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Genetic Improvement of Software

Justyna Petke

CREST UCL

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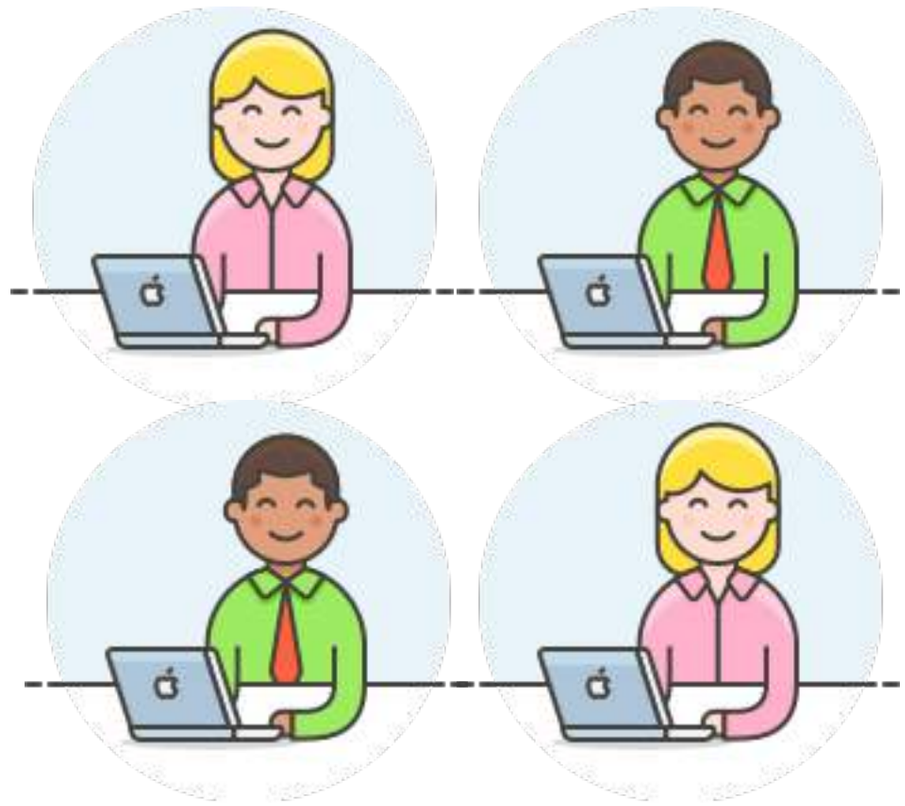
Human Programming



Programmer icons by Streamline Icons http://www.streamlineicons.com License: CC Attribution 4.0

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Automated 🏆 Programming

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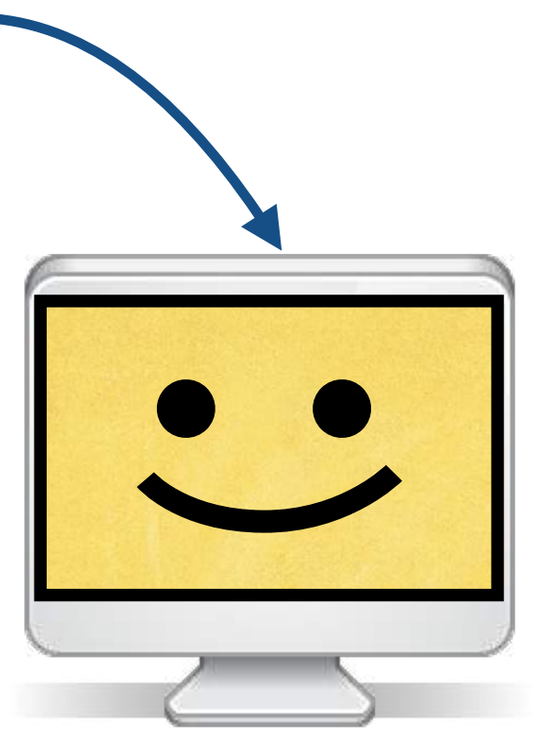
Automated Software Improvement

human writes code

computer improves it



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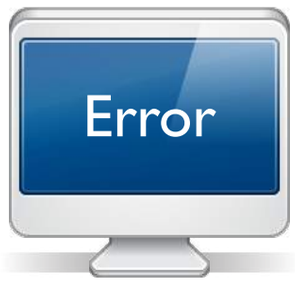
Functional Properties

