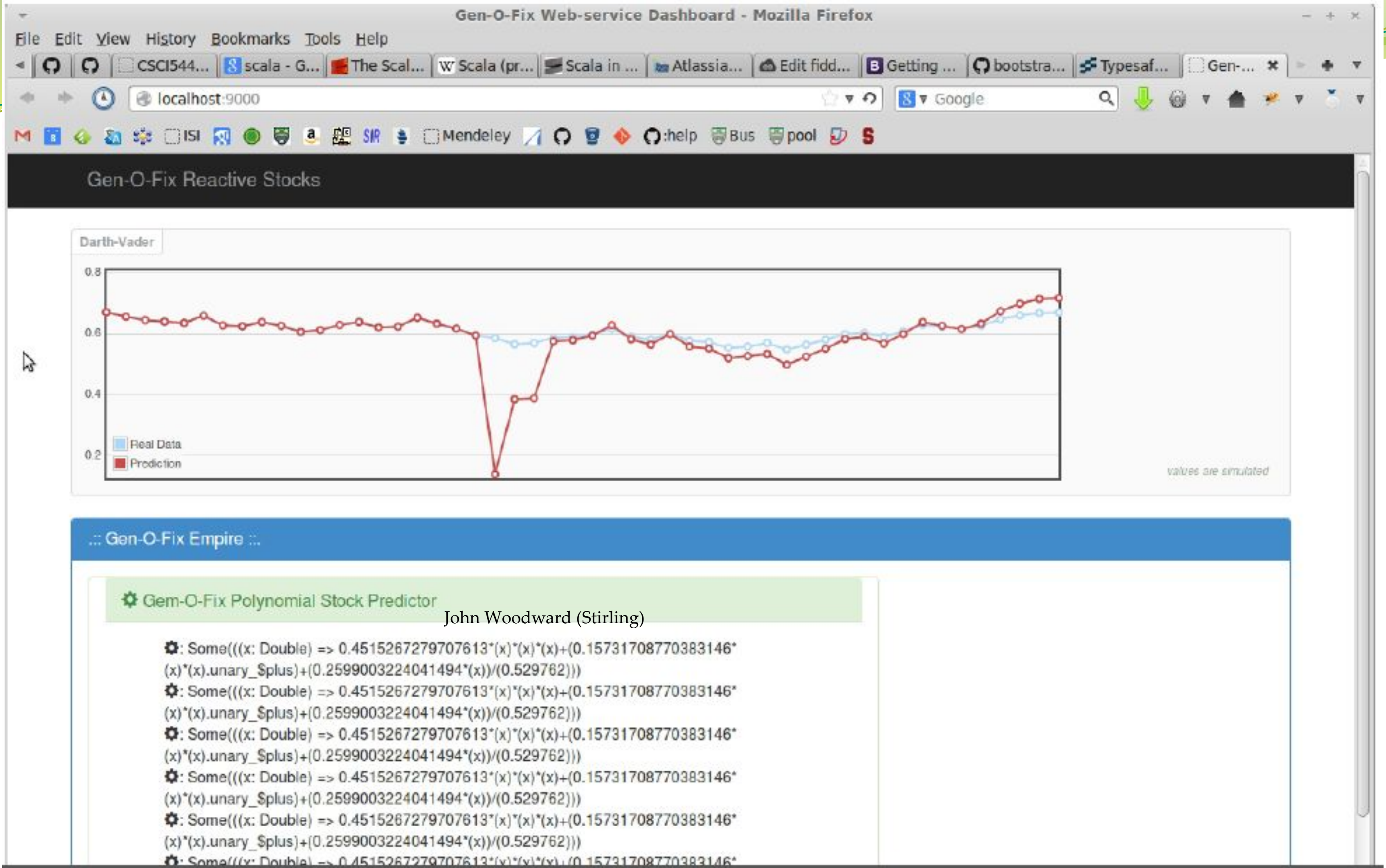
Code as data, data as code.

```
// 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
```


Gen-O-Fix Web-service Dashboard - Mozilla Firefox
File Edit View History Bookmarks Tools Help
CSCI544... scala - G... The Scal... Scala (pr... Scala in ... Atlassia... Edit fidd... Getting ... bootstra... Typesaf... Gen-...
localhost:9000
Google
ISI Mendeley :help Bus pool
Gen-O-Fix Reactive Stocks
Darth-Vader
0.8
0.6
0.4
0.2
Real Data
Prediction
values are simulated
.:: Gen-O-Fix Empire ::.
Gem-O-Fix Polynomial Stock Predictor

```
: Some(((x: Double) => 0.4515267279707613*(x)*(x)*(x)+(0.1573170877038314 6*
(x)*(x).unary_$plus)+(0.259900322404 1494*(x))/(0.529762)))
: Some(((x: Double) => 0.4515267279707613*(x)*(x)*(x)+(0.1573170877038314 6*
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: Some(((x: Double) => 0.4515267279707613*(x)*(x)*(x)+(0.1573170877038314 6*
```

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

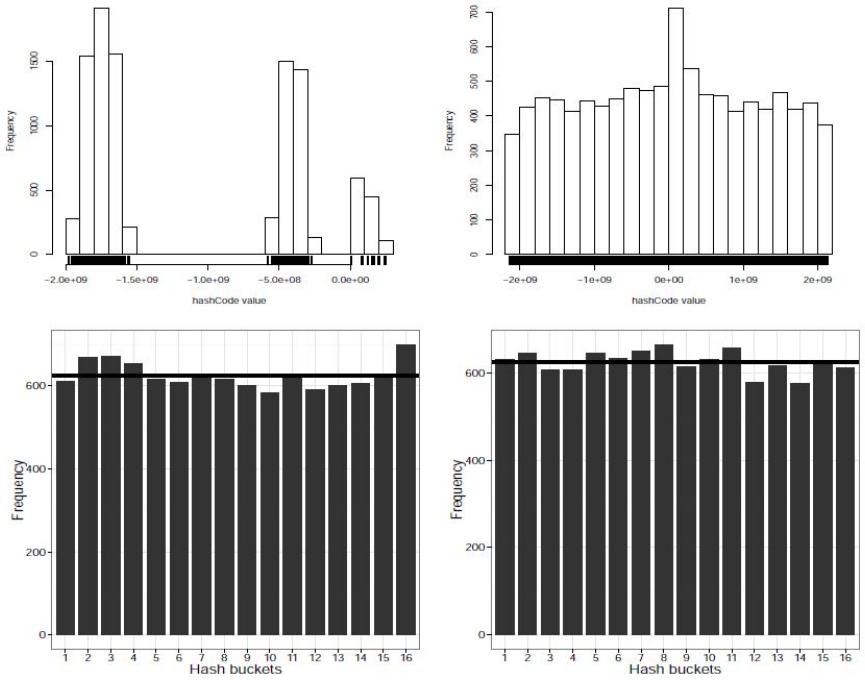

Fig. 1: The distribution of the hashcode values (top) and the distribution of the created objects in hash buckets (bottom), generated by the Apache commons (left) and the evolved function (right)

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

FIXIE

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EP/S005730/1

EPSRC
Engineering and Physical Sciences
Research Council

Lancaster University

Operational Research
Queen Mary University of London

Brunel
University
London

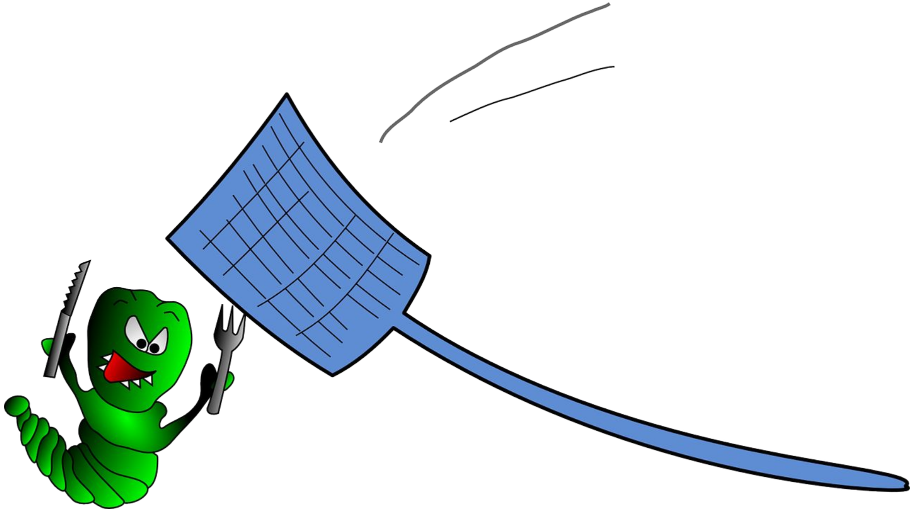
Fixing bugs

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

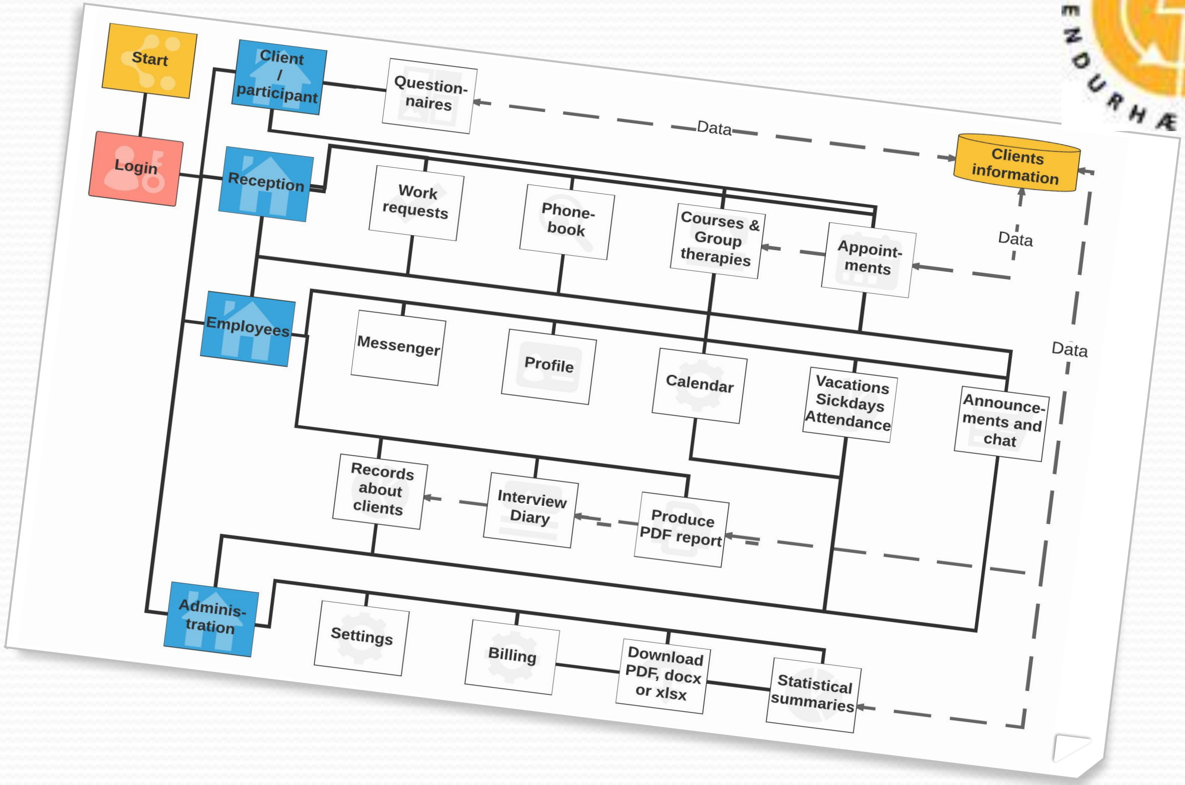
S. O. Haraldsson, J. R. Woodward and A. I. E. Brownlee, "The Use of Automatic Test Data Generation for Genetic Improvement in a Live System," 2017 IEEE/ACM 10th International Workshop on Search-Based Software Testing (SBST), Buenos Aires, 2017, pp. 28-31. DOI: https://10.1109/SBST.2017.10