New Feature

Functionality Improvement

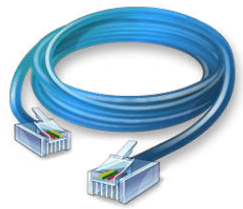


Bug Repair

Non-functional Properties

Execution Time

Memory



Bandwidth

Energy

Size

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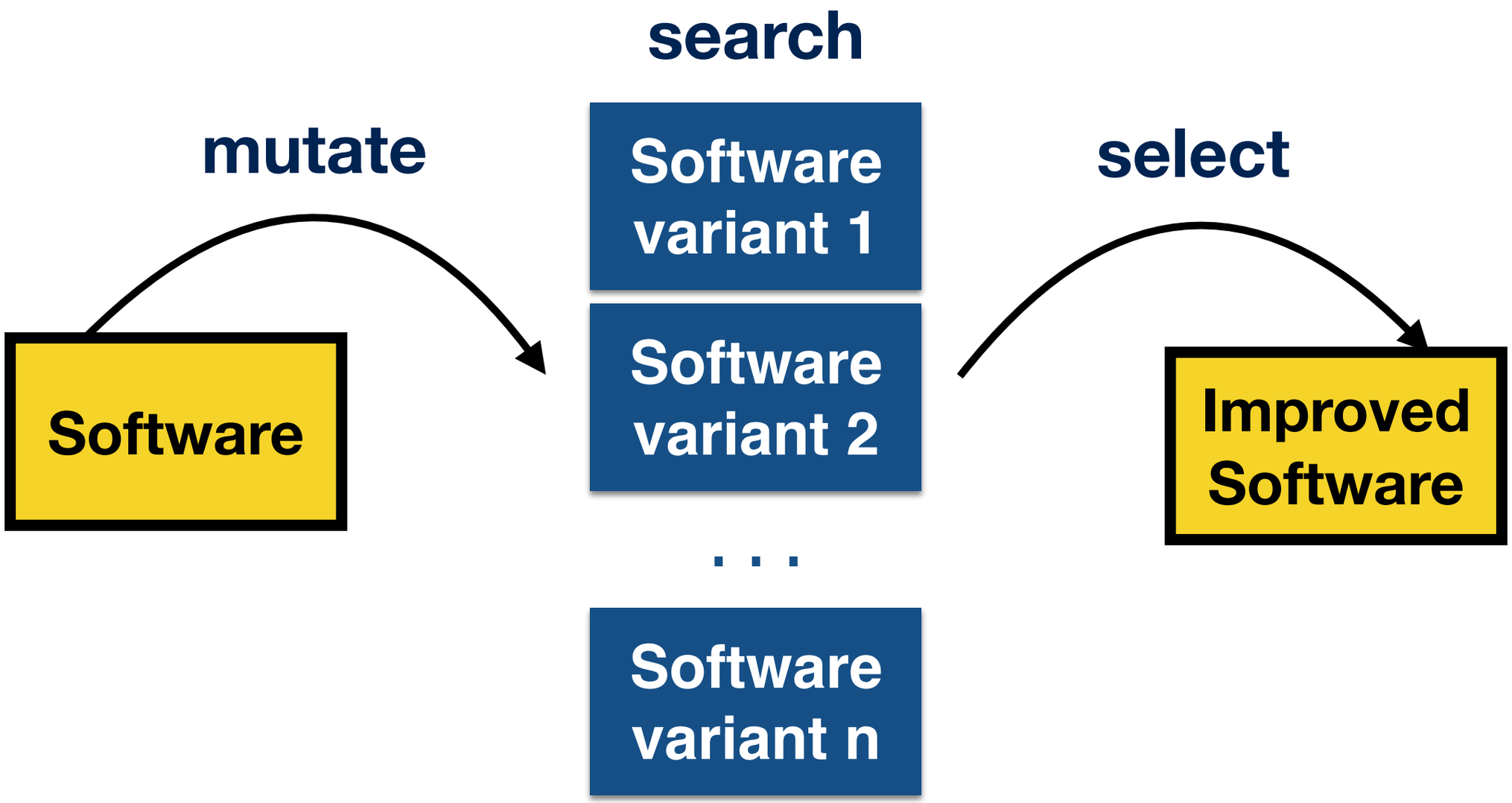
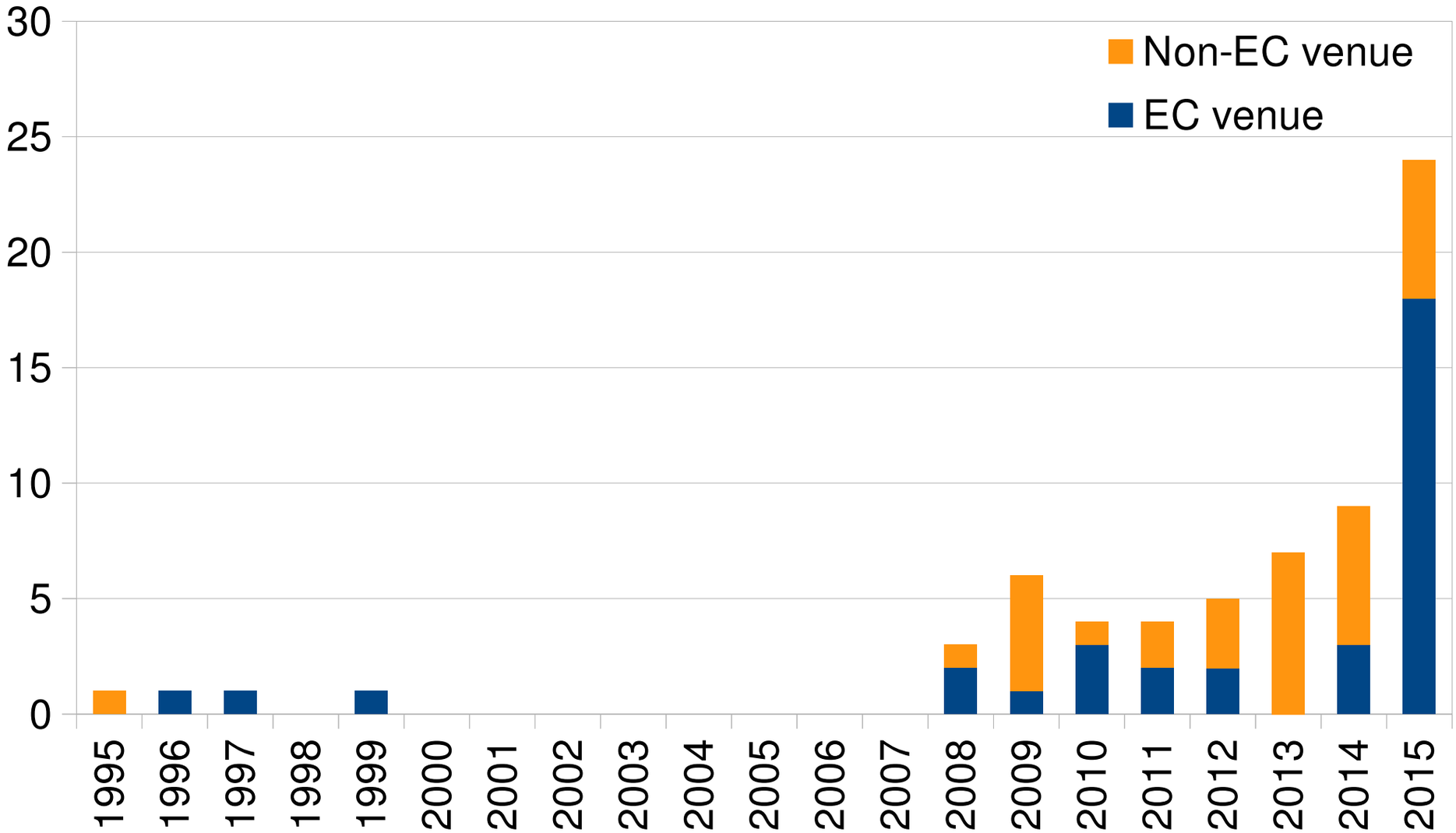
Genetic Improvement