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



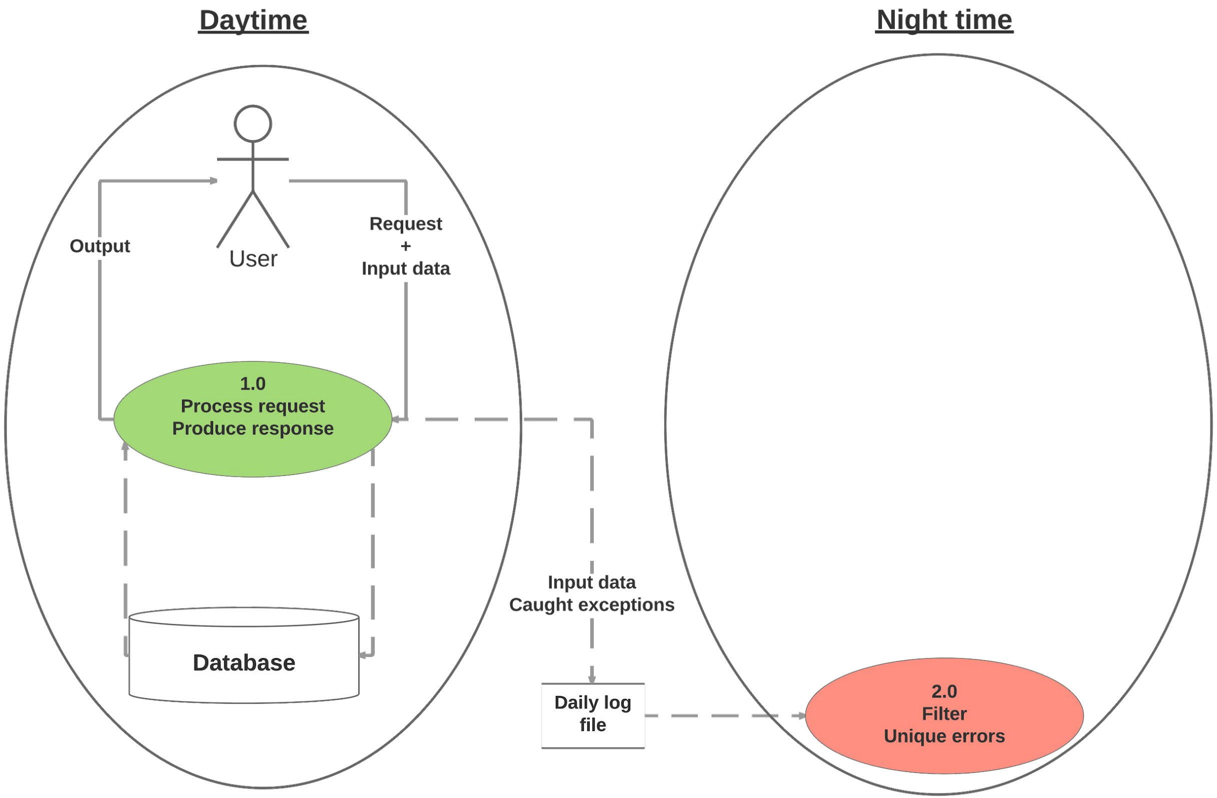
Janus Manager

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



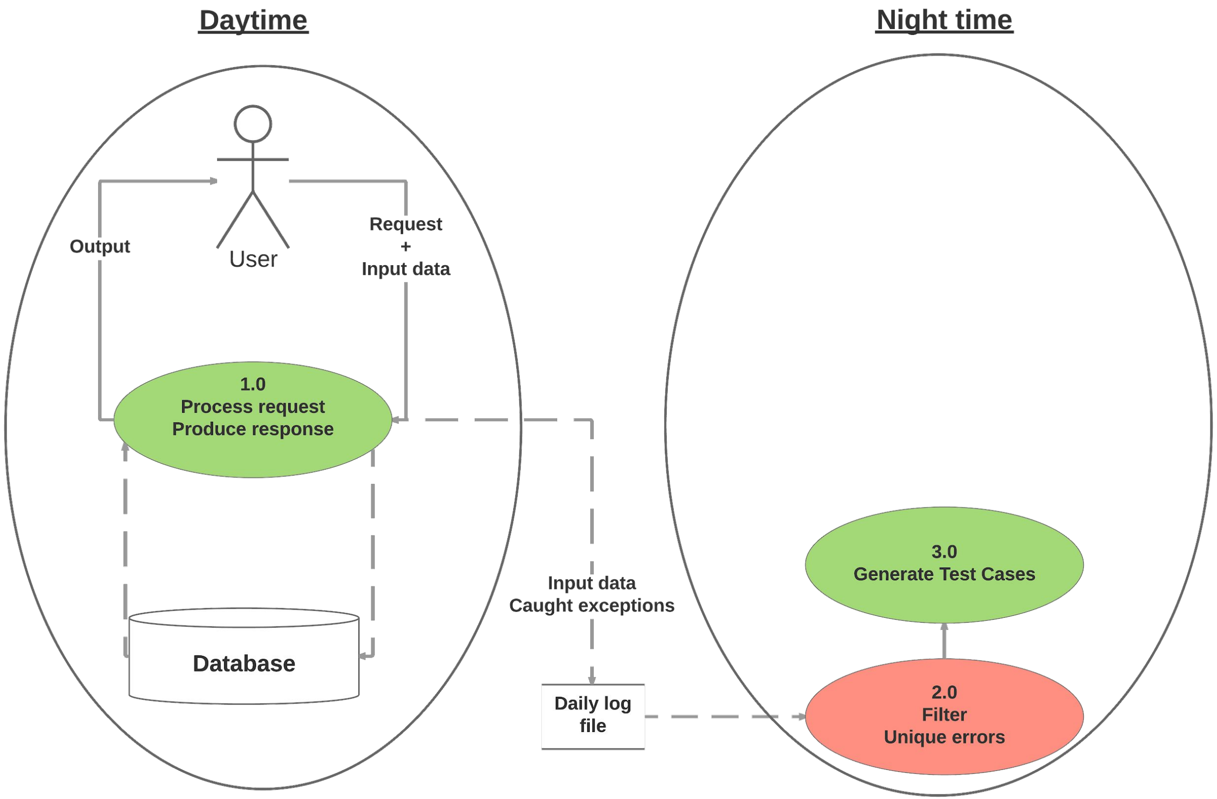
When last user logs out

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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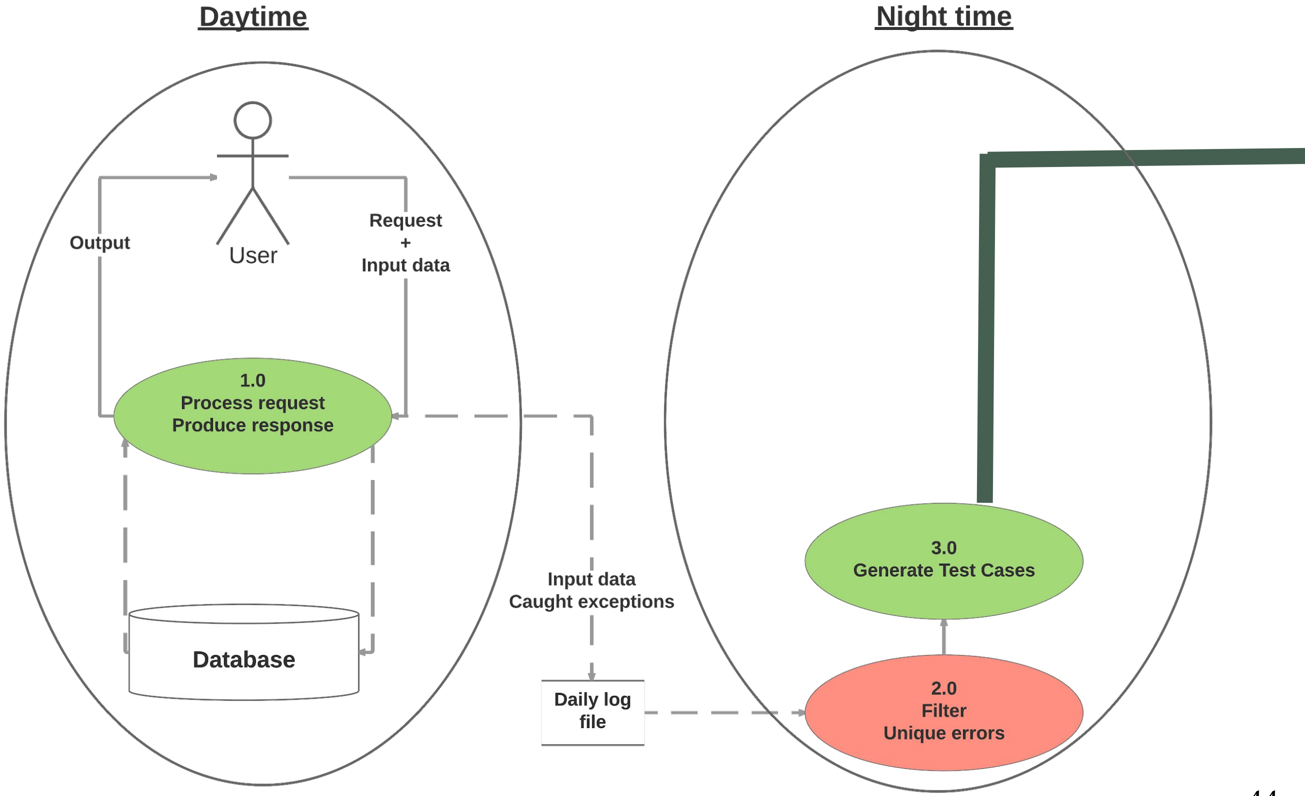
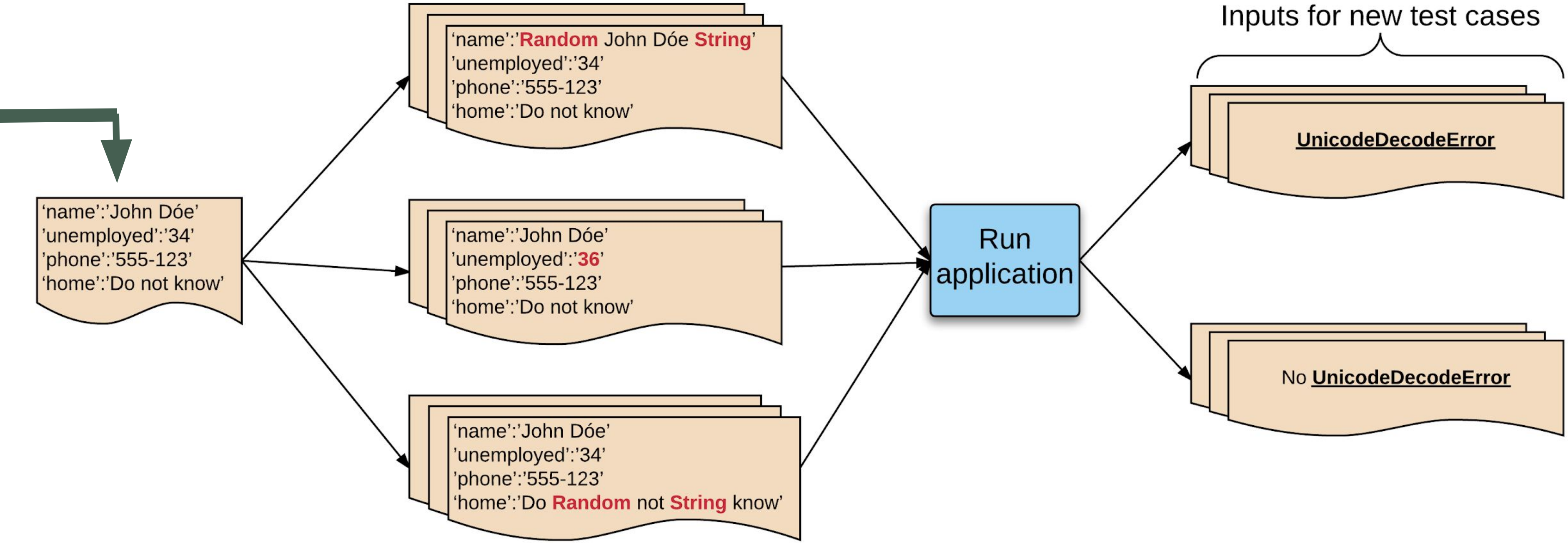
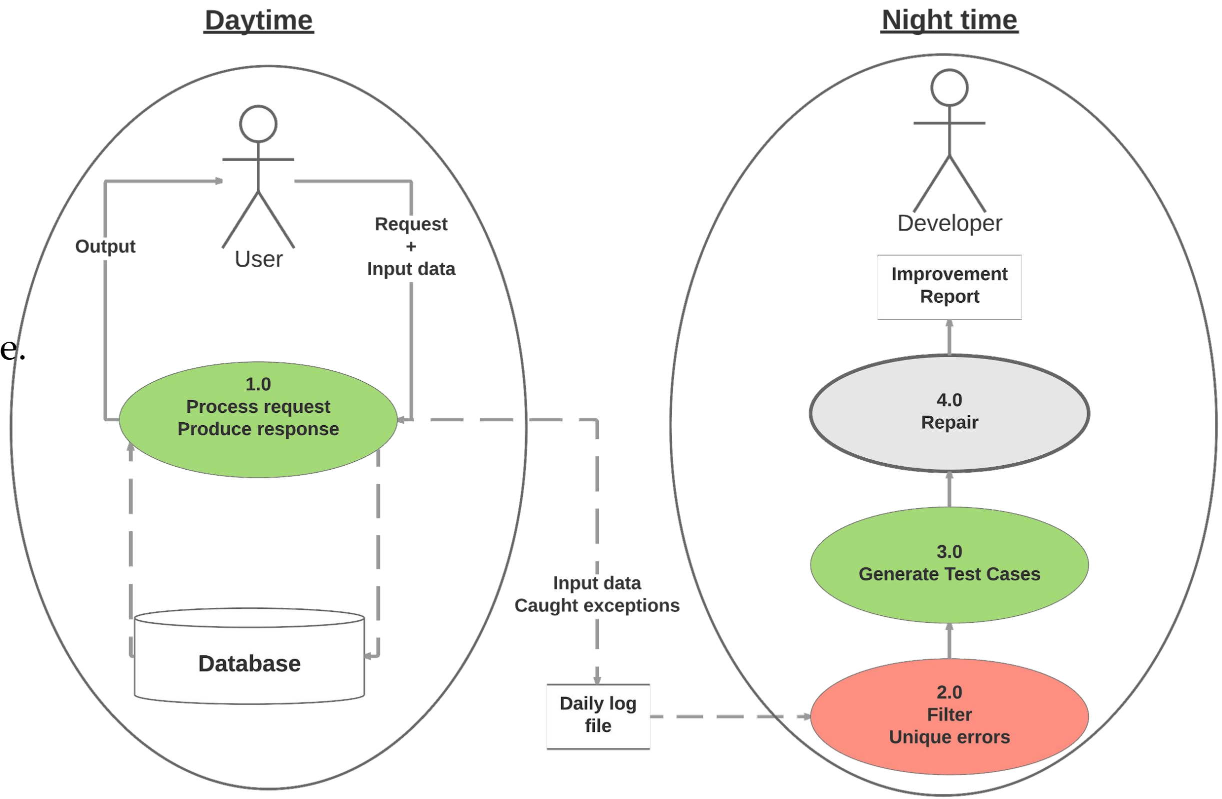


Procedure 3.0

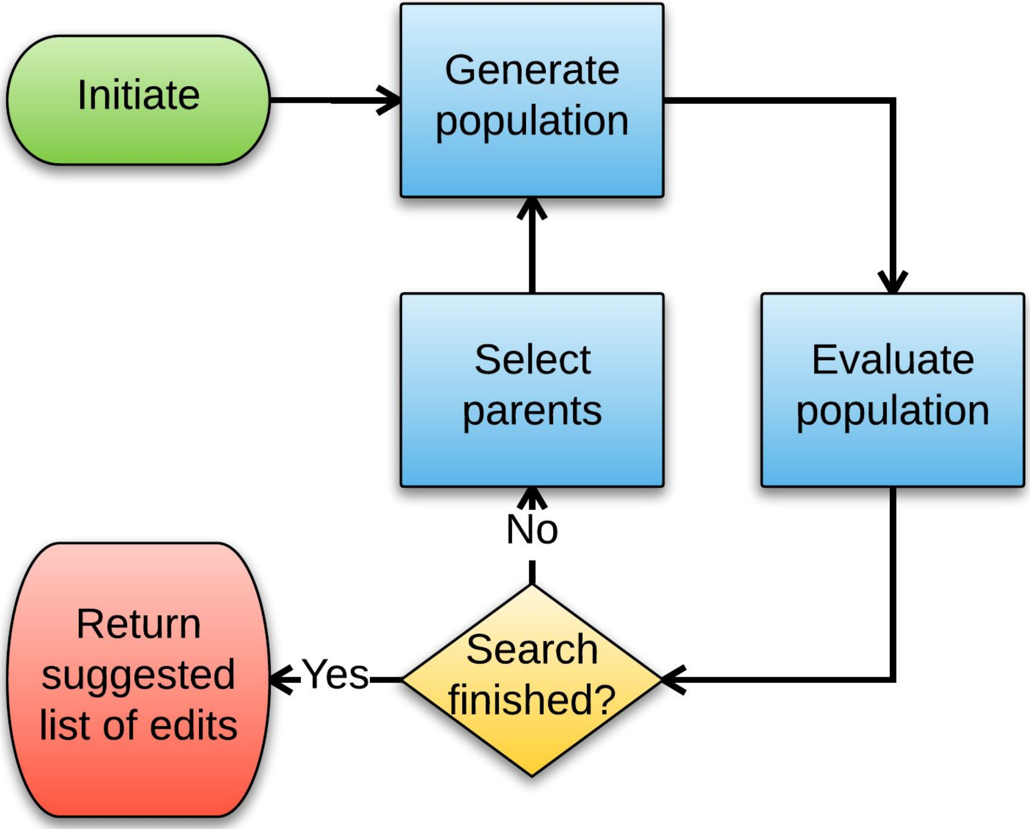


When last user logs out

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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  - Pop.= 50 patches
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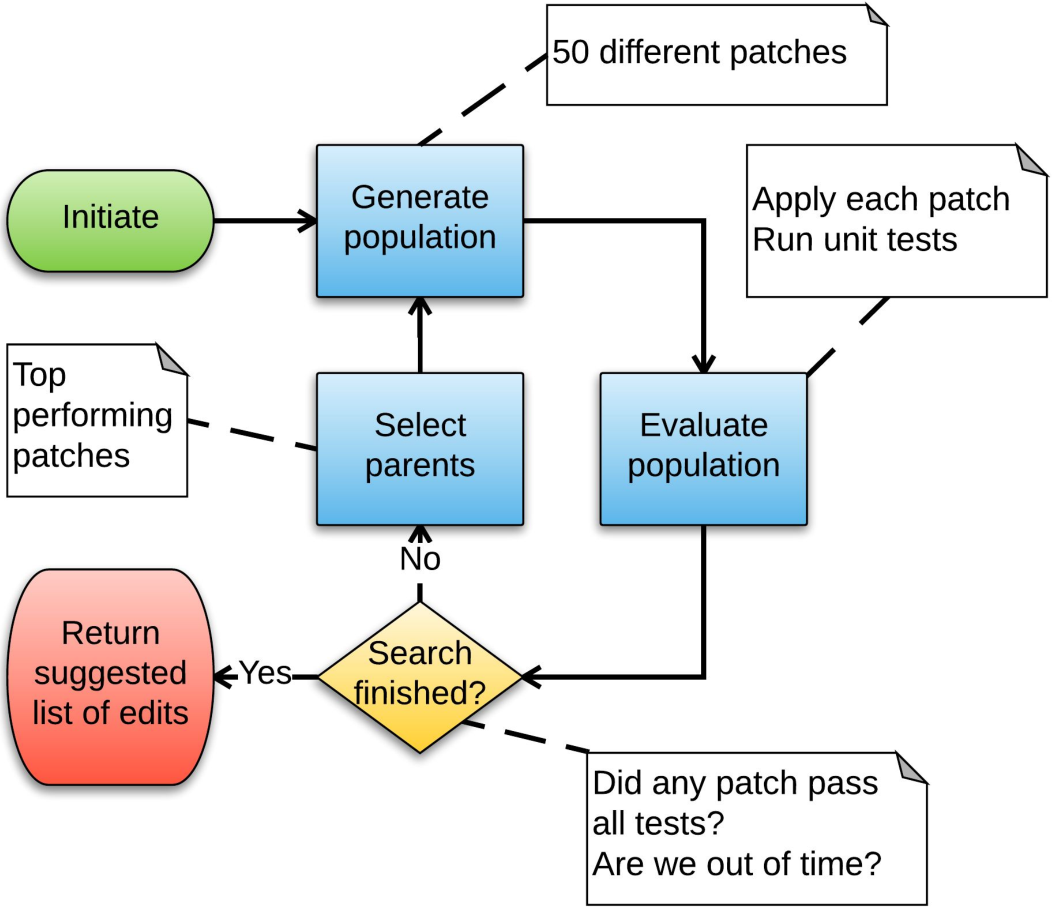


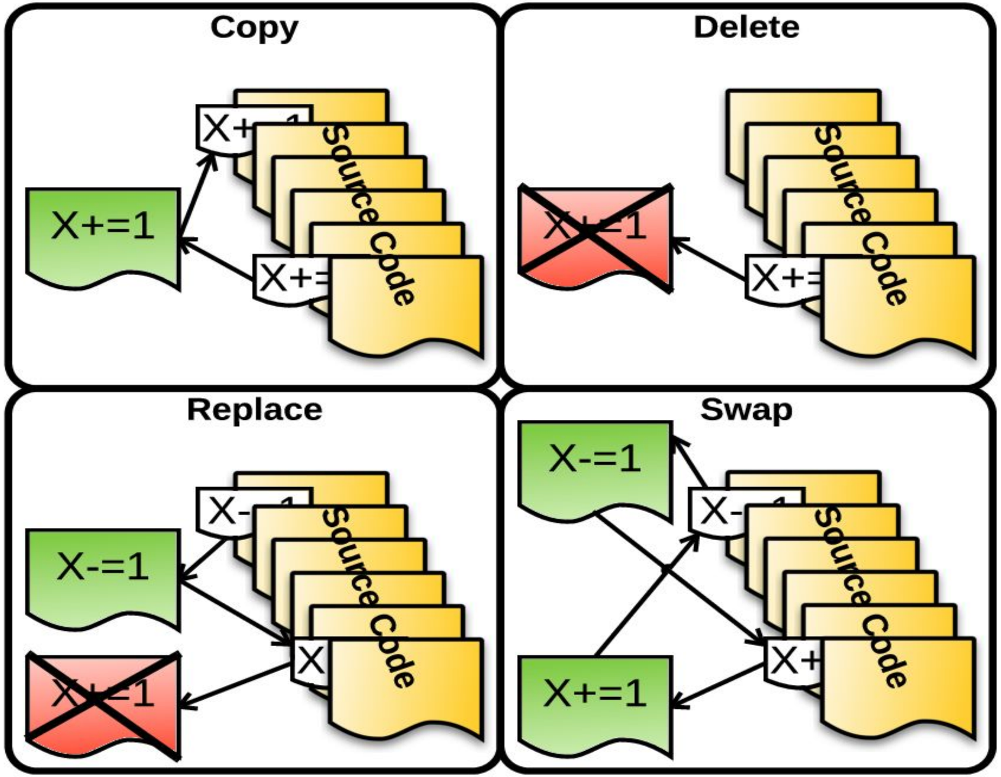
4 different types of implemented **Edits**

Primitive types:

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

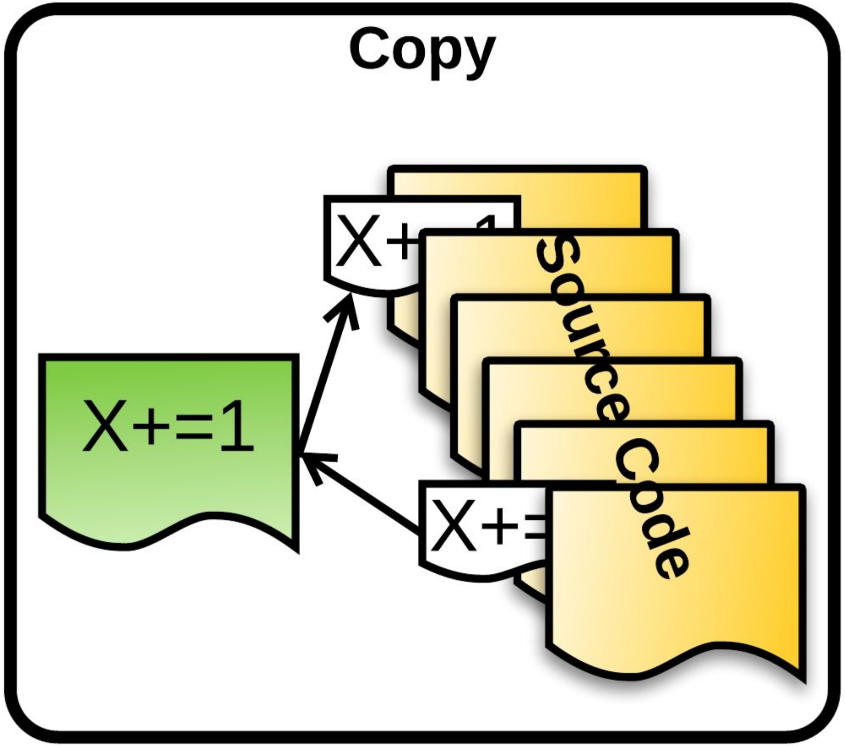
Composite types:

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



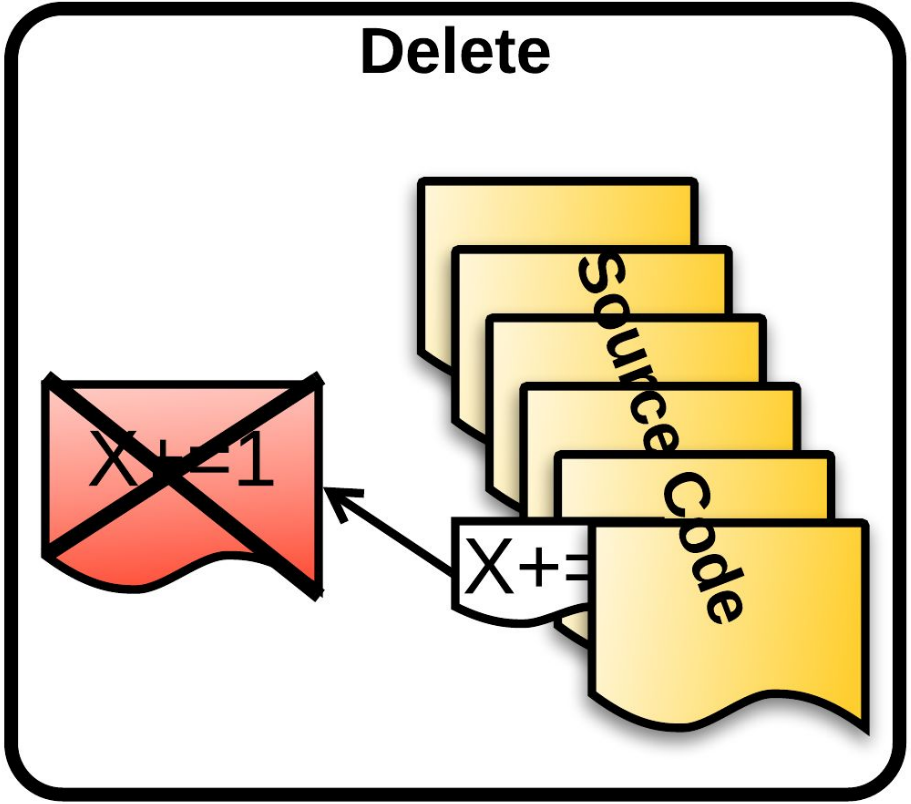
Copy

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



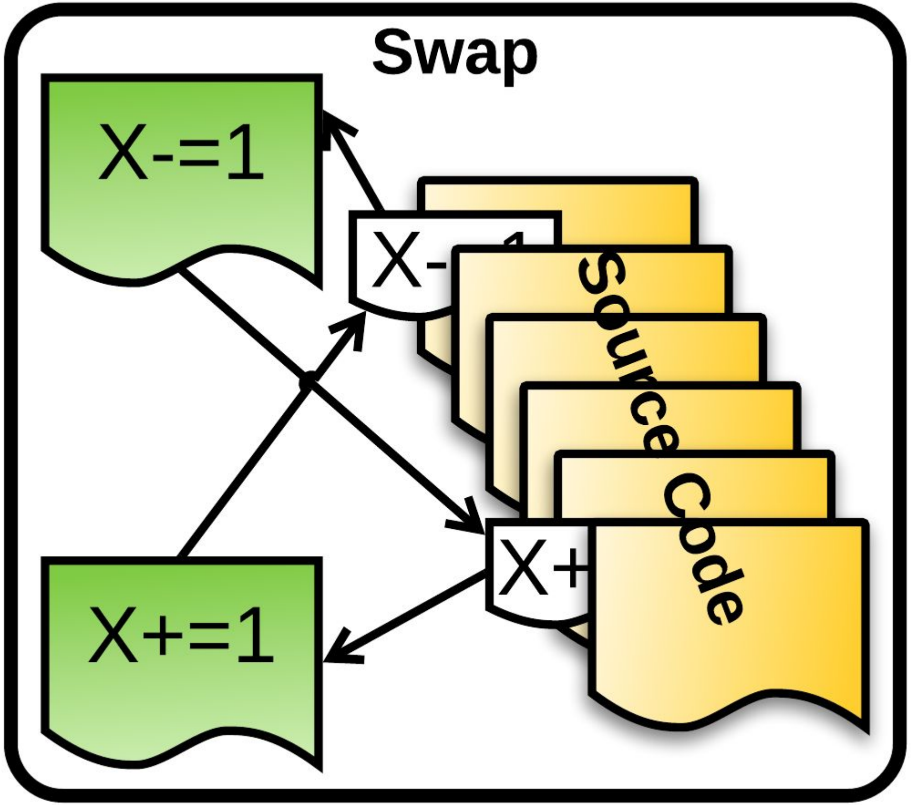
Delete

- 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"



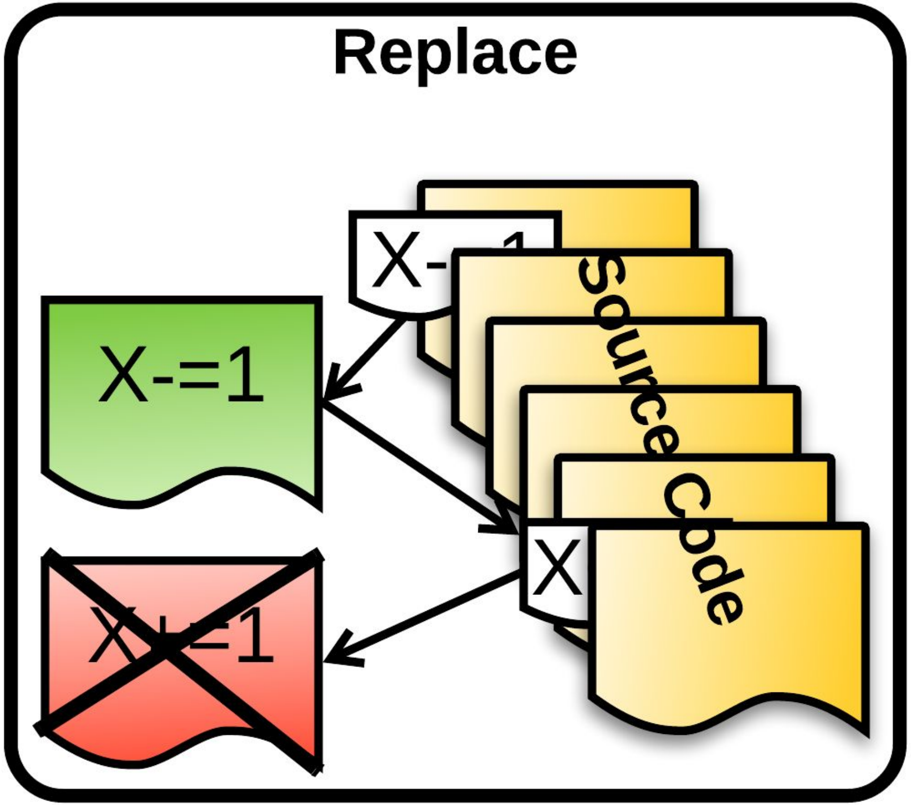
Swap

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



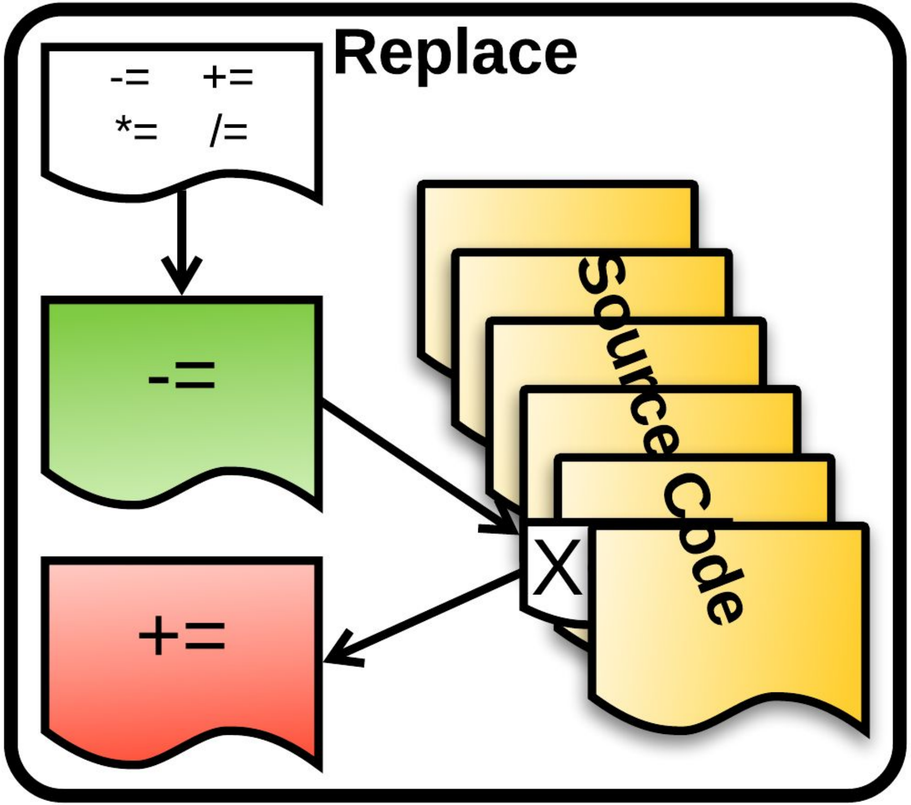
Replace

- Copies one line above another
- Then deletes that line



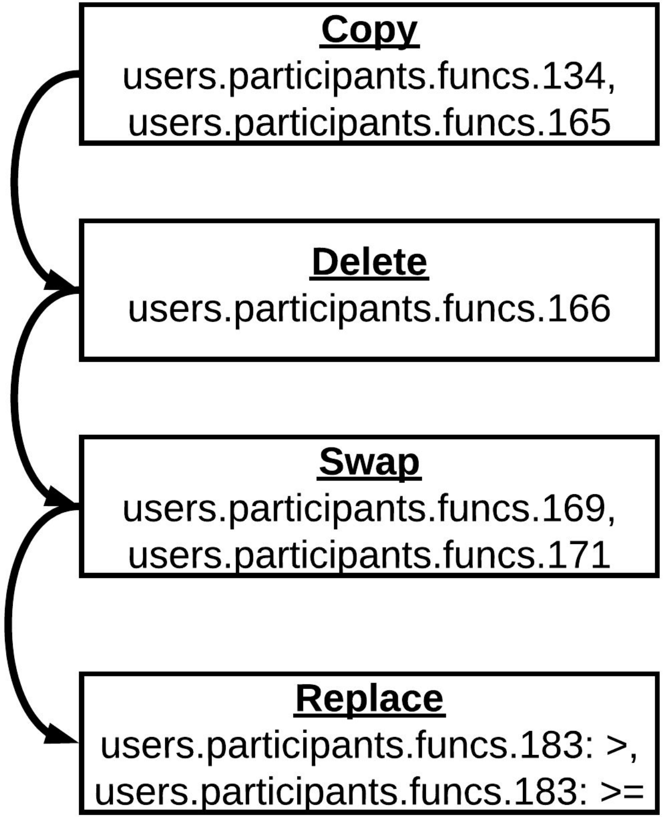
Replace -- extra

- 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



Copy
users.participants.funcs.134,
users.participants.funcs.165

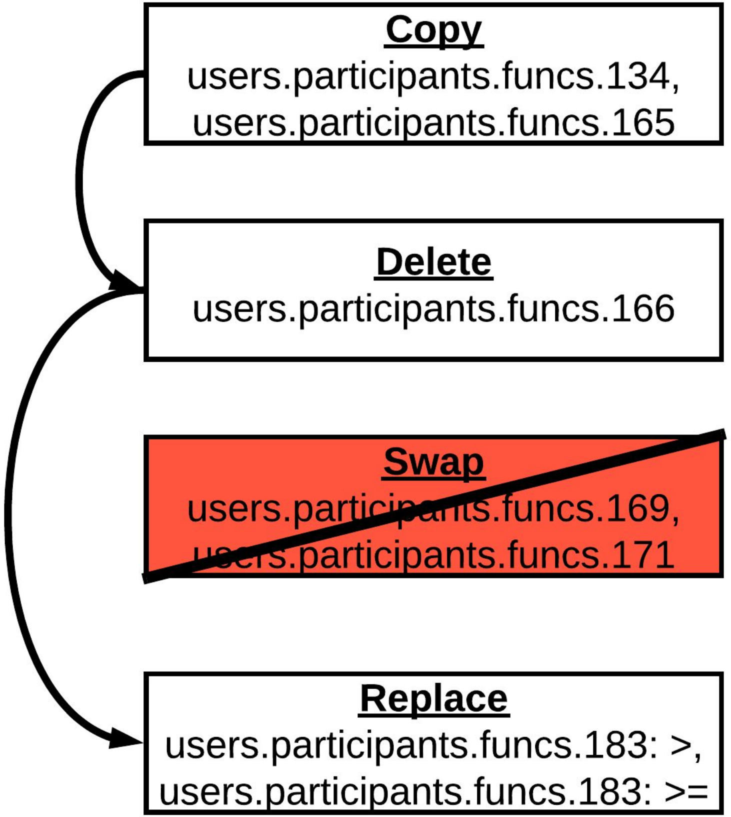
Delete
users.participants.funcs.166

Swap
users.participants.funcs.169,
users.participants.funcs.171

Replace
users.participants.funcs.183: >,
users.participants.funcs.183: >=

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



Copy
users.participants.funcs.134,
users.participants.funcs.165

Delete
users.participants.funcs.166

~~**Swap**
users.participants.funcs.169,
users.participants.funcs.171~~

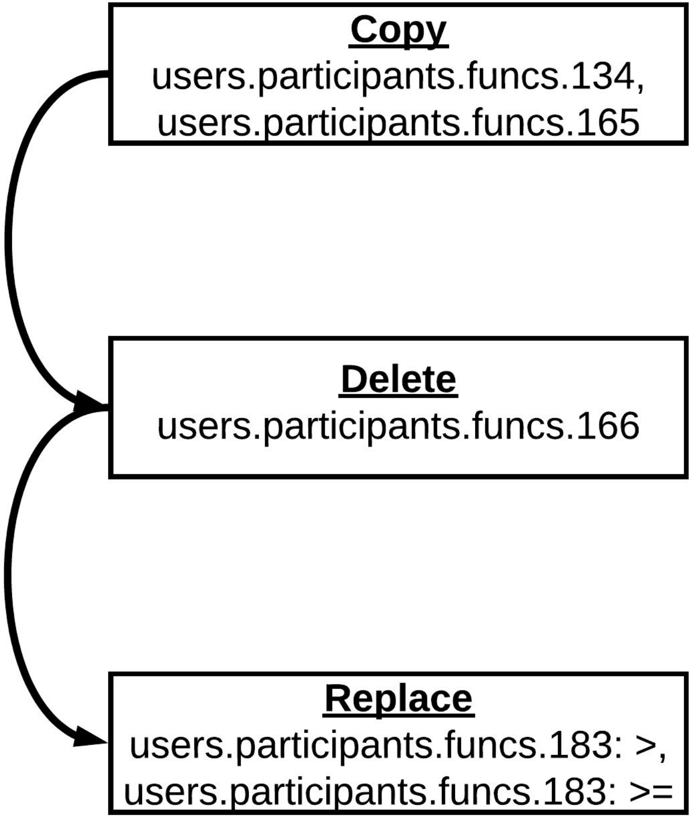
Replace
users.participants.funcs.183: >,
users.participants.funcs.183: >=

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



Copy
users.participants.funcs.134,
users.participants.funcs.165

Delete
users.participants.funcs.166

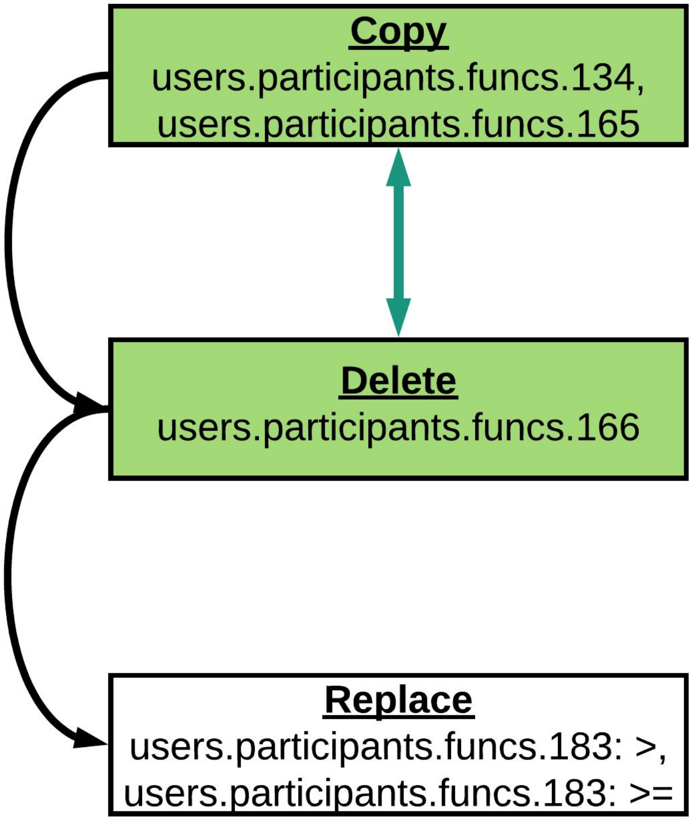
Replace
users.participants.funcs.183: >,
users.participants.funcs.183: >=

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



Copy
users.participants.funcs.134,
users.participants.funcs.165

Delete
users.participants.funcs.166

Replace
users.participants.funcs.183: >,
users.participants.funcs.183: >=

A list of edits makes a suggestion

- Reads like a recipe
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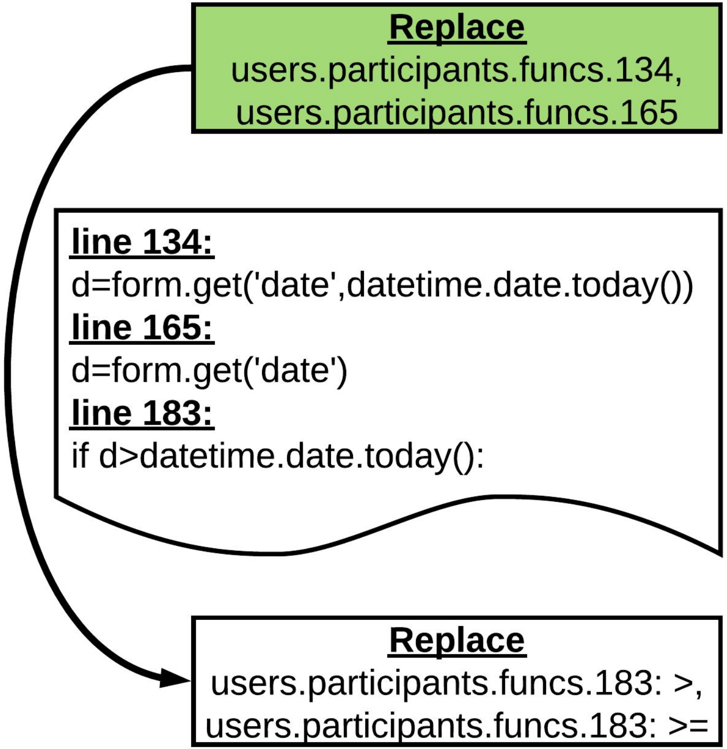


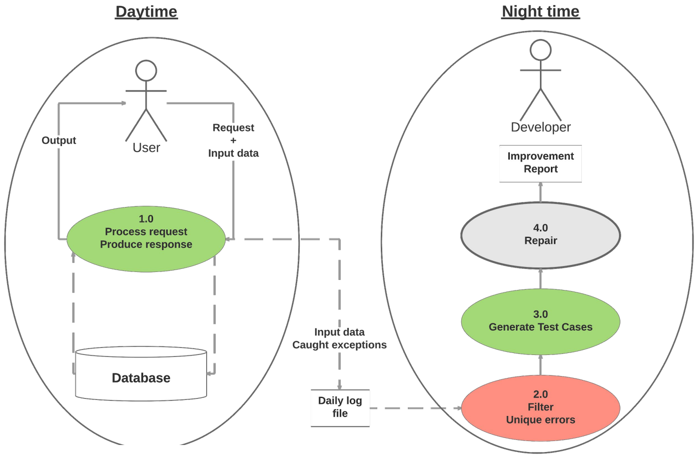
Replace
users.participants.funcs.134,
users.participants.funcs.165

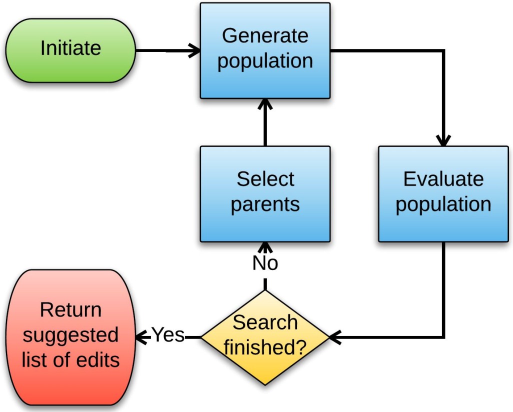
line 134:
```
d=form.get('date',datetime.date.today())
```
line 165:
```
d=form.get('date')
```
line 183:
```
if d>datetime.date.today():
```

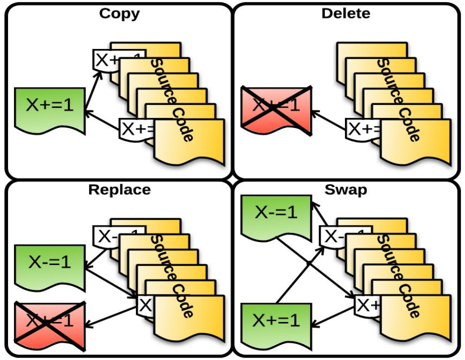
Replace
users.participants.funcs.183: >,
users.participants.funcs.183: >=

Summary

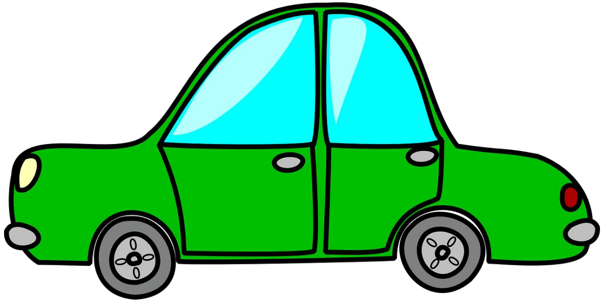
- Real-world example
- Catches inputs that produce crashes
- Line(-ish) based GI
    - 4 types of edits
- Overnight repair
- Developers are the gatekeepers