mutates software to find an improved software version



Genetic Improvement of Software: A Comprehensive Survey

Petke et al., Transactions on Evolutionary Computation 2017



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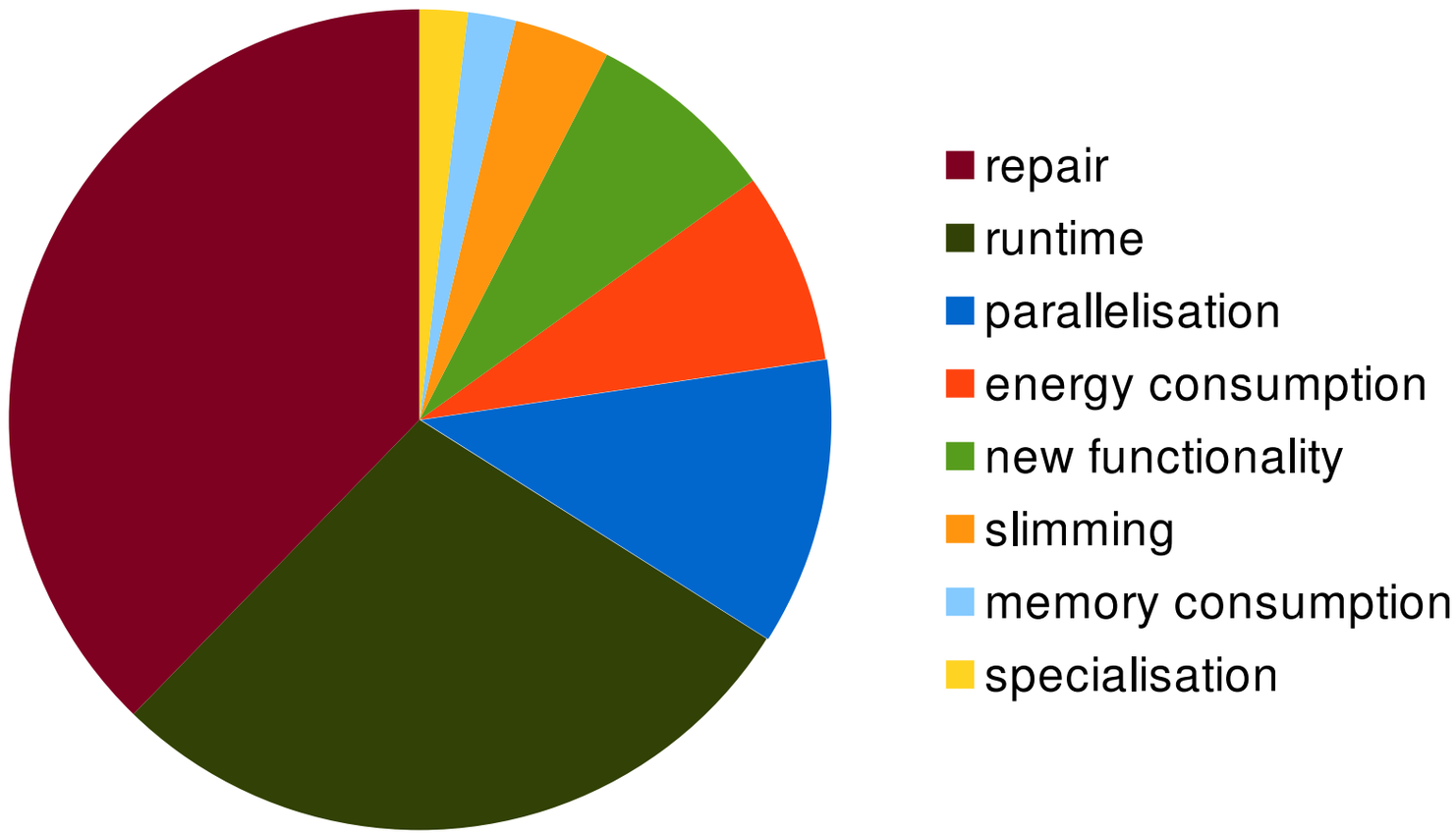
Petke et al., Transactions on Evolutionary Computation 2017