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

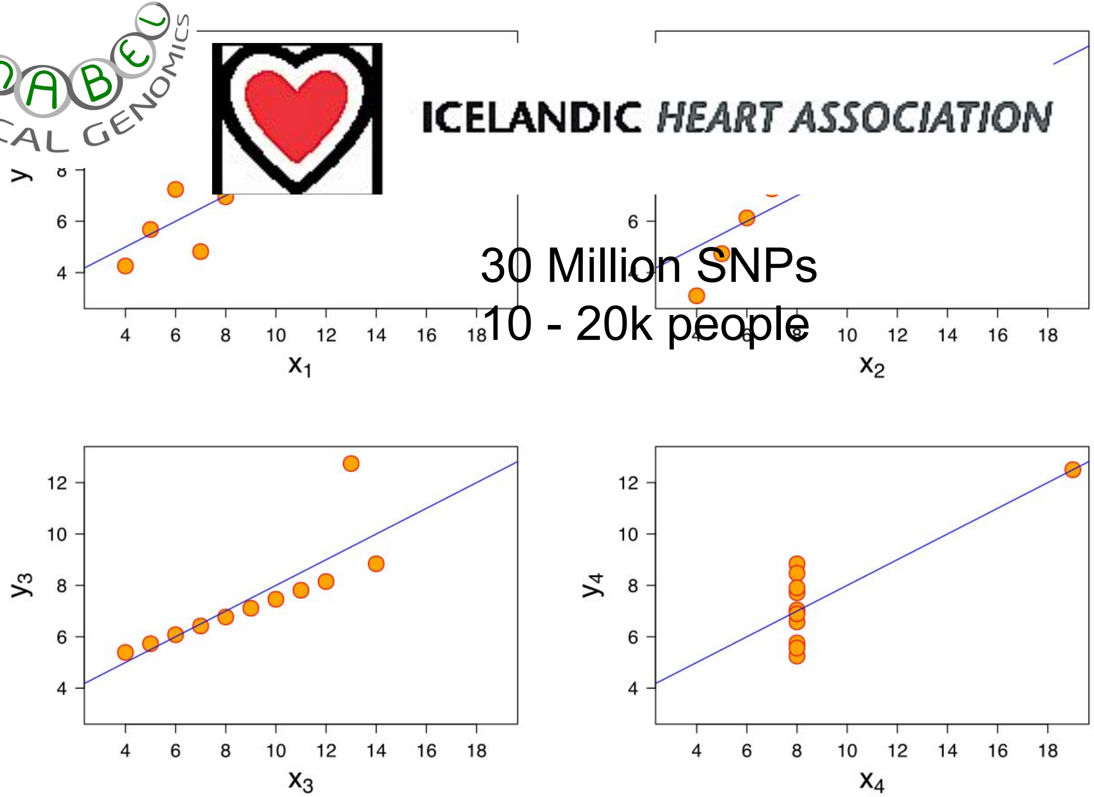
The software

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

GenABEL STATISTICAL GENOMICS

ICELANDIC HEART ASSOCIATION



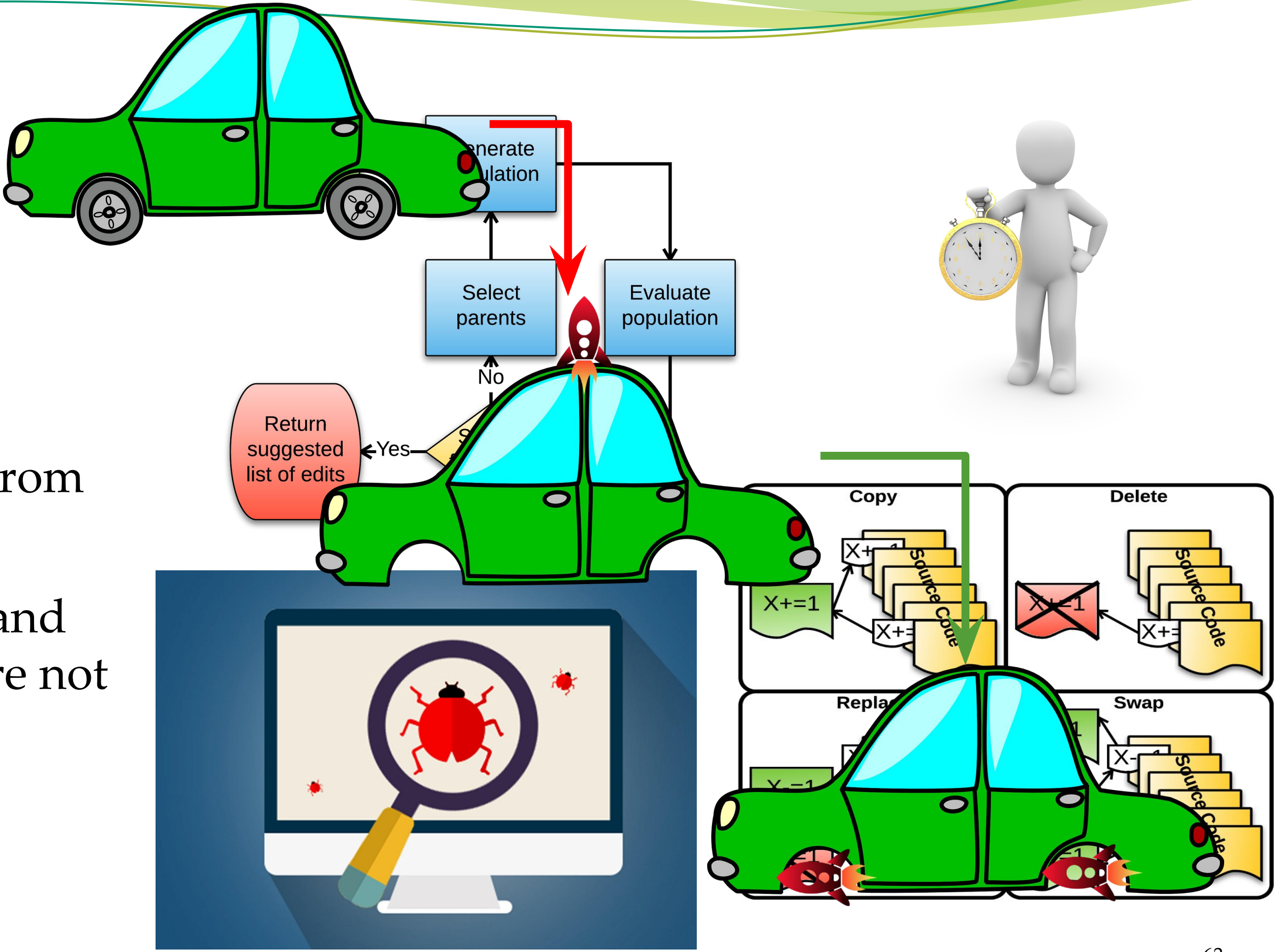
30 Million SNPs

10 - 20k people

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

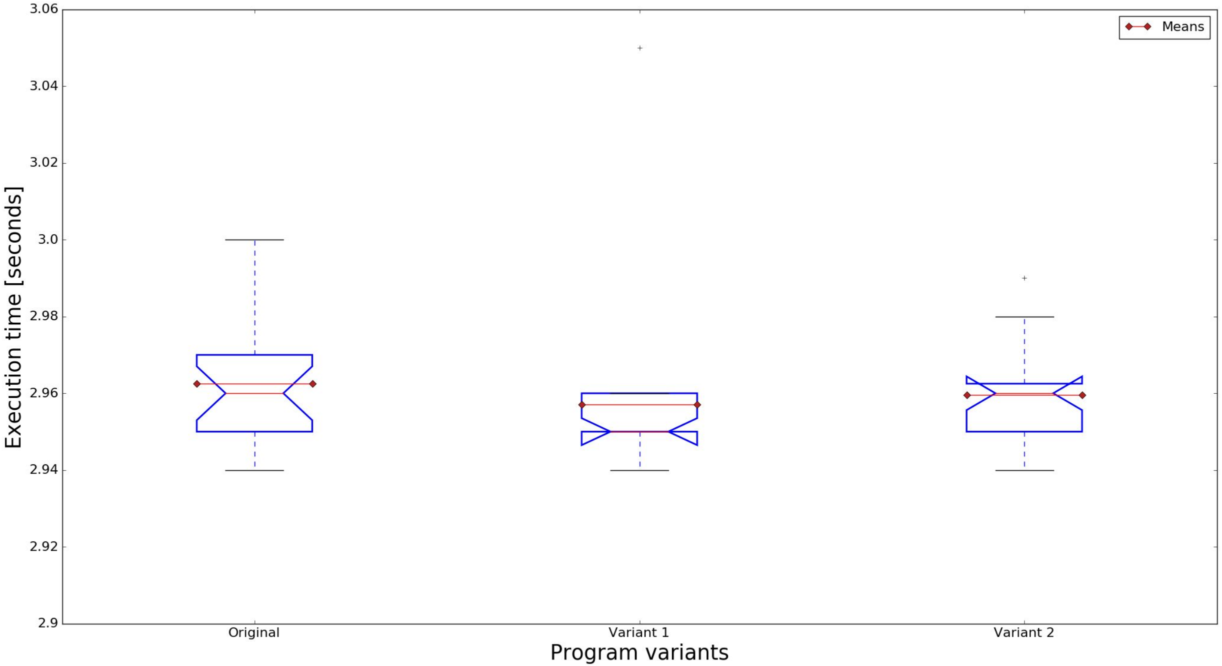
The GI setup

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



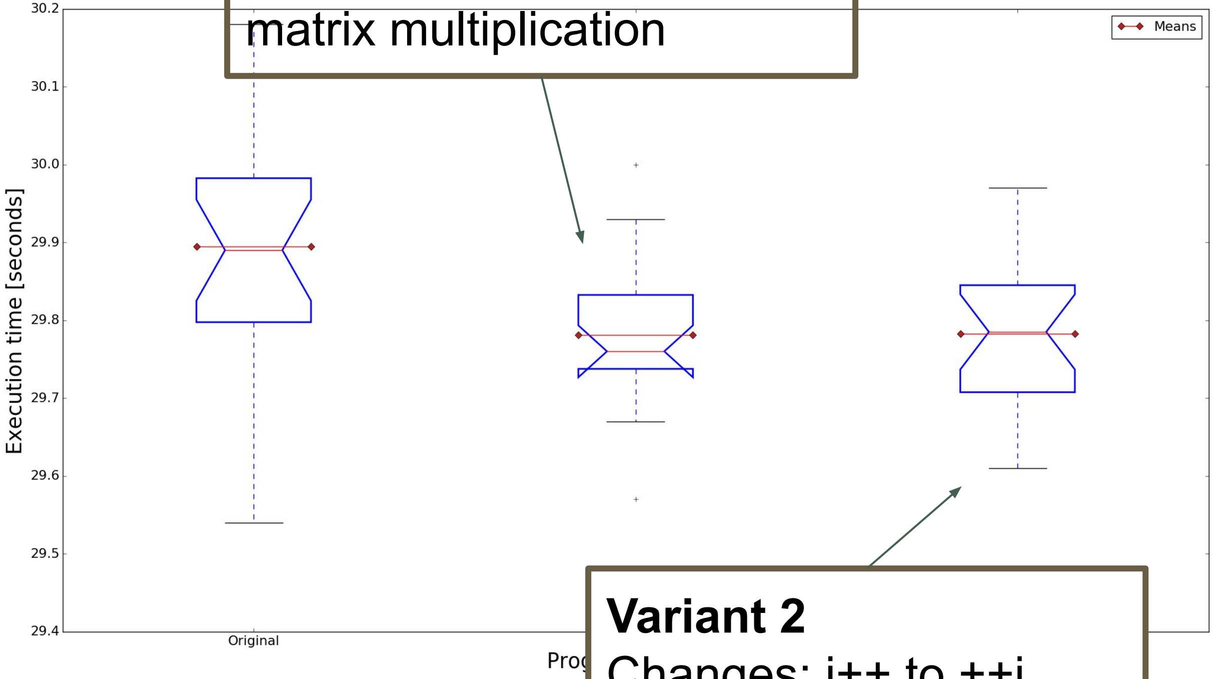
Results

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



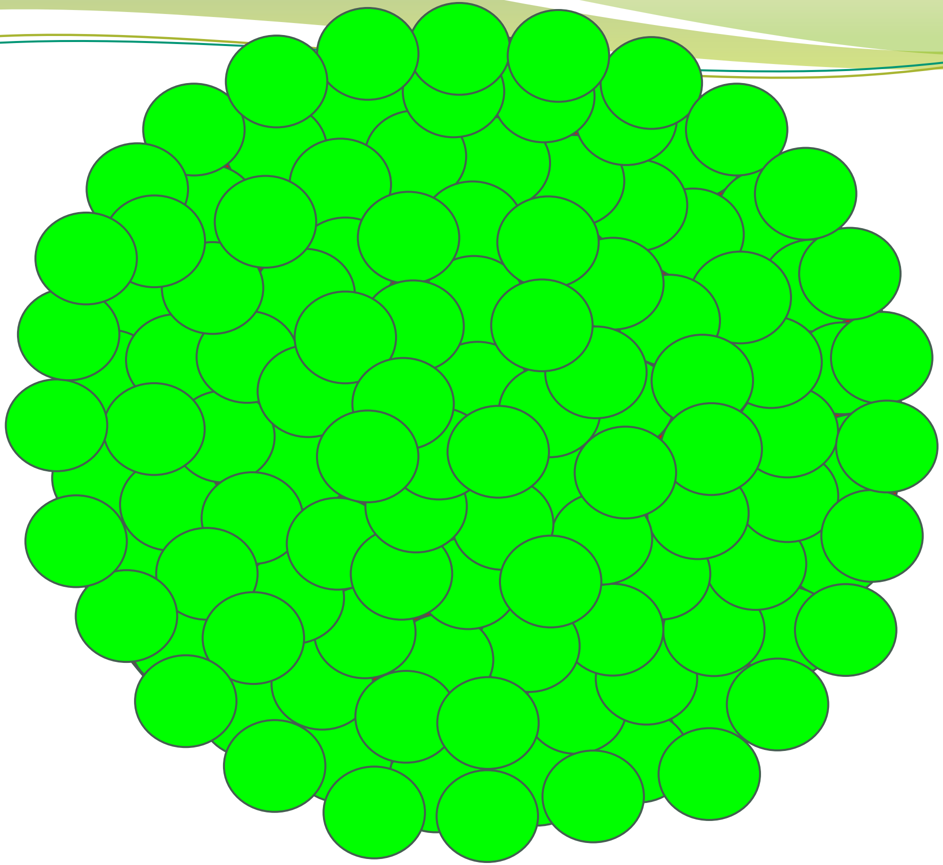
Results

- 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



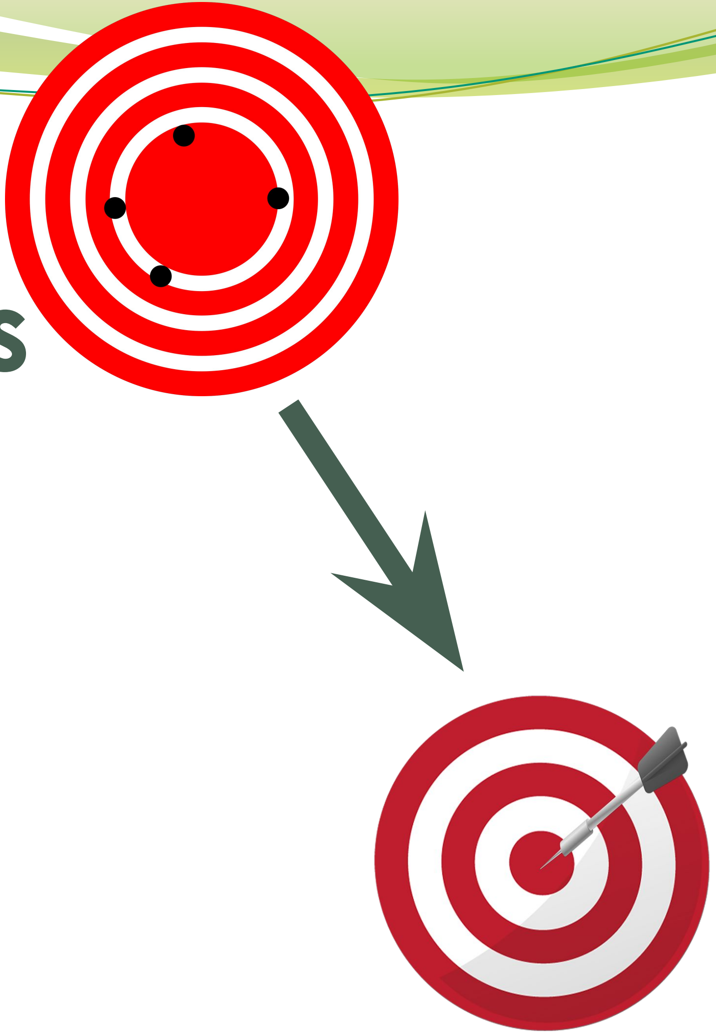
Variant 1
Deletes a single line that performs an expensive matrix multiplication

Variant 2
Changes: i++ to ++i



🟢 Gained improvement per execution

Better predictions



And even more examples of GI in action

S. O. Haraldsson, R. D. Brynjolfsdottir, J. R. Woodward, K. Siggeirsdottir and V. Gudnason, "The use of predictive models in dynamic treatment planning," 2017 IEEE Symposium on Computers and Communications (ISCC), Heraklion, 2017, pp. 242-247. DOI: https://10.1109/ISCC.2017.8024536

S. O. Haraldsson, R. D. Brynjolfsdottir, V. Gudnason, K. Tomasson and K. Siggeirsdottir, "Predicting changes in quality of life for patients in vocational rehabilitation," 2018 IEEE Conference on Evolving and Adaptive Intelligent Systems (EAIS), Rhodes, 2018, pp. 1-8. DOI: https://10.1109/EAIS.2018.8397182

Siggeirsdottir, K., Brynjolfsdottir, R.D., Haraldsson, S.O., Vidar, S., Gudmundsson, E.G., Brynjolfsson, J.H., Jonsson, H., Hjaltason, O. and Gudnason, V., 2016. Determinants of outcome of vocational rehabilitation. Work, 55(3), pp.577-583. DOI: https://10.3233/WOR-162436

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

Dynamic updates to a prediction tool

- Used by Janus Rehabilitation
  - Since June 2016
  - Consulted in all team meetings
- Updated whenever there are new information
  - No developer as gatekeeper
- Target software is the updating script
  - Small python file

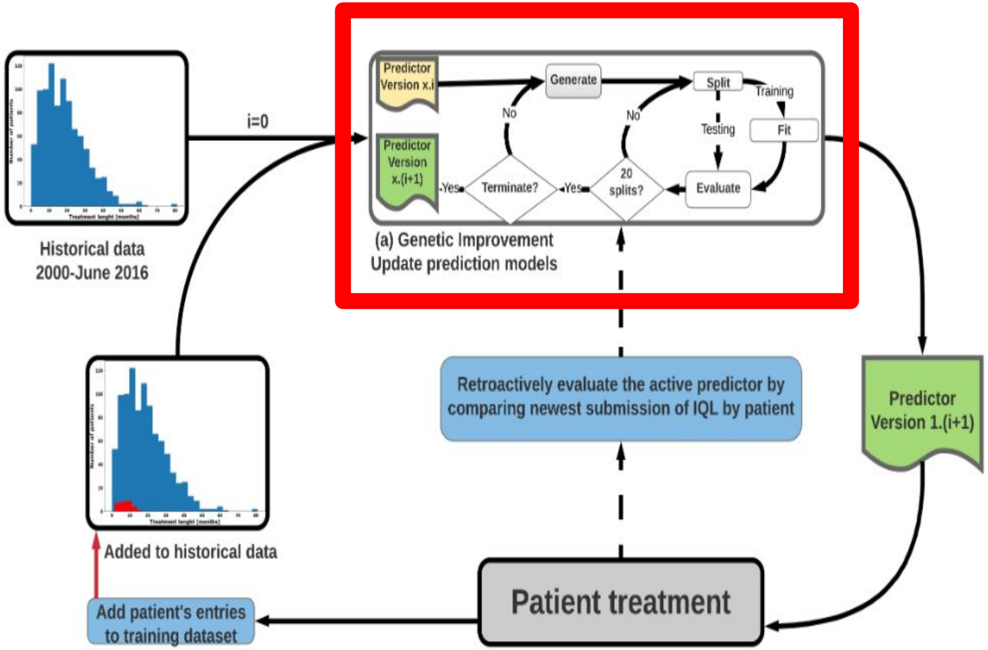


Fig. 1. The cycle of providing treatment, collecting data and updating the predictive models. This cycle is simulated from June 2016 until December 2017 of the simulation

The predictions

- Vocational rehabilitation outcome
  - Updated on every patient’s discharge
  - Successful / Unsuccessful
  - Dropout
  - Length
- Next measurement of Icelandic Health-related Quality of Life (IQL)
  - Updated on every submission of questionnaire
  - 12 categories
  - Measured every 3-6 months

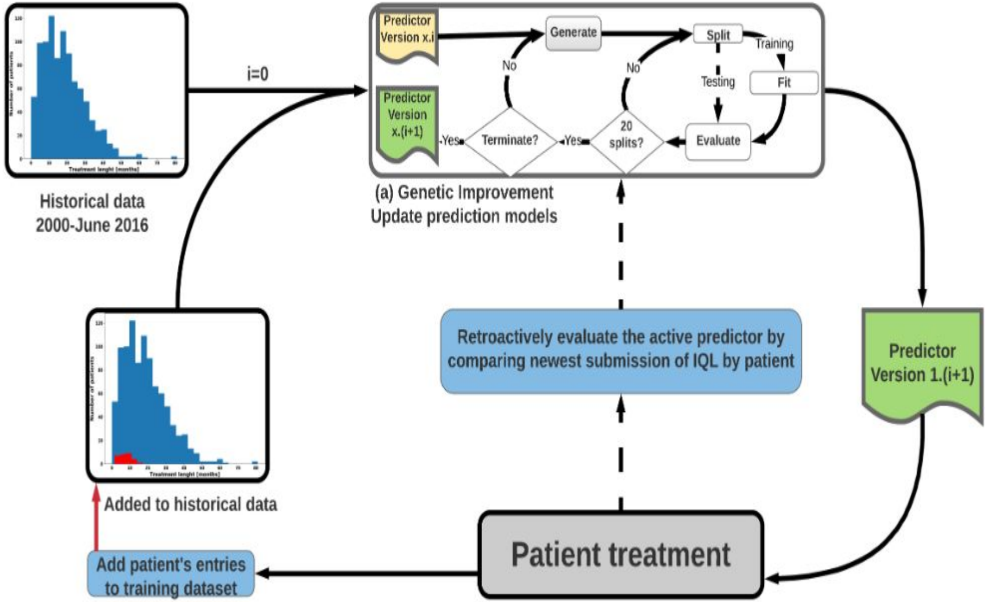
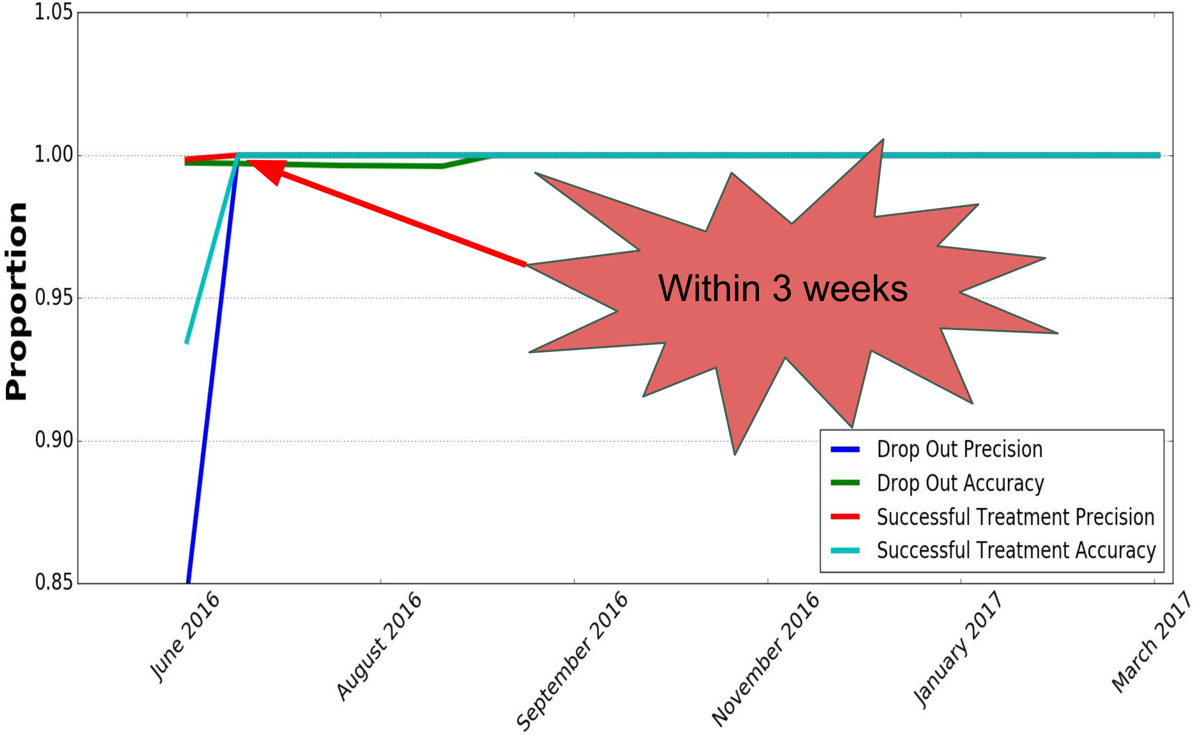


Fig. 1. The cycle of providing treatment, collecting data and updating the predictive models. This cycle is simulated from June 2016 until December 2017 of the simulation

JANUS ENDURHÆFING EHF

Predicting the outcome

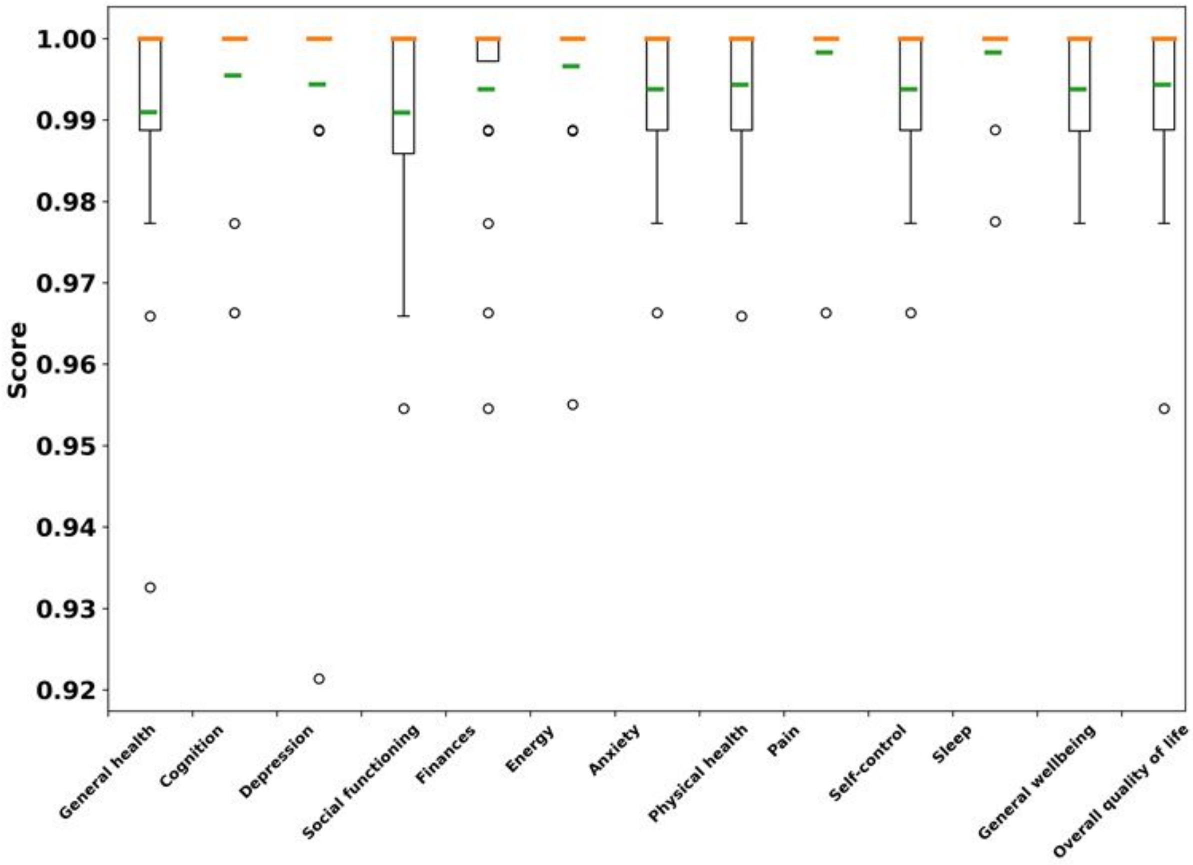
- Implemented in June 2016
  - Forgotten about for 10 months
- 72 updates over the 10 month period
  - Reached maximum accuracy early
- All predictions are for events that had not occured.
  - Real people
  - Real events



Within 3 weeks

Predicting the IQL

- Simulation
    - Bootstrapped accuracy distribution
- Never under 92% accuracy in any IQL subcategory
- Mean accuracy over 99%



Overview

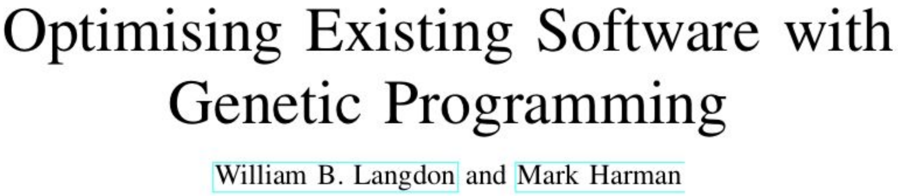
- Introduction
- Fixing Bugs and other examples
- Noteworthy papers and issues
- Getting involved
- Summary and Q&A

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

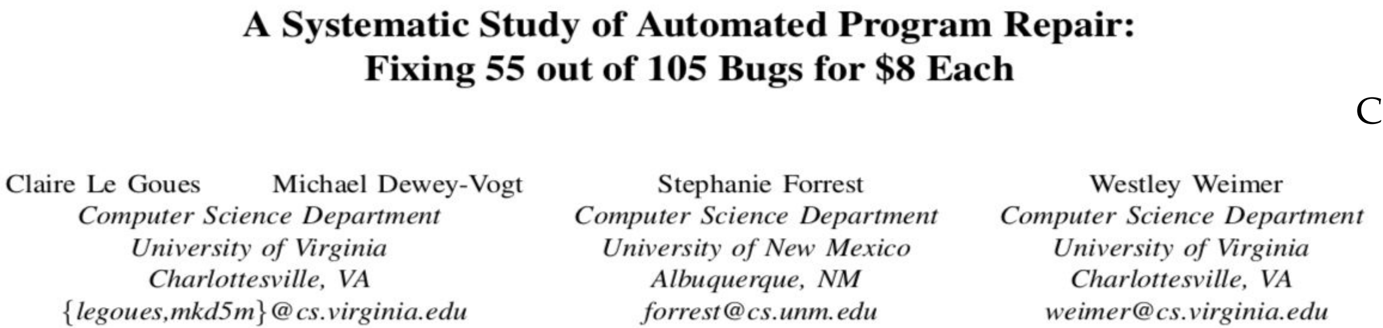
A 50,000 line system



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.



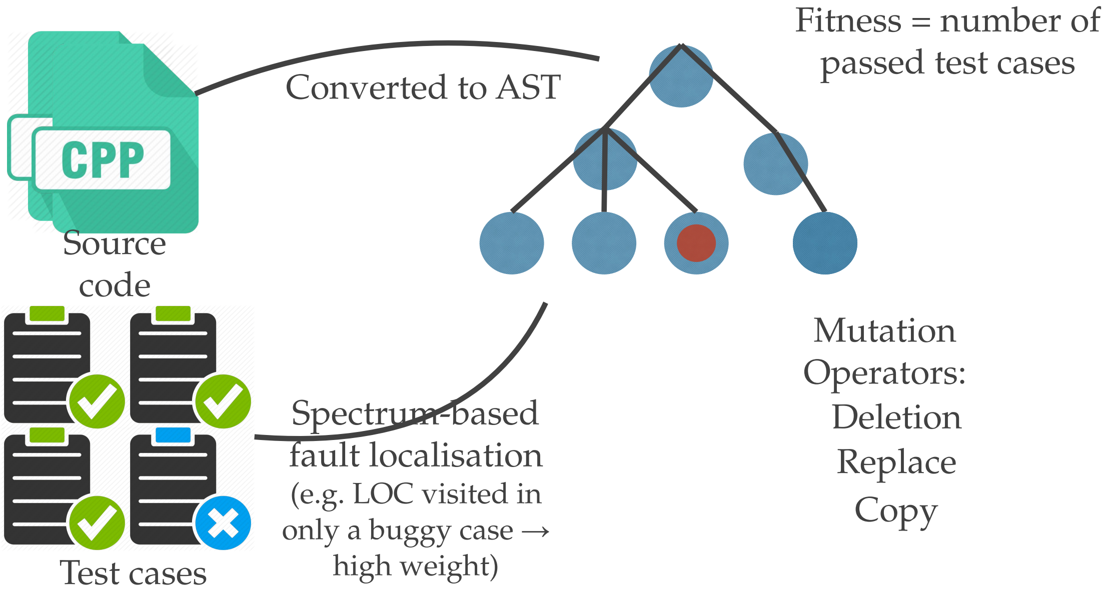
A Systematic Study of Automated Program Repair: Fixing 55 out of 105 Bugs for $8 Each

Claire Le Goues   Michael Dewey-Vogt
Computer Science Department
University of Virginia
Charlottesville, VA
{legoues,mkd5m}@cs.virginia.edu

Stephanie Forrest
Computer Science Department
University of New Mexico
Albuquerque, NM
forrest@cs.unm.edu

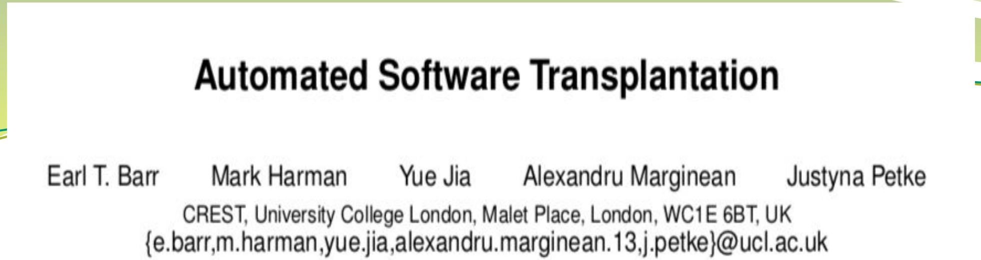
Westley Weimer
Computer Science Department
University of Virginia
Charlottesville, VA
weimer@cs.virginia.edu

(2012)
Cited ~400 times



CPP
Source code
Test cases
Converted to AST
Fitness = number of passed test cases
Spectrum-based fault localisation (e.g. LOC visited in only a buggy case → high weight)
Mutation Operators:
Deletion
Replace
Copy

- 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

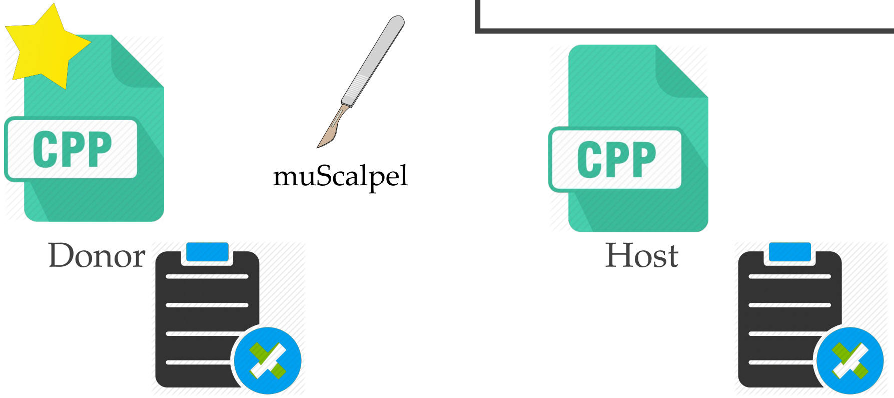
Earl T. Barr Mark Harman Yue Jia Alexandru Marginean Justyna Petke
CREST, University College London, Malet Place, London, WC1E 6BT, UK
{e.barr,m.harman,yue.jia,alexandru.marginean.13,j.petke}@ucl.ac.uk

(2015)

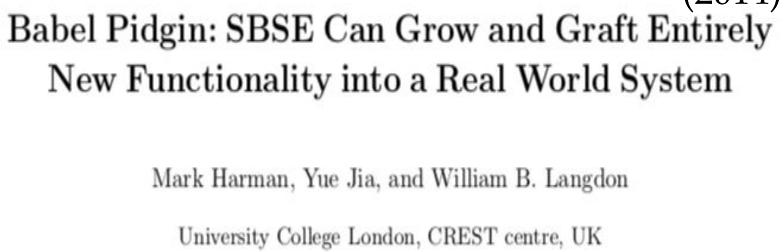
Featured in:

WIRED

CLICK



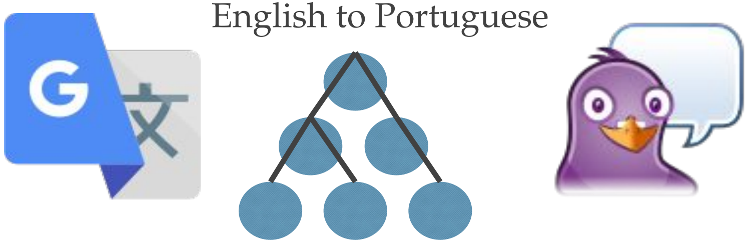
(2014)

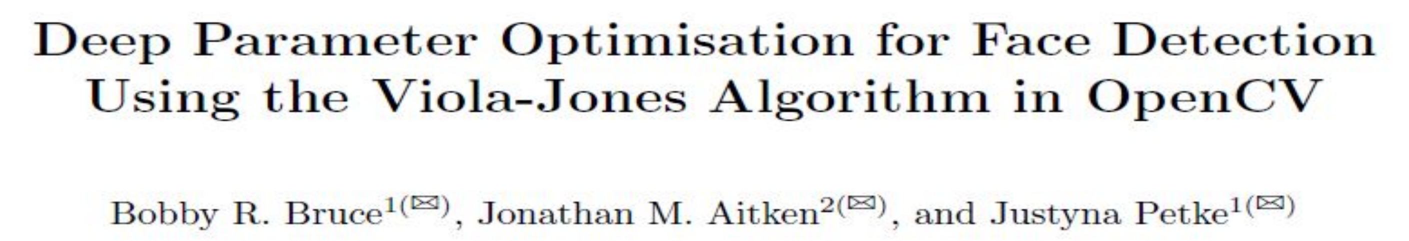


Babel Pidgin: SBSE Can Grow and Graft Entirely New Functionality into a Real World System

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

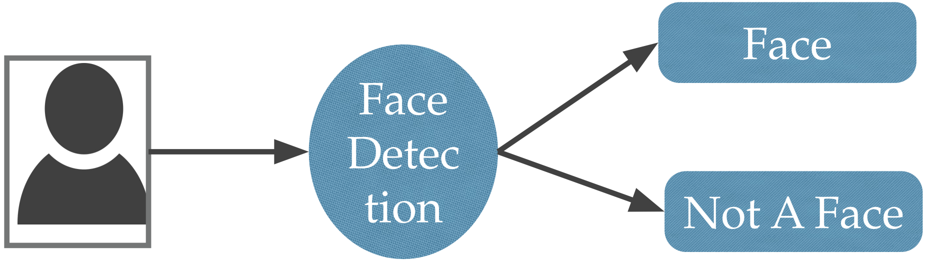
English to Korean;
English to Portuguese

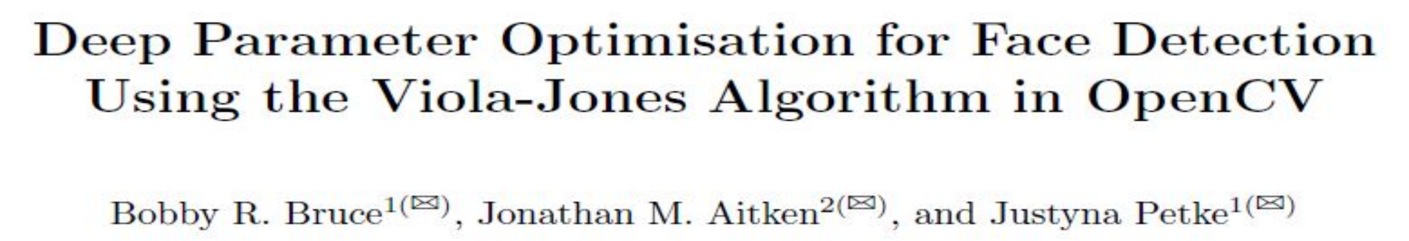




Deep Parameter Optimisation for Face Detection Using the Viola-Jones Algorithm in OpenCV

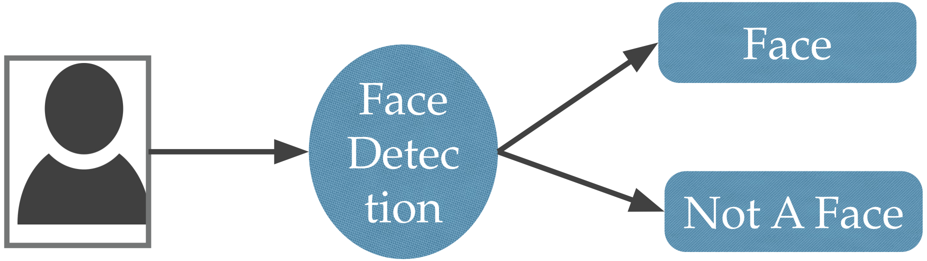
Bobby R. Bruce[1](✉), Jonathan M. Aitken[2](✉), and Justyna Petke[1](✉)

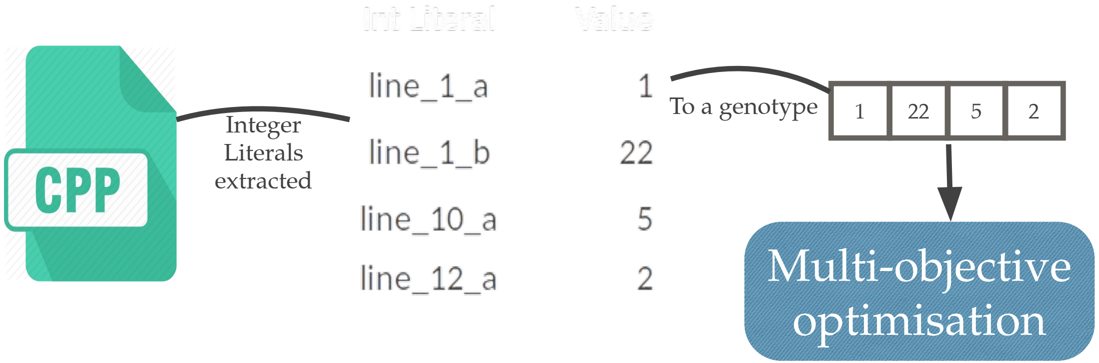




Deep Parameter Optimisation for Face Detection Using the Viola-Jones Algorithm in OpenCV

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





Int Literal	Value
line_1_a	1
line_1_b	22
line_10_a	5
line_12_a	2

1	22	5	2

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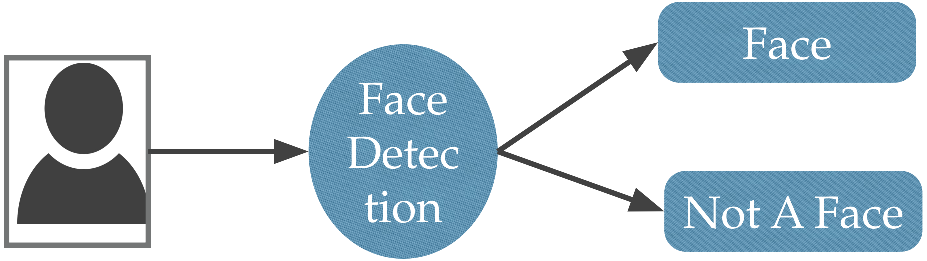


Face Detec tion

Face

Not A Face

Integer Literals extracted

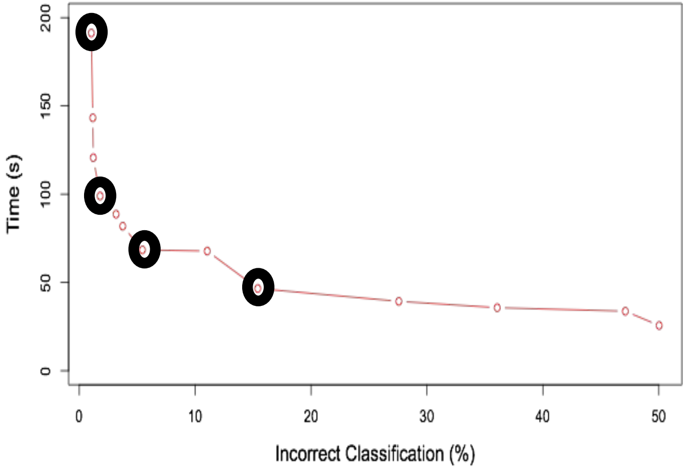
Int Literal	Value
line_1_a	1
line_1_b	22
line_10_a	5
line_12_a	2