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The Genetic Programming Bibliography

http://gpbib.cs.ucl.ac.uk/

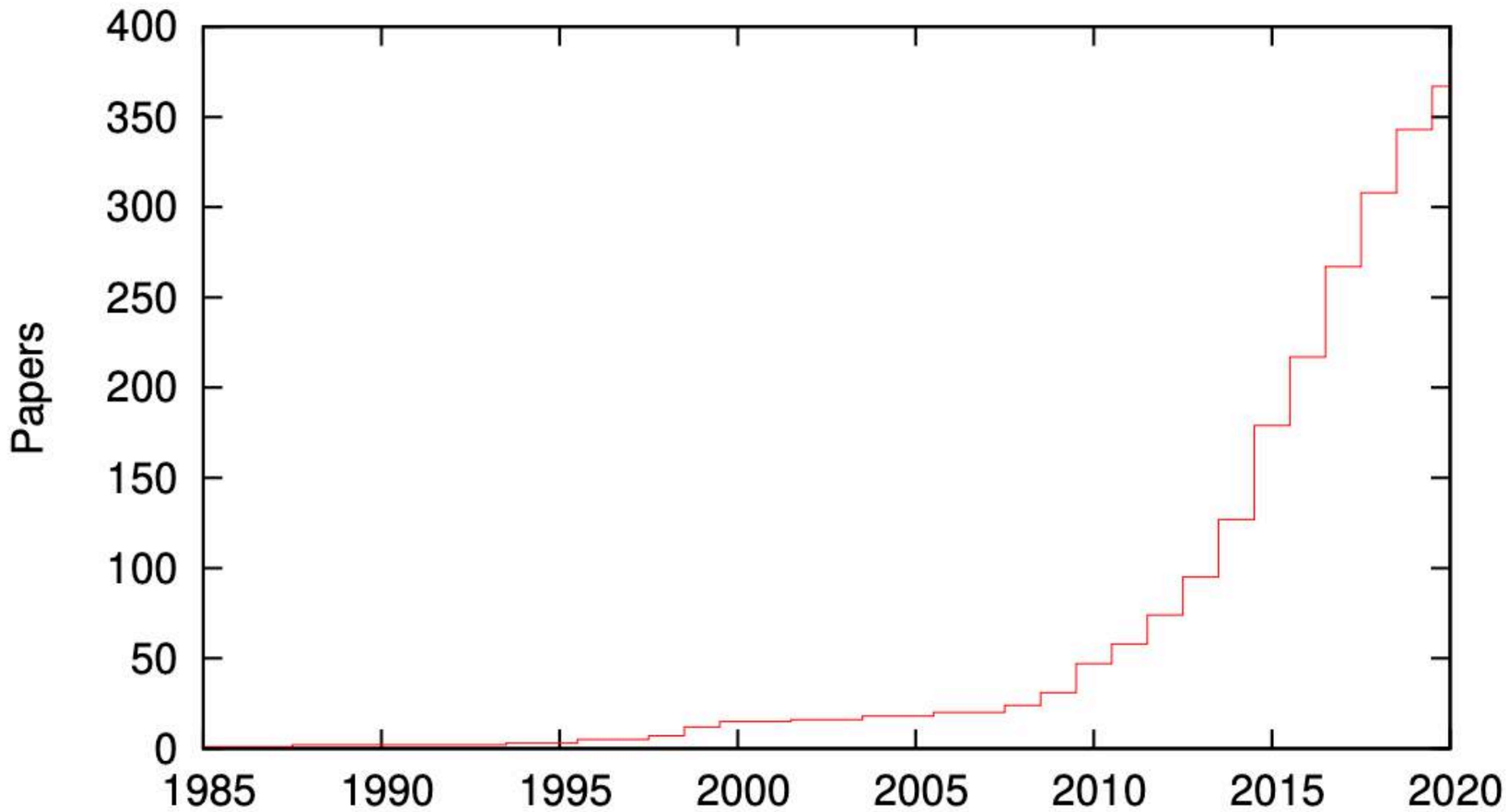

Fig. 1. No. of core papers on genetic improvement by year.

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Example Real-world Applications

Bug fixing:

Janus Manager: “Fixing bugs in your sleep: how genetic improvement became an overnight success” Haraldsson et al. (GI@GECCO 2017)

SapFix (partially): “SapFix: automated end-to-end repair at scale.” Marginean et al. (ICSE-SEIP 2019)

Runtime improvement:

BarraCUDA: “Improving CUDA DNA Analysis Software with Genetic Programming” Langdon et al. (GECCO 2015)

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Automated Software Specialisation: Preliminary Result




“Using Genetic Improvement & Code Transplants to Specialise a C++ Program to a Problem Class”
Justyna Petke, Mark Harman, William B. Langdon & Westley Weimer
17th European Conference on Genetic Programming (EuroGP 2014)

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Human Software Improvement

Satisfiability (SAT) solvers e.g. **MiniSAT**

Used in several application domains:
planning, testing, verification and many other

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Human Software Improvement

Satisfiability (SAT) solvers e.g. **MiniSAT**

Used in several application domains:
planning, testing, verification and many other

Optimised for efficiency by expert human developers

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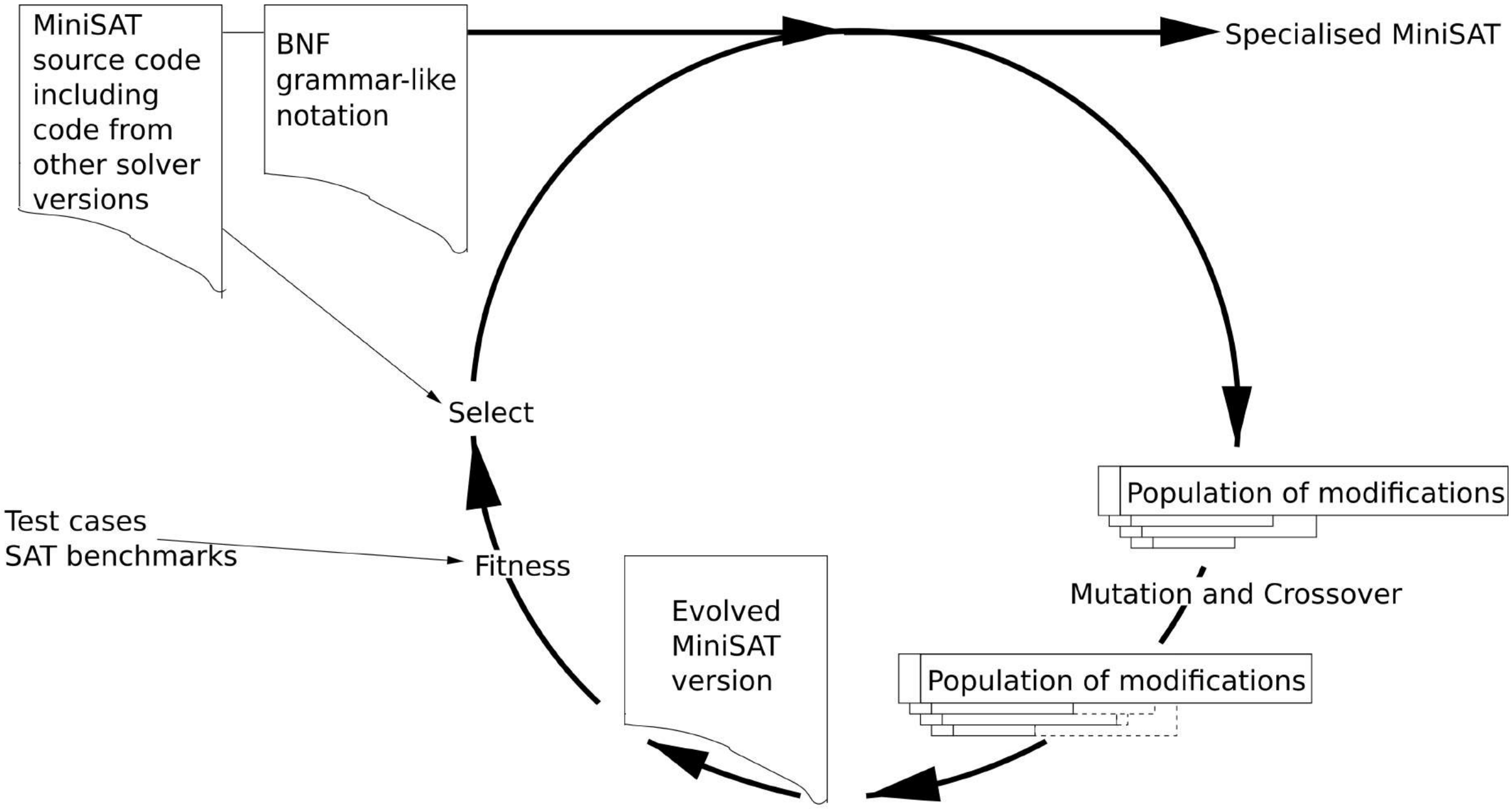
Specialising MiniSAT Using GI