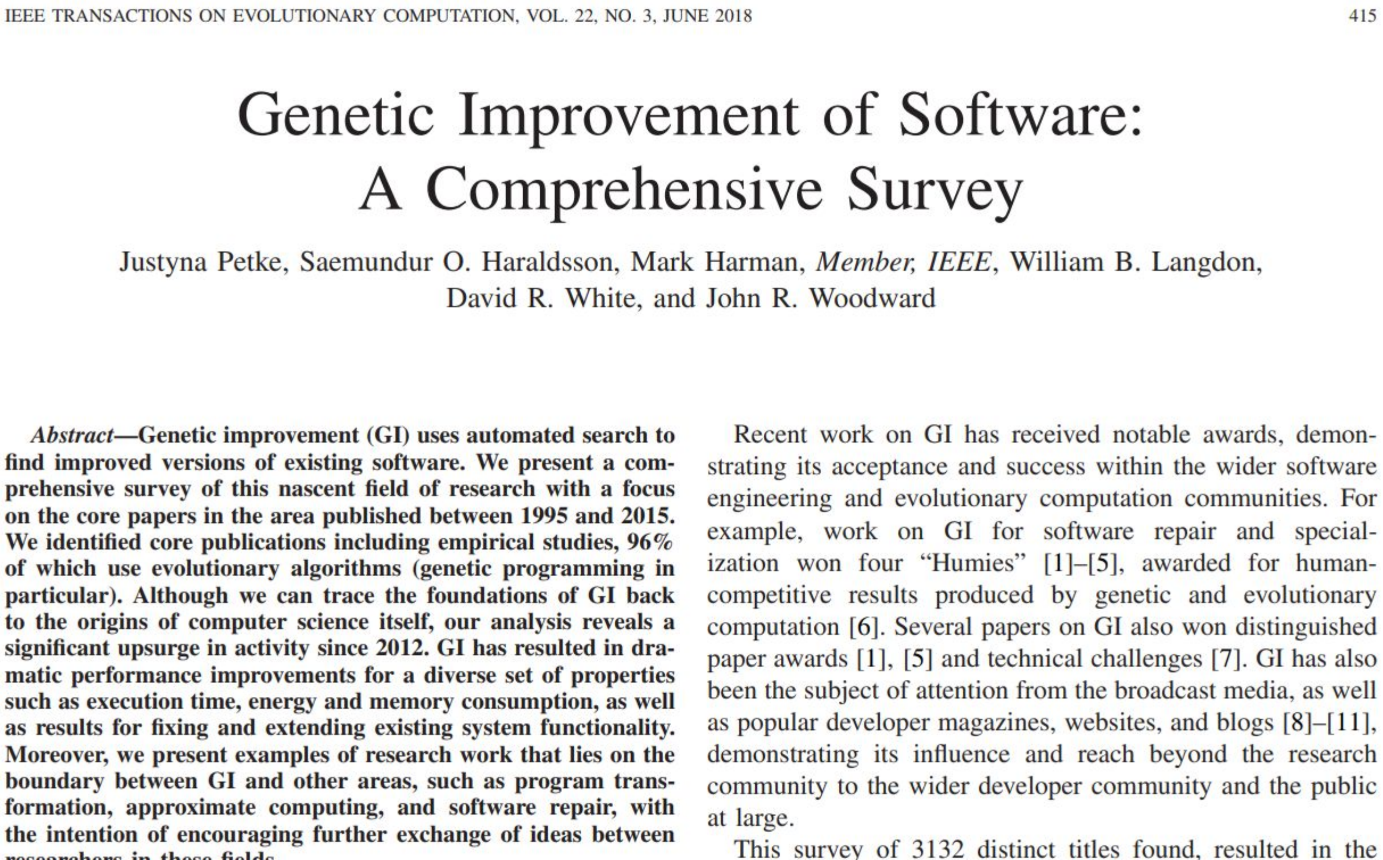
To a genotype

1	22	5	2

Multi-objective optimisation

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





Genetic Improvement of Software: A Comprehensive Survey

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

***Abstract*—Genetic improvement (GI) uses automated search to find improved versions of existing software. We present a comprehensive survey of this nascent field of research with a focus on the core papers in the area published between 1995 and 2015. We identified core publications including empirical studies, 96% of which use evolutionary algorithms (genetic programming in particular). Although we can trace the foundations of GI back to the origins of computer science itself, our analysis reveals a significant upsurge in activity since 2012. GI has resulted in dramatic performance improvements for a diverse set of properties such as execution time, energy and memory consumption, as well as results for fixing and extending existing system functionality. Moreover, we present examples of research work that lies on the boundary between GI and other areas, such as program transformation, approximate computing, and software repair, with the intention of encouraging further exchange of ideas between researchers in these fields.**

Recent work on GI has received notable awards, demonstrating its acceptance and success within the wider software engineering and evolutionary computation communities. For example, work on GI for software repair and specialization won four "Humies" [1]–[5], awarded for human-competitive results produced by genetic and evolutionary computation [6]. Several papers on GI also won distinguished paper awards [1], [5] and technical challenges [7]. GI has also been the subject of attention from the broadcast media, as well as popular developer magazines, websites, and blogs [8]–[11], demonstrating its influence and reach beyond the research community to the wider developer community and the public at large.

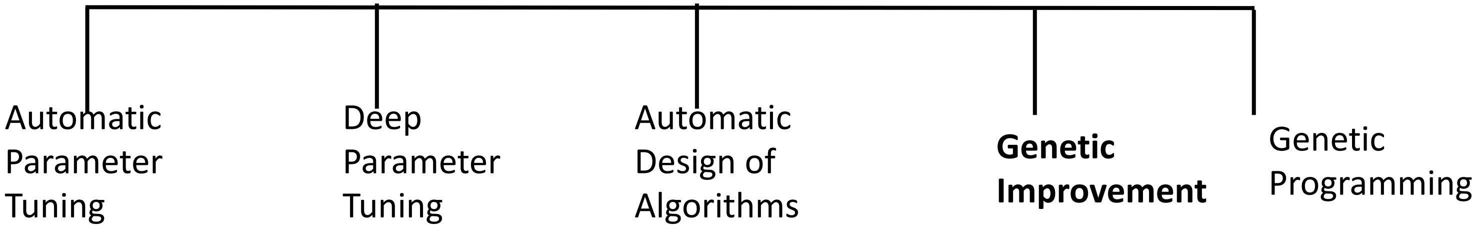
This survey of 3132 distinct titles found, resulted in the

Phd Theses

- David R. White
- Andrea Arcuri
- 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



Automatic Parameter Tuning

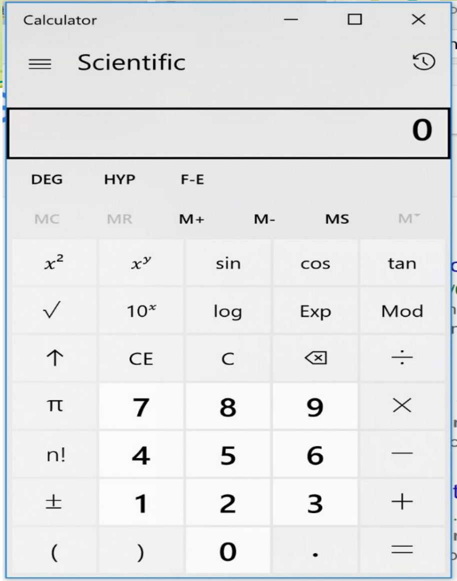
Deep Parameter Tuning

Automatic Design of Algorithms

Genetic Improvement

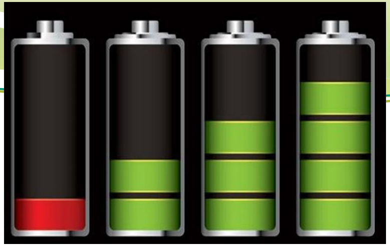
Genetic Programming

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

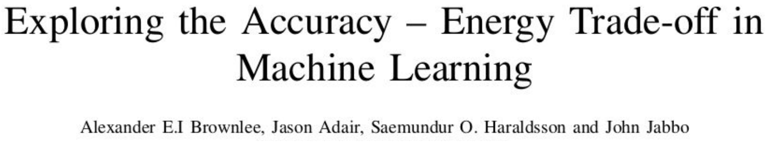
physically measure and validate(e.g. see Bokhari et al.)

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

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]

Measuring Energy

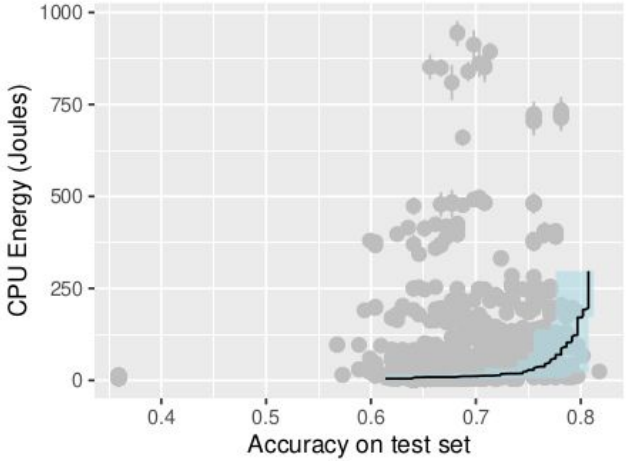
Trade-offs to exploit, but lots of noise and many confounding factors

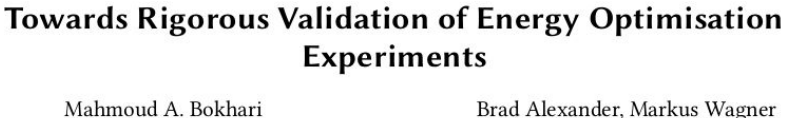


Exploring the Accuracy – Energy Trade-off in Machine Learning

Alexander E.I Brownlee, Jason Adair, Saemundur O. Haraldsson and John Jabbo

GI@ICSE'21



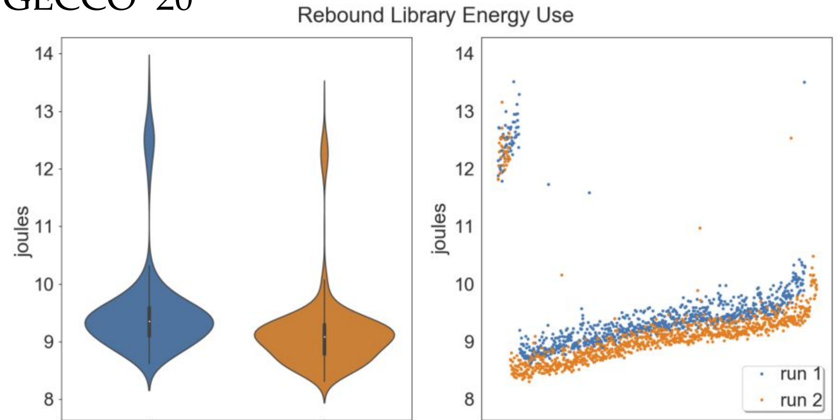


Towards Rigorous Validation of Energy Optimisation Experiments

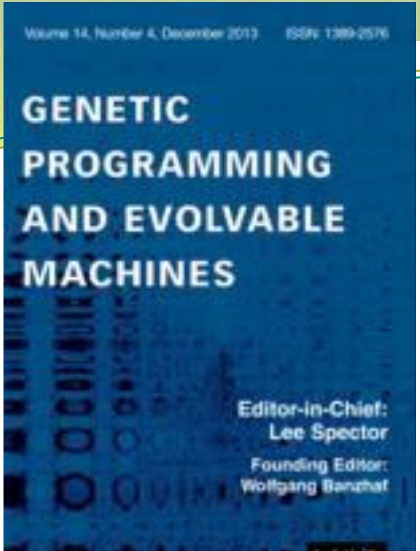
Mahmoud A. Bokhari

Brad Alexander, Markus Wagner

GECCO '20



activities



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GENETIC PROGRAMMING AND EVOLVABLE MACHINES

Editor-in-Chief: Lee Spector

Founding Editor: Wolfgang Banzhaf

Springer

International Workshop on Automatic Software Optimisation

Ninth GI Workshop, 2020,(now running online!)

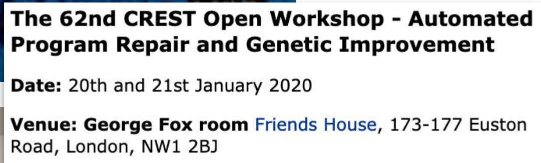
GI @ ICSE 2020

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

International Workshop on Automatic Software Optimisation

Seventh edition of GI @ GECCO 2019 in Prague, Czech Republic

The 6th International Workshop on Genetic Improvement @ICSE 2019



The 62nd CREST Open Workshop - Automated Program Repair and Genetic Improvement

Date: 20th and 21st January 2020

Venue: George Fox room Friends House, 173-177 Euston Road, London, NW1 2BJ

video

2nd International Summer School

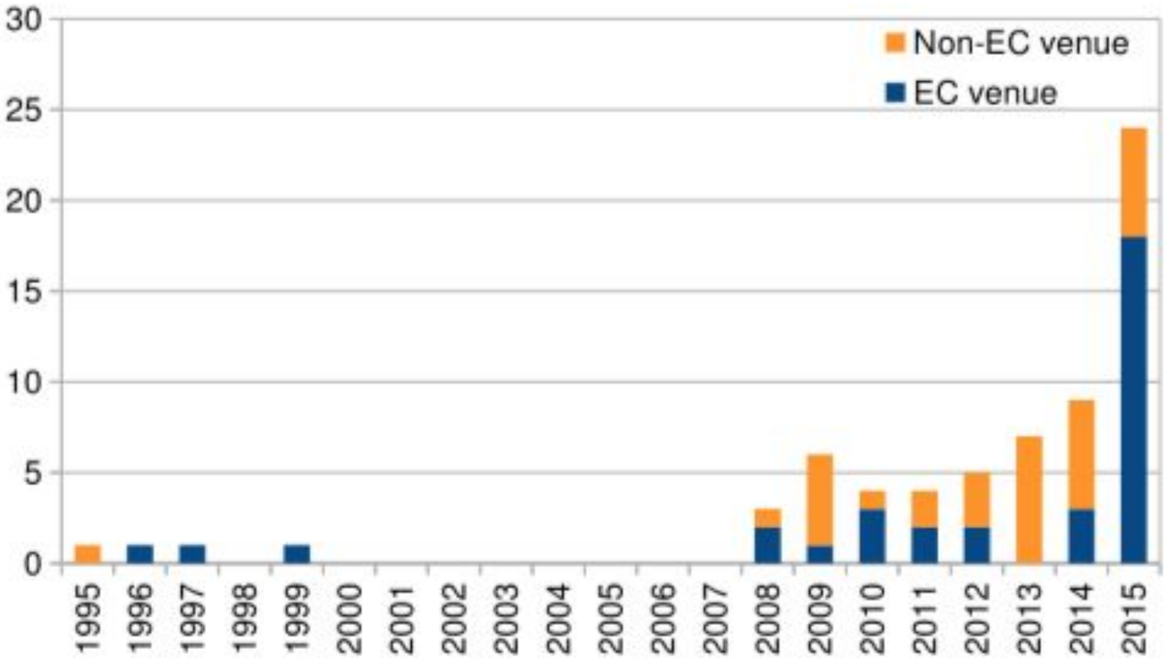
We are proud to announce the Second International Summer School on Search-Based Software Engineering (SS-SBSE 2017).

January 2018

SCHLOSS DAGSTUHL

Leibniz-Zentrum für Informatik

Growth of papers



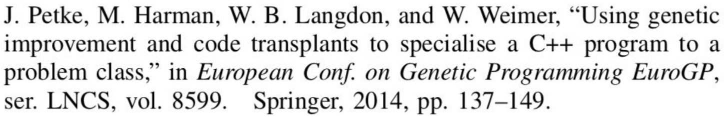
How will it continue…???

SOURCE CODE
WILL ALWAYS
BE IMPORTANT

Source of Genetic Material

1. the program being improved,

2. a different program written in the same language (Petke: MiniSAT competition),



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.

3. a piece of code generated from scratch (GP),

4. different programming language other than the software to be improved.

Theory

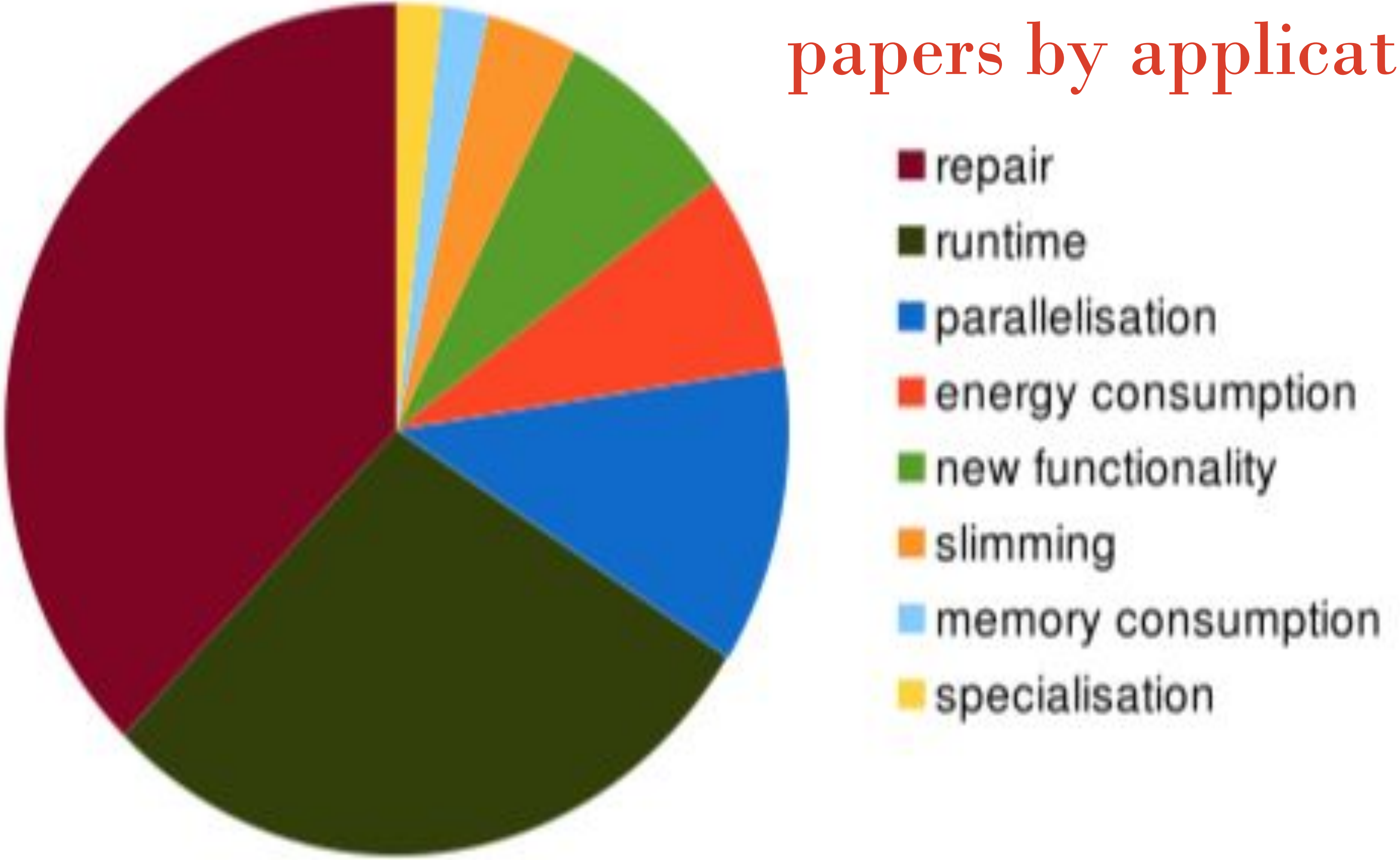
- Hard!

- 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

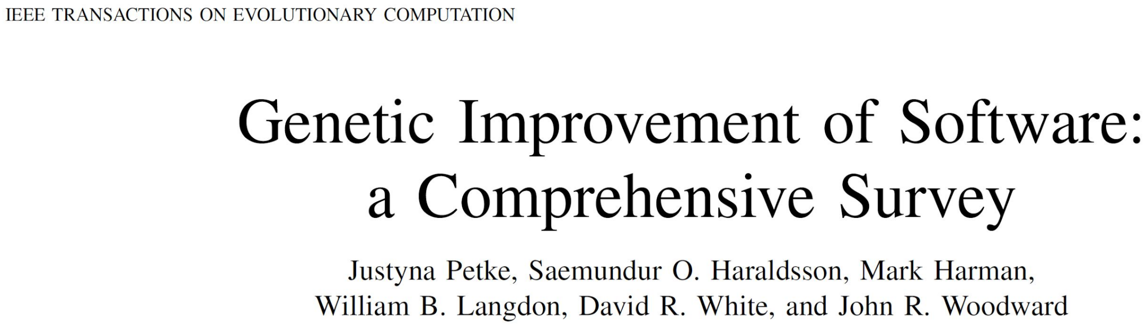
An International Workshop on the Repair and Optimisation of Software using Computational Search

- 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

label:genetic_improvement

CREST

Starting point – POP science, GIN, Survey



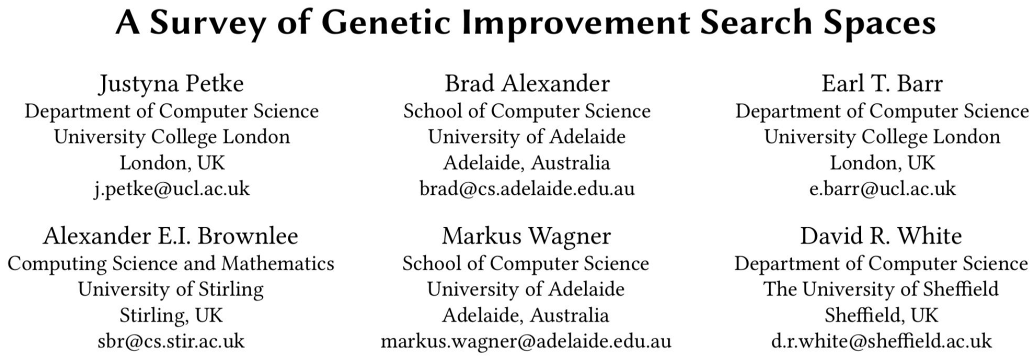
IEEE TRANSACTIONS ON EVOLUTIONARY COMPUTATION

Genetic Improvement of Software: a Comprehensive Survey

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

(2017)

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

GI in No Time

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

(Inaugural paper at GI@GECCO 2017)

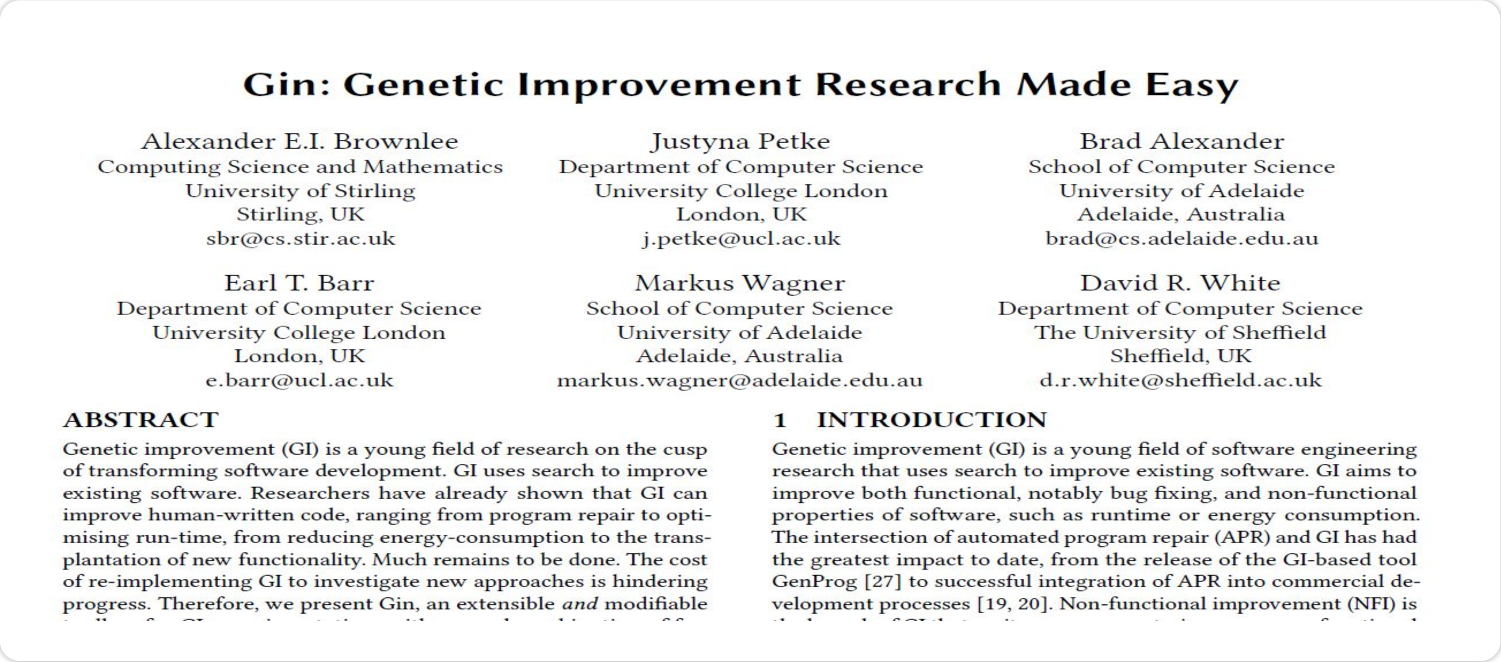
Available at
https://github.com/gintool/gin

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

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

The inaugural paper

official V2.1 released on 7 March 2023: 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

Maven™

Gradle Build Tool

JAVAPARSER

FOR PROCESSING JAVA CODE

Apache Commons™
http://commons.apache.org/

GUAVA

MIT

Java

Libraries

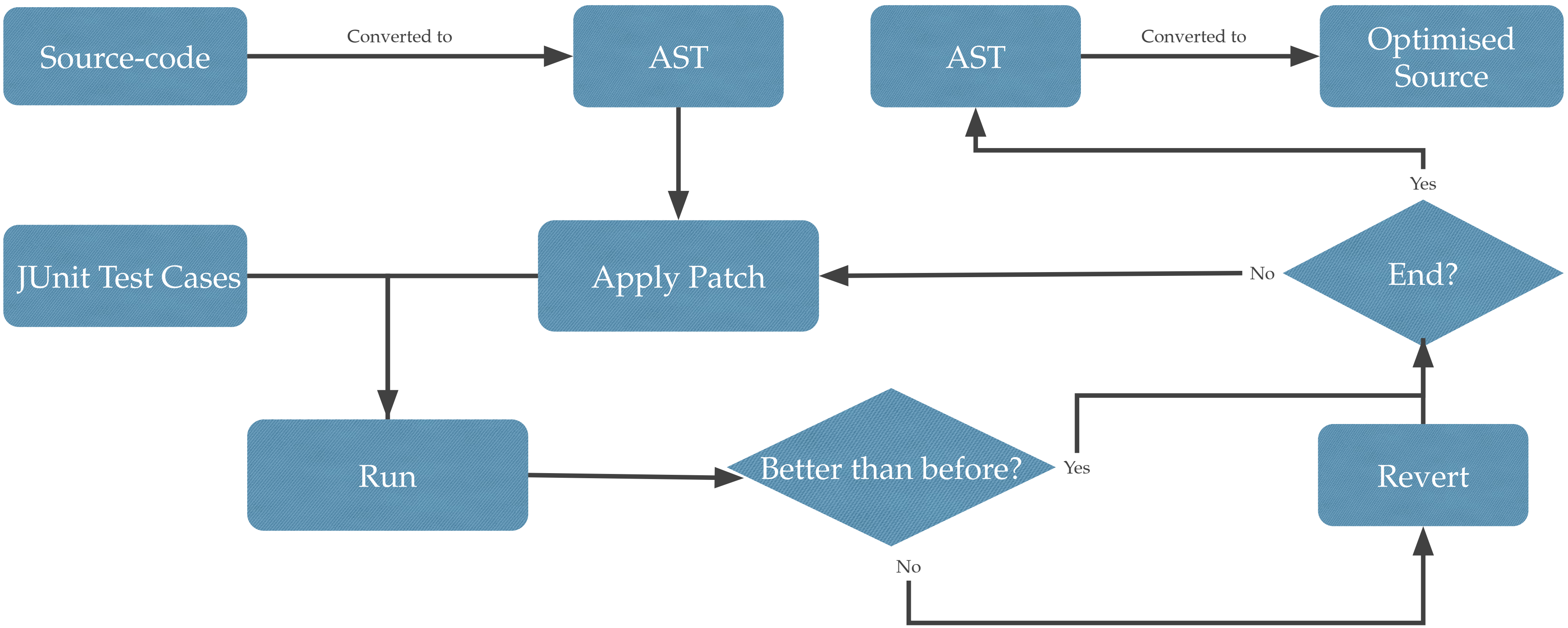
License

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, Java Flight Recorder)
- Build tool integration (Maven, Gradle)

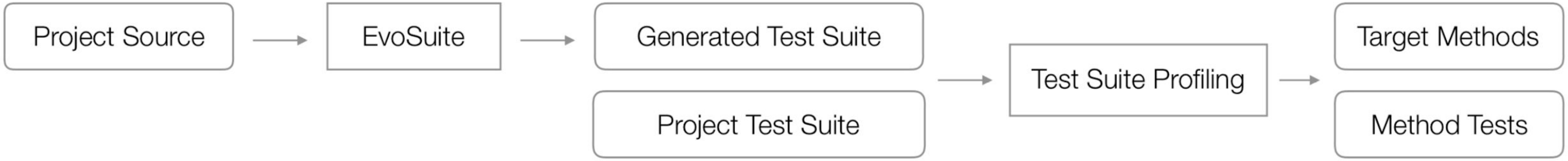
Let's see those in more detail...

Vanilla GIN: Neighbourhood search

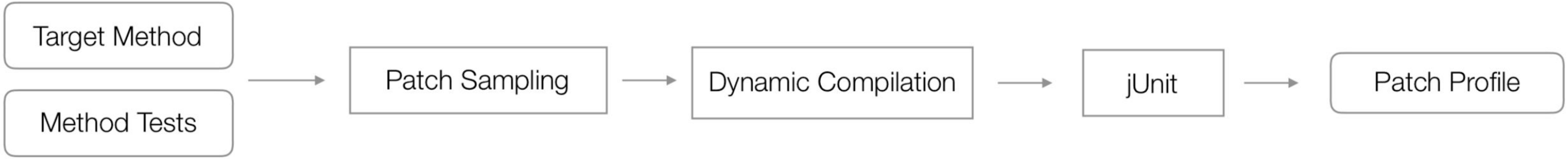


Gin Pipelines

Preprocessing



Search Space Analysis



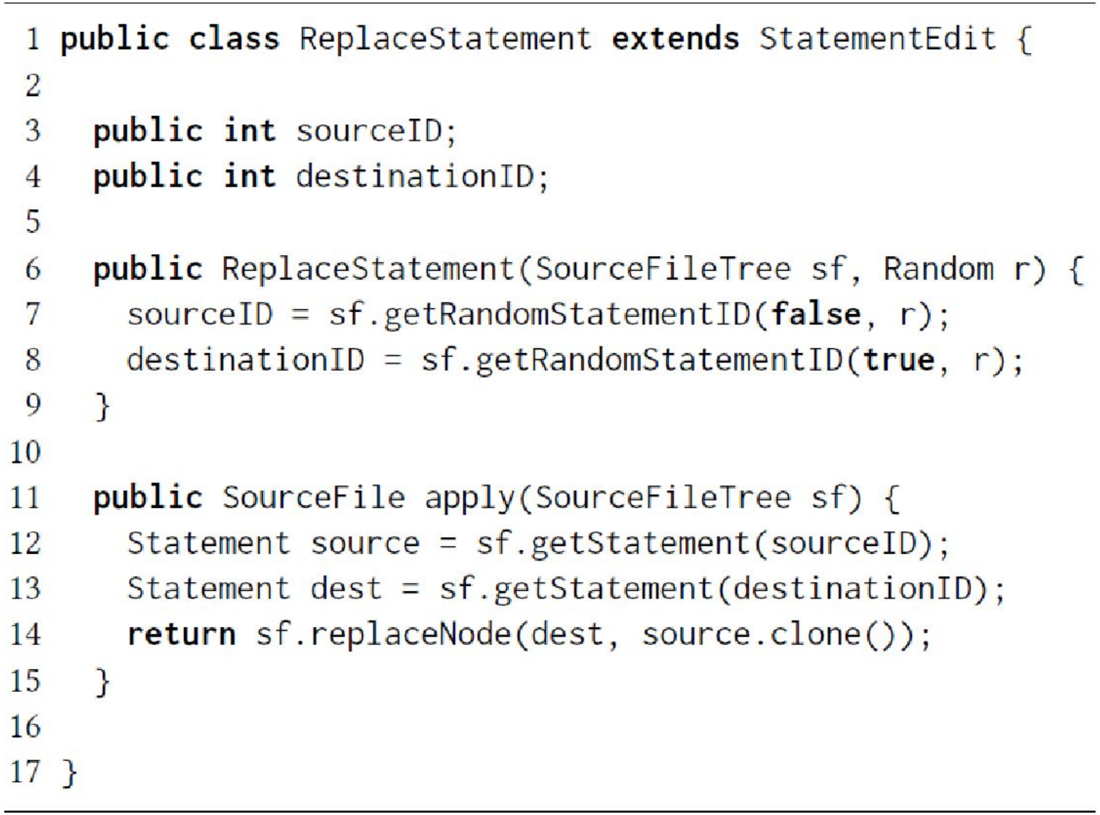
Edits

- 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…

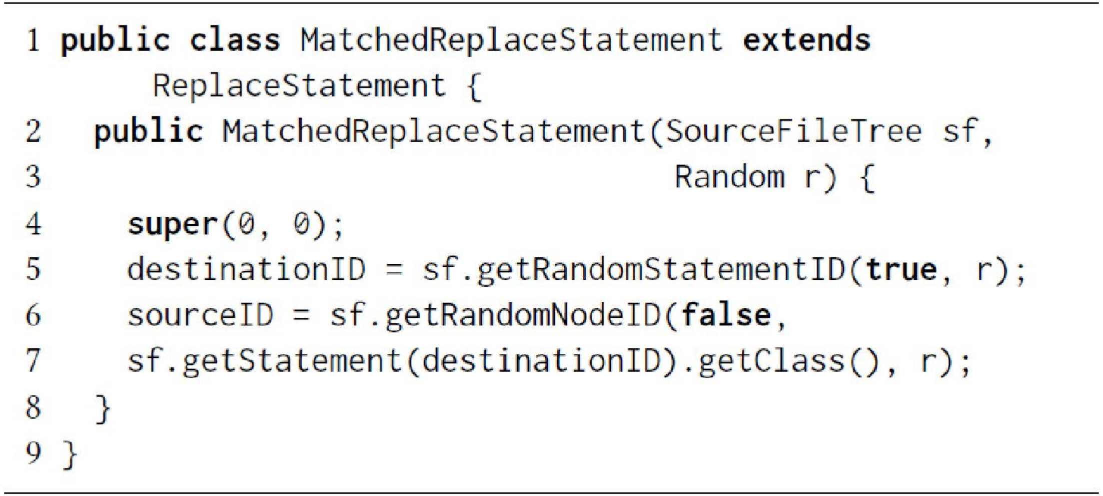
Example edits



```
public class ReplaceStatement extends StatementEdit {

  public int sourceID;
  public int destinationID;

  public ReplaceStatement(SourceFileTree sf, Random r) {
    sourceID = sf.getRandomStatementID(false, r);
    destinationID = sf.getRandomStatementID(true, r);
  }

  public SourceFile apply(SourceFileTree sf) {
    Statement source = sf.getStatement(sourceID);
    Statement dest = sf.getStatement(destinationID);
    return sf.replaceNode(dest, source.clone());
  }

}
```

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.

Example edits

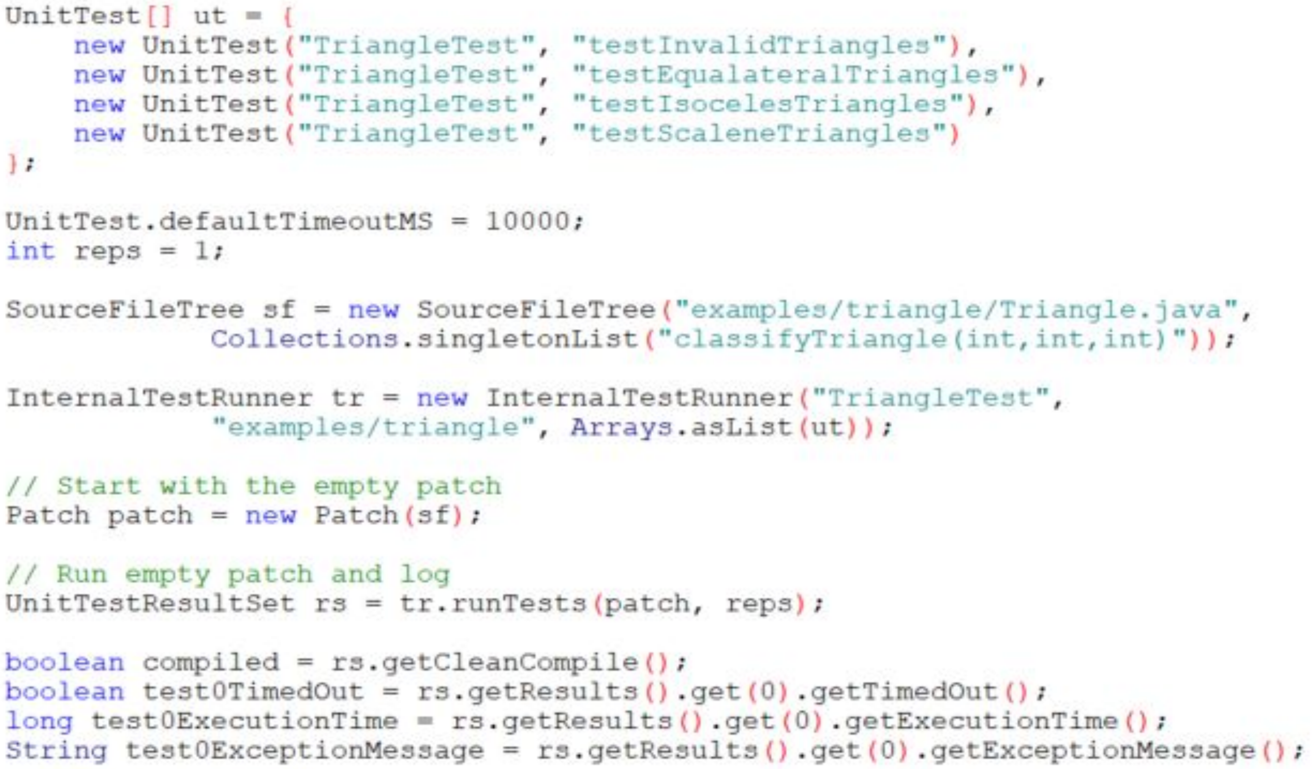


```java
public class MatchedReplaceStatement extends
      ReplaceStatement {
  public MatchedReplaceStatement(SourceFileTree sf,
                                 Random r) {
    super(0, 0);
    destinationID = sf.getRandomStatementID(true, r);
    sourceID = sf.getRandomNodeID(false,
    sf.getStatement(destinationID).getClass(), r);
  }
}
```

Patch Evaluation

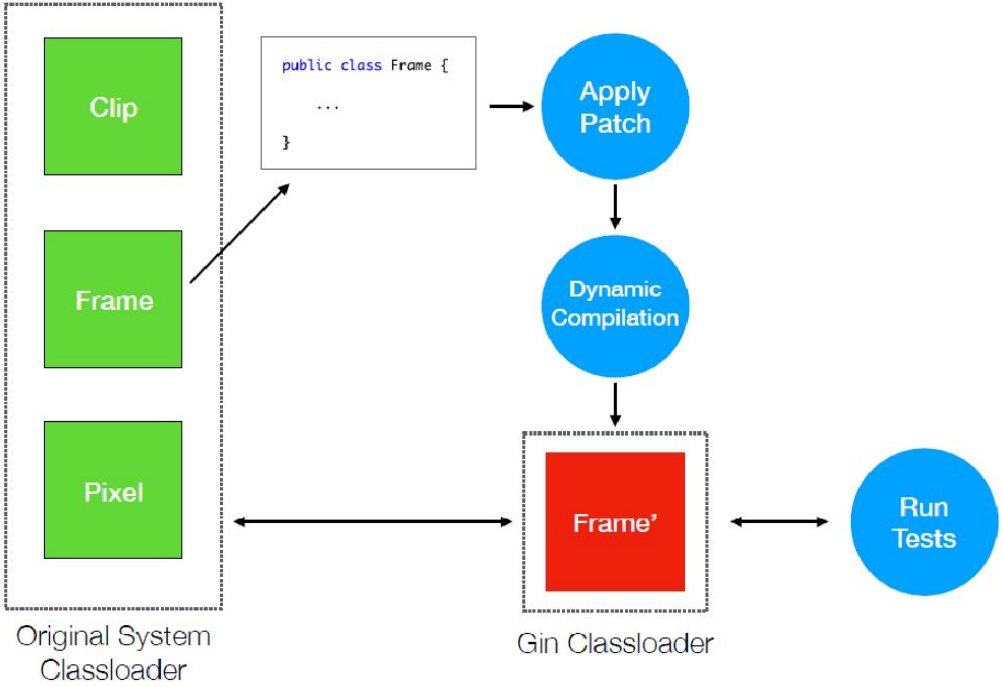
Gin invokes test cases via Junit and tracks:

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



```
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



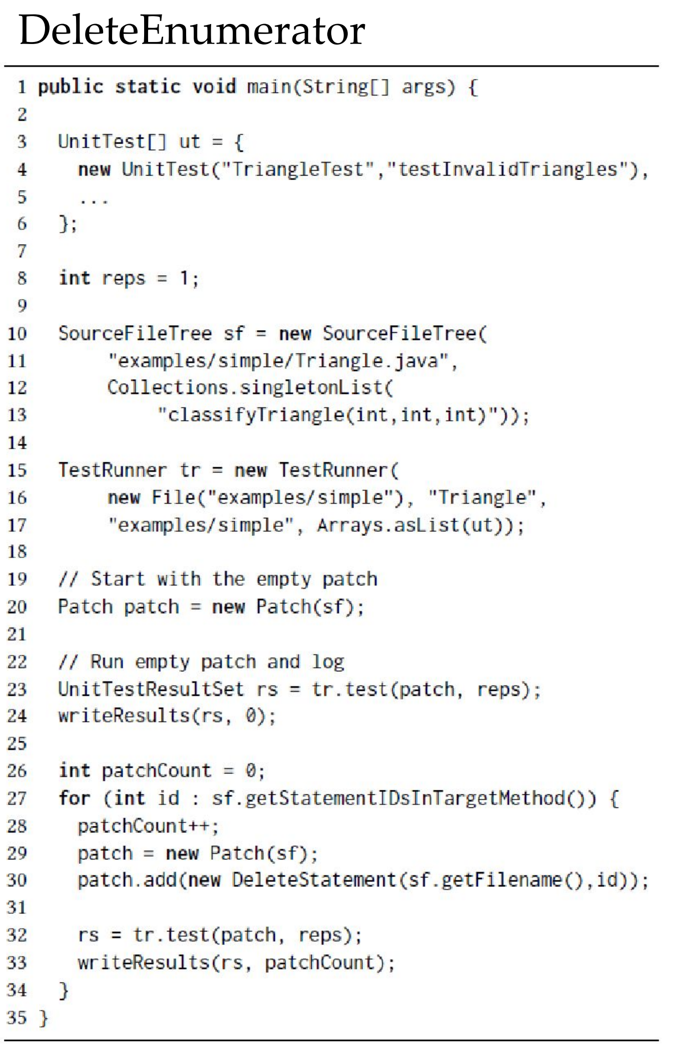
```
public class Frame {

    ...

}
```

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, NSGA-II

- 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?
  - ...

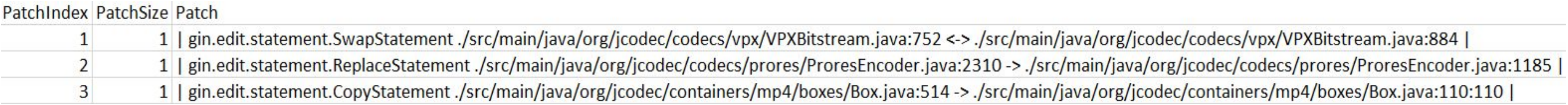


DeleteEnumerator

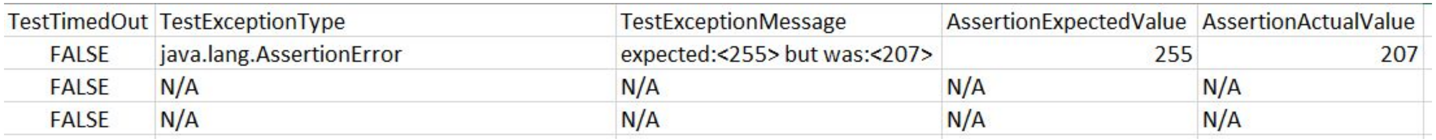
```
public static void main(String[] args) {

  UnitTest[] ut = {
    new UnitTest("TriangleTest","testInvalidTriangles"),
    ...
  };

  int reps = 1;

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

  TestRunner tr = new TestRunner(
       new File("examples/simple"), "Triangle",
       "examples/simple", Arrays.asList(ut));

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

  // Run empty patch and log
  UnitTestResultSet rs = tr.test(patch, reps);
  writeResults(rs, 0);

  int patchCount = 0;
  for (int id : sf.getStatementIDsInTargetMethod()) {
    patchCount++;
    patch = new Patch(sf);
    patch.add(new DeleteStatement(sf.getFilename(),id));

    rs = tr.test(patch, reps);
    writeResults(rs, patchCount);
  }
}
```

Sampling

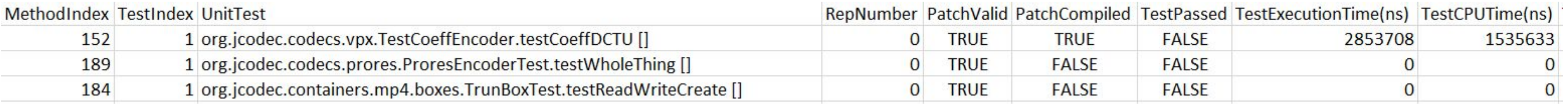
The following is one really wide output file - here of RandomSampler:



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 |

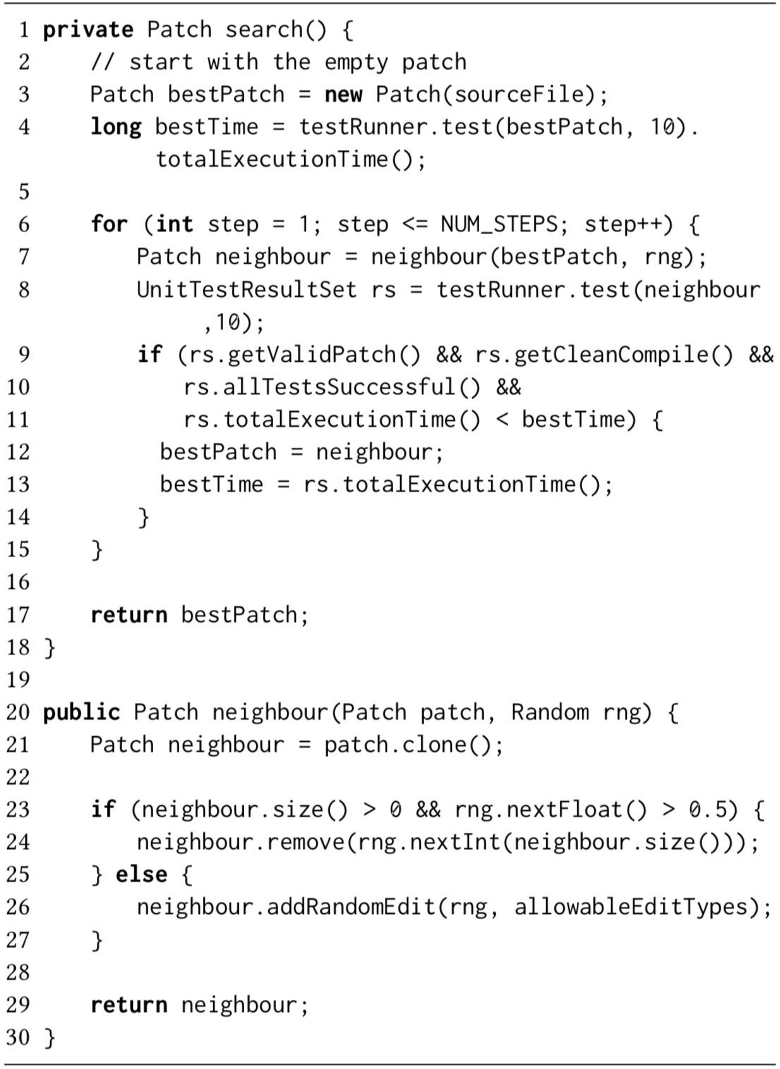


TestTimedOut	TestExceptionType	TestExceptionMessage	AssertionExpectedValue	AssertionActualValue
FALSE	java.lang.AssertionError	expected:<255> but was:<207>	255	207
FALSE	N/A	N/A	N/A	N/A
FALSE	N/A	N/A	N/A	N/A



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



```java
private Patch search() {
    // start with the empty patch
    Patch bestPatch = new Patch(sourceFile);
    long bestTime = testRunner.test(bestPatch, 10).
         totalExecutionTime();

    for (int step = 1; step <= NUM_STEPS; step++) {
        Patch neighbour = neighbour(bestPatch, rng);
        UnitTestResultSet rs = testRunner.test(neighbour
             ,10);
        if (rs.getValidPatch() && rs.getCleanCompile() &&
            rs.allTestsSuccessful() &&
            rs.totalExecutionTime() < bestTime) {
          bestPatch = neighbour;
          bestTime = rs.totalExecutionTime();
        }
    }

    return bestPatch;
}

public Patch neighbour(Patch patch, Random rng) {
    Patch neighbour = patch.clone();

    if (neighbour.size() > 0 && rng.nextFloat() > 0.5) {
        neighbour.remove(rng.nextInt(neighbour.size()));
    } else {
        neighbour.addRandomEdit(rng, allowableEditTypes);
    }

    return neighbour;
}
```

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)"
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
```

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
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
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)
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?

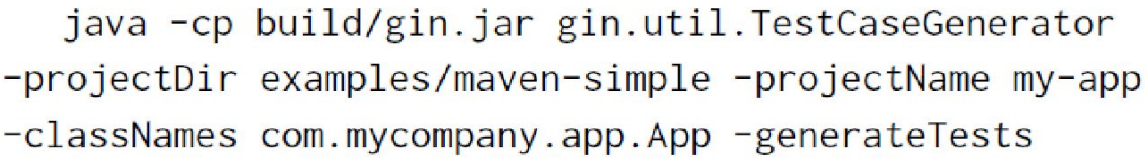
```
-bash-4.1$ cat examples/triangle/Triangle.java
public class Triangle {

          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) {

          }
          }

}
```

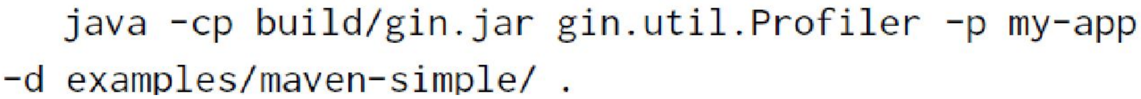
Generating tests and Profiling

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’;
```

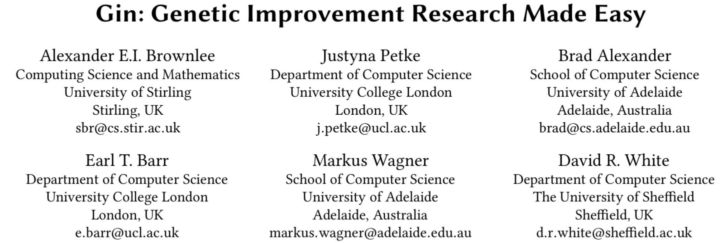
```
java -Dtinylog.level=trace -cp ../../ginfork/build/gin.jar gin.util.EmptyPatchTester -h
~/.sdkman/candidates/maven/current/ -p $projectnameforgin -d .
-m $projectnameforgin.Profiler_output.csv
-o $projectnameforgin.EmptyPatchTester_output.csv
```

- 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

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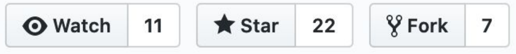
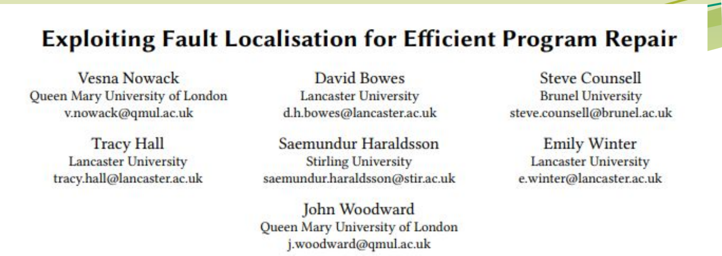
- Available at https://github.com/gintool/gin

- 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





Exploiting Fault Localisation for Efficient Program Repair

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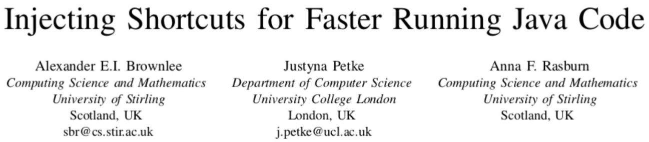

Injecting Shortcuts for Faster Running Java Code

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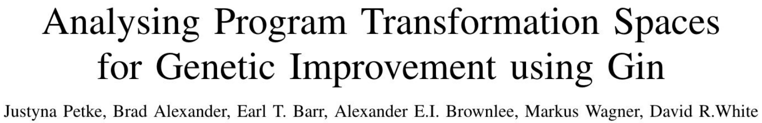
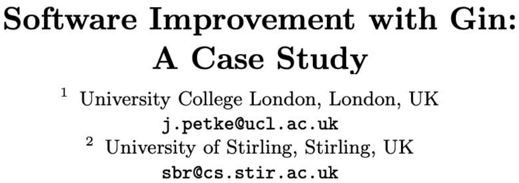


Analysing Program Transformation Spaces for Genetic Improvement using Gin

Justyna Petke, Brad Alexander, Earl T. Barr, Alexander E.I. Brownlee, Markus Wagner, David R.White



Software Improvement with Gin: A Case Study

[1] University College London, London, UK
`j.petke@ucl.ac.uk`
[2] University of Stirling, Stirling, UK
`sbr@cs.stir.ac.uk`

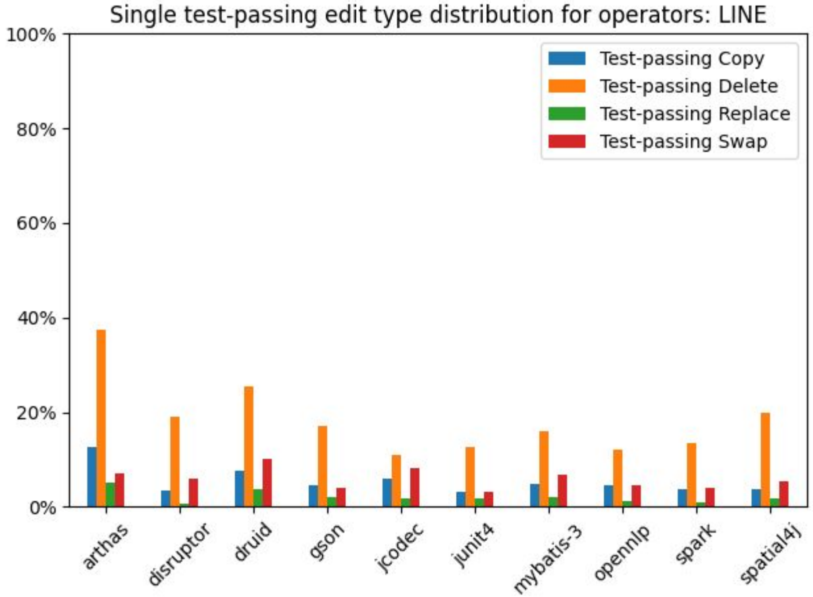
Comments/questions: Sandy (Alexander E.I. Brownlee) sbr@cs.stir.ac.uk

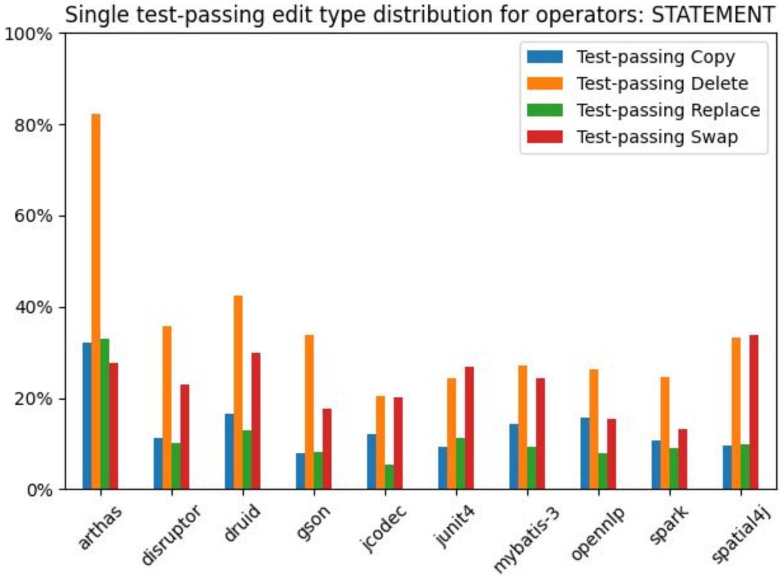
Search spaces and targeting

- Recent study using Gin
- We looked at 10 open source projects
  - arthas, disruptor, druid, gson, jcodec, junit4, mybatis-3, opennlp, apache spark, spatial4j
- Applied 1M patches to these
  - Copy/Delete/Replace/Swap
  - 10k each of 1-5 edits
  - Line and Statement
- Profiled (using Gin HPROF)
- Measured compile/test pass rates (Using Gin RandomSampler)

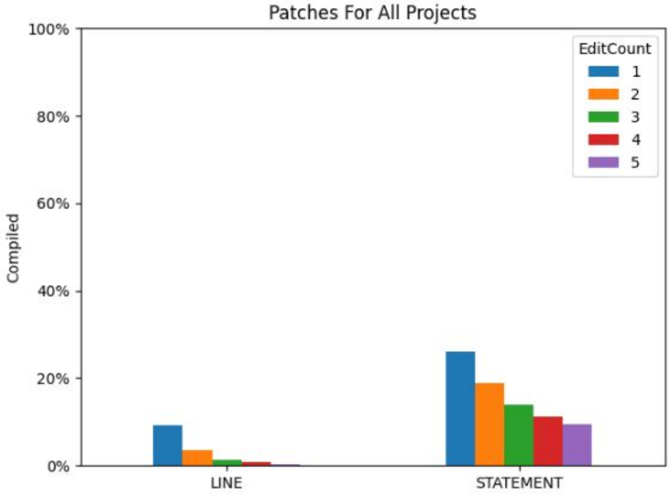
Line	Statement
Delete 16.5%	Delete 30.2%
Swap 5.6%	Swap 23.6%
Copy 4.6%	Copy 11.6%
Replace 1.7%	Replace 9.6%

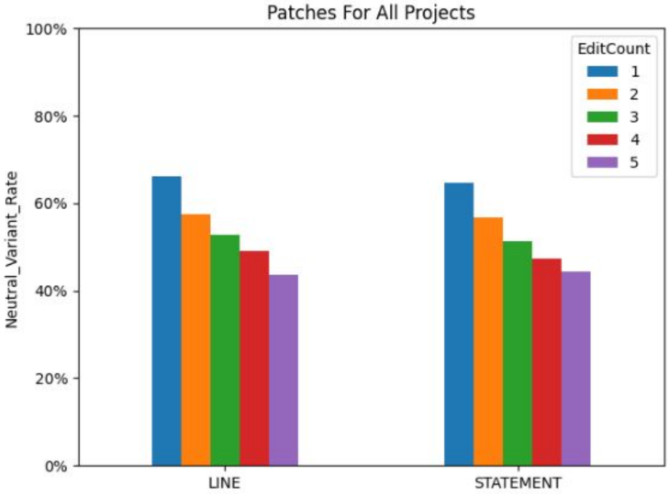
Line edits generate ⅓ as many test passing variants as statement





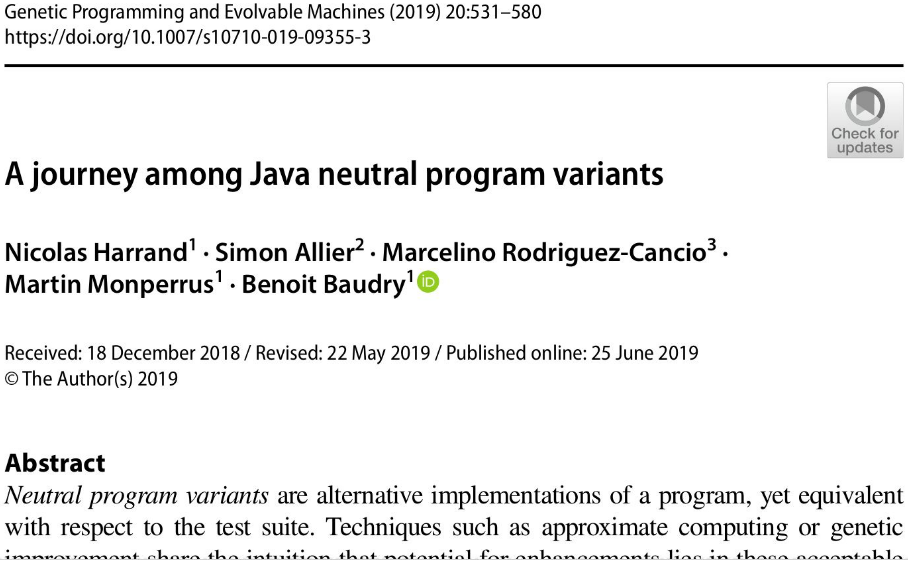
Big hurdle is compilation: rates drop 50% with each additional edit for line, and 25% for statement. Of compiling variants, drop in test-pass rate less severe





Targeting

Still learning where and when GI works well



Genetic Programming and Evolvable Machines (2019) 20:531–580
https://doi.org/10.1007/s10710-019-09355-3

Check for updates

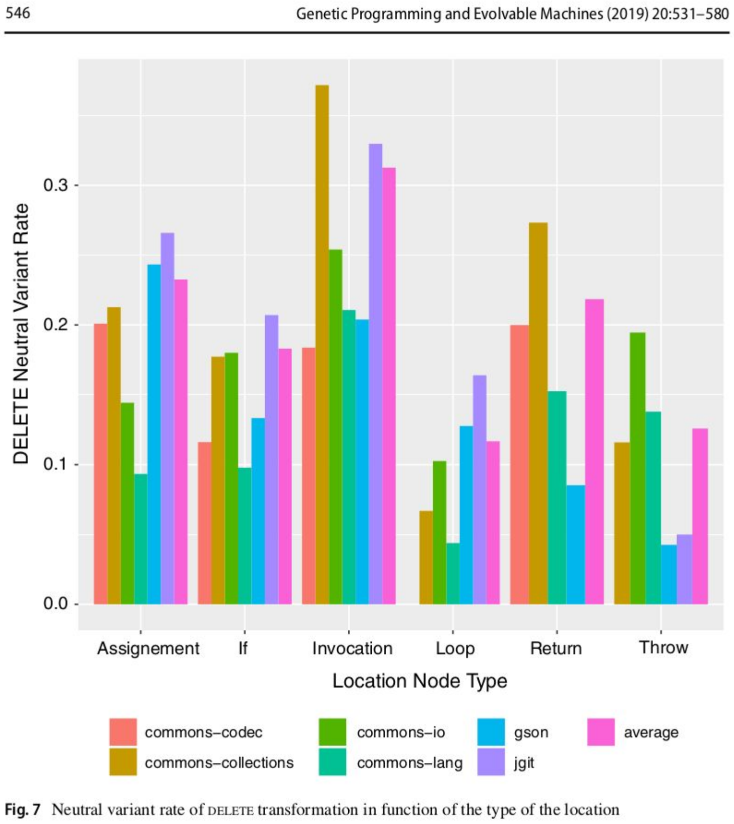
A journey among Java neutral program variants

Nicolas Harrand[1] · Simon Allier[2] · Marcelino Rodriguez-Cancio[3] · Martin Monperrus[1] · Benoit Baudry[1]

Received: 18 December 2018 / Revised: 22 May 2019 / Published online: 25 June 2019

Abstract

Neutral program variants are alternative implementations of a program, yet equivalent with respect to the test suite. Techniques such as approximate computing or genetic improvement share the intuition that potential for enhancements lies in these acceptable



546 Genetic Programming and Evolvable Machines (2019) 20:531–580

Fig. 7 Neutral variant rate of DELETE transformation in function of the type of the location

Targeting

Still learning where and when GI works well

Lots of open questions here:

- Good edits
- What to target them?
- Landscapes…

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

- **Open Question: where do humans fit in?**

GI Workshop

The 12th International Workshop on Genetic Improvement @ICSE 2023

- Held on 20 May
- Keynotes from Myra B. Cohen and Sebastian Baltes
- 6 accepted papers
- Future workshops http://geneticimprovementofsoftware.com

Questions?

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Latest version of slides at https://cs.stir.ac.uk/~sbr/files/GI_tutorial_GECCO_2023.pdf

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