the framework



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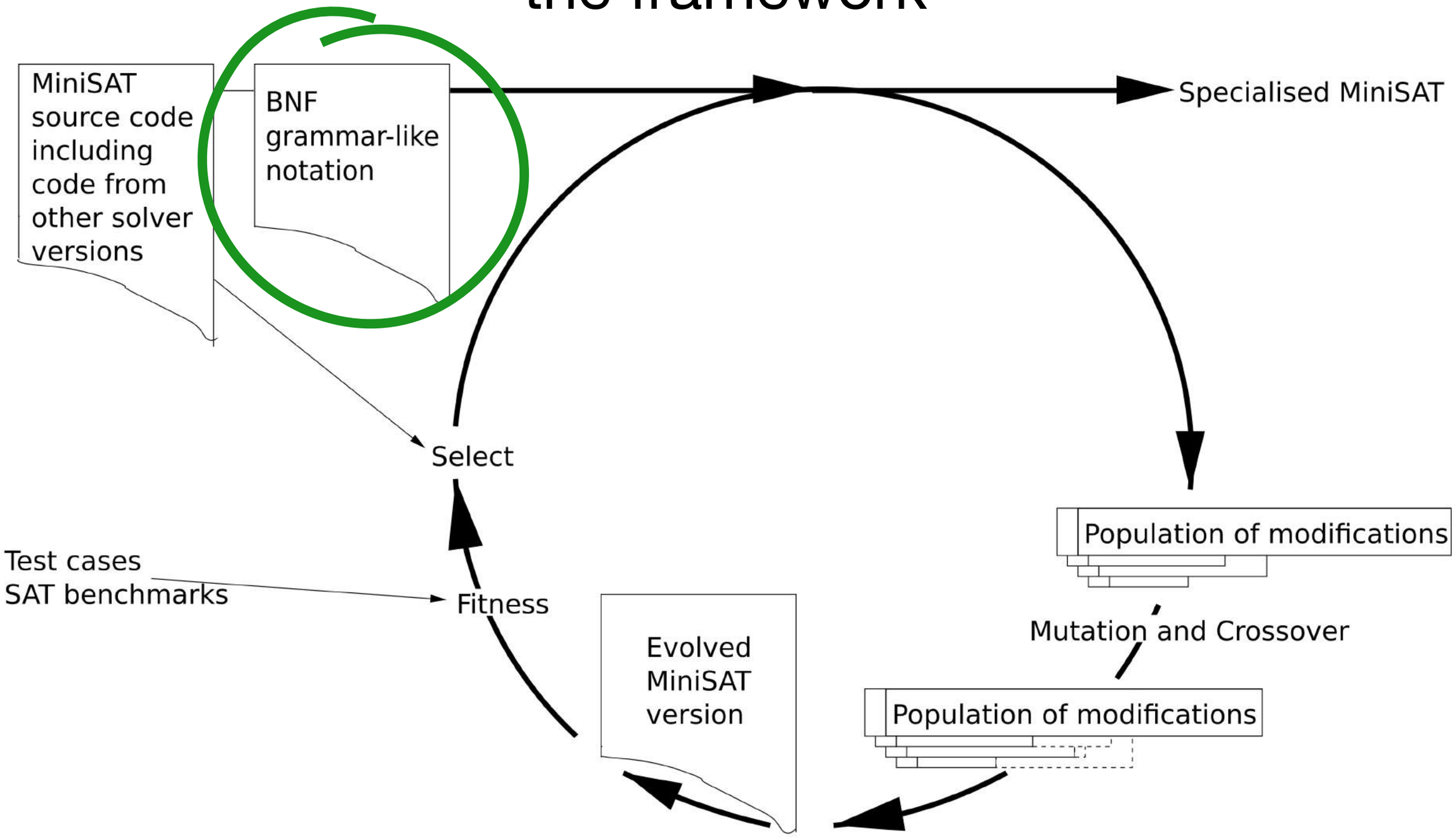
Specialising MiniSAT Using GI

the framework



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Specialising MiniSAT Using GI

software representation

Software representation:

Changes at the level of lines of source code

Each individual is composed of a list of changes

Specialised notation used to preserve syntax

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Specialising MiniSAT Using GI

software representation: example

<Solver_135> ::= " if" <IF_Solver_135> " return false;\n"

<IF_Solver_135> ::= "(!ok)"

<Solver_138> ::= "" <_Solver_138> "{Log_count64++;/*138*/}\n"

<_Solver_138> ::= "sort(ps);"

<Solver_139> ::= "Lit p; int i, j;\n"

<Solver_140> ::= "for(" <for1_Solver_140> ";" <for2_Solver_140> ";" <for3_Solver_140> ") {\n"

<for1_Solver_140> ::= "i=j=,p=lit_Undef"

<for2_Solver_140> ::= "i < ps.size()"

<for3_Solver_140> ::= “i++"

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Specialising MiniSAT Using GI

code transplants

Search (Genetic Programming) has access to both:

the host program to be evolved

the donor program(s)

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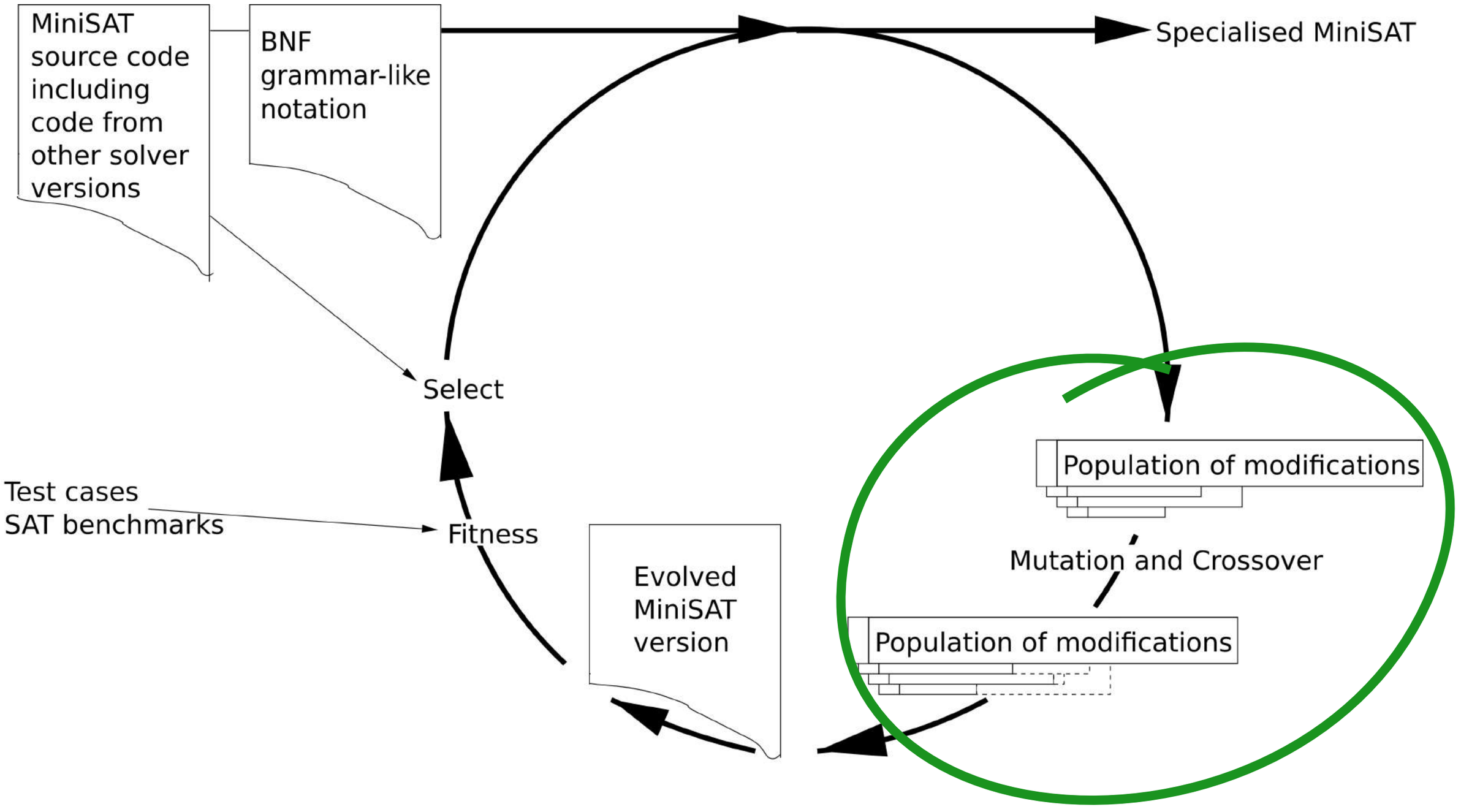
Specialising MiniSAT Using GI

the framework



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Specialising MiniSAT Using GI

mutation

Addition of one of the following operations:

DELETE, COPY or REPLACE

Examples:

<_Solver_135>

<_Solver_138>+<_Solver_140>

<for3_Solver_140><for3_Solver_836>

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Specialising MiniSAT Using GI

crossover

Concatenation of two individuals by appending two lists of mutations

<_Solver_135>

<_Solver_138>+<_Solver_140>

<_Solver_135> <_Solver_138>+<_Solver_140>

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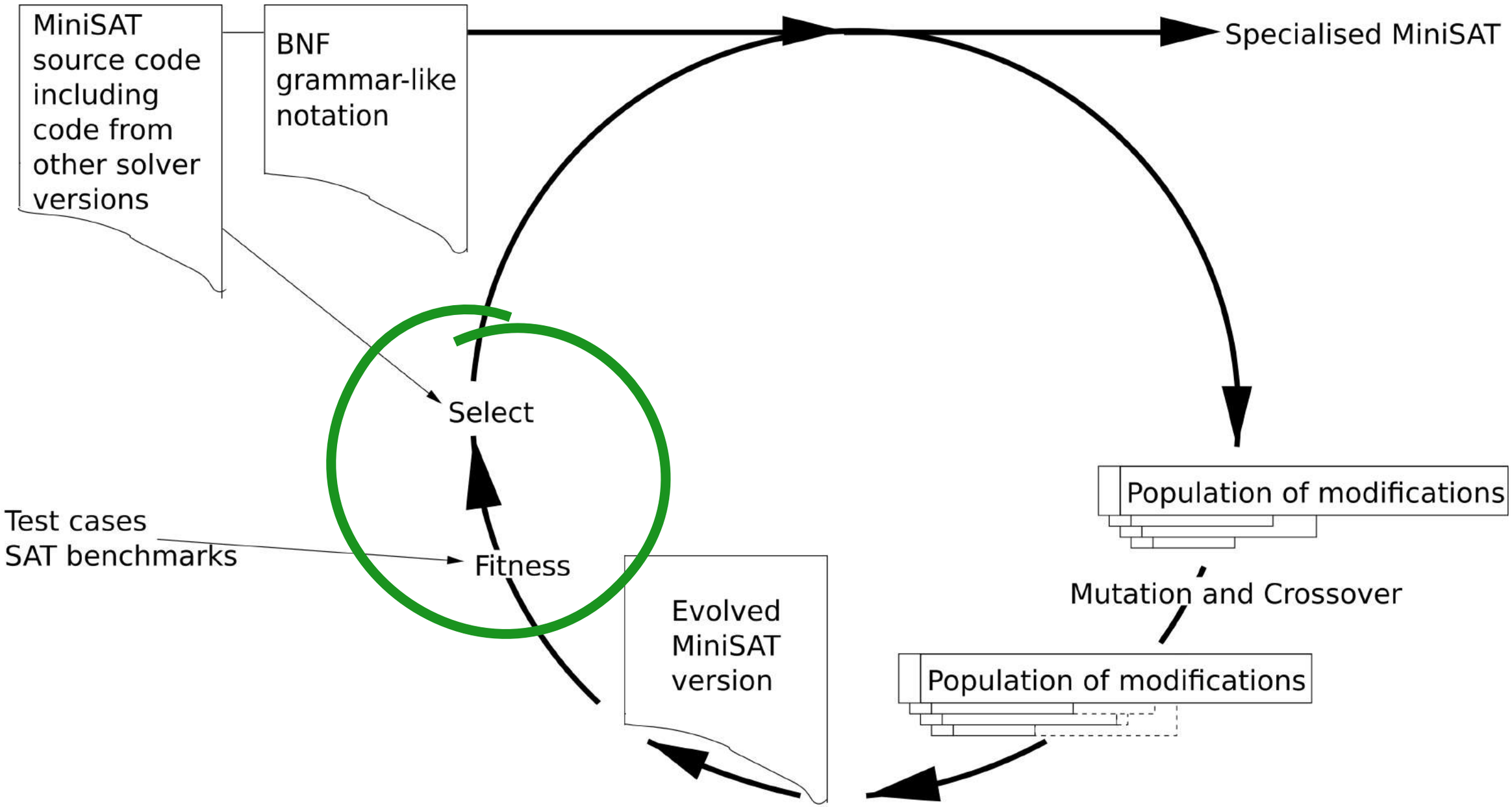
Specialising MiniSAT Using GI

the framework



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Specialising MiniSAT Using GI

fitness

Fitness of each software variant is evaluated by:

Test case result

Runtime on the set of test cases

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Specialising MiniSAT Using GI

selection

Fixed number of generations & fixed population size

Initial population contains single-mutation individuals

Top-half of population selected

Based on a threshold fitness value

Mutation applied with 50% probability

Crossover applied with 50% probability

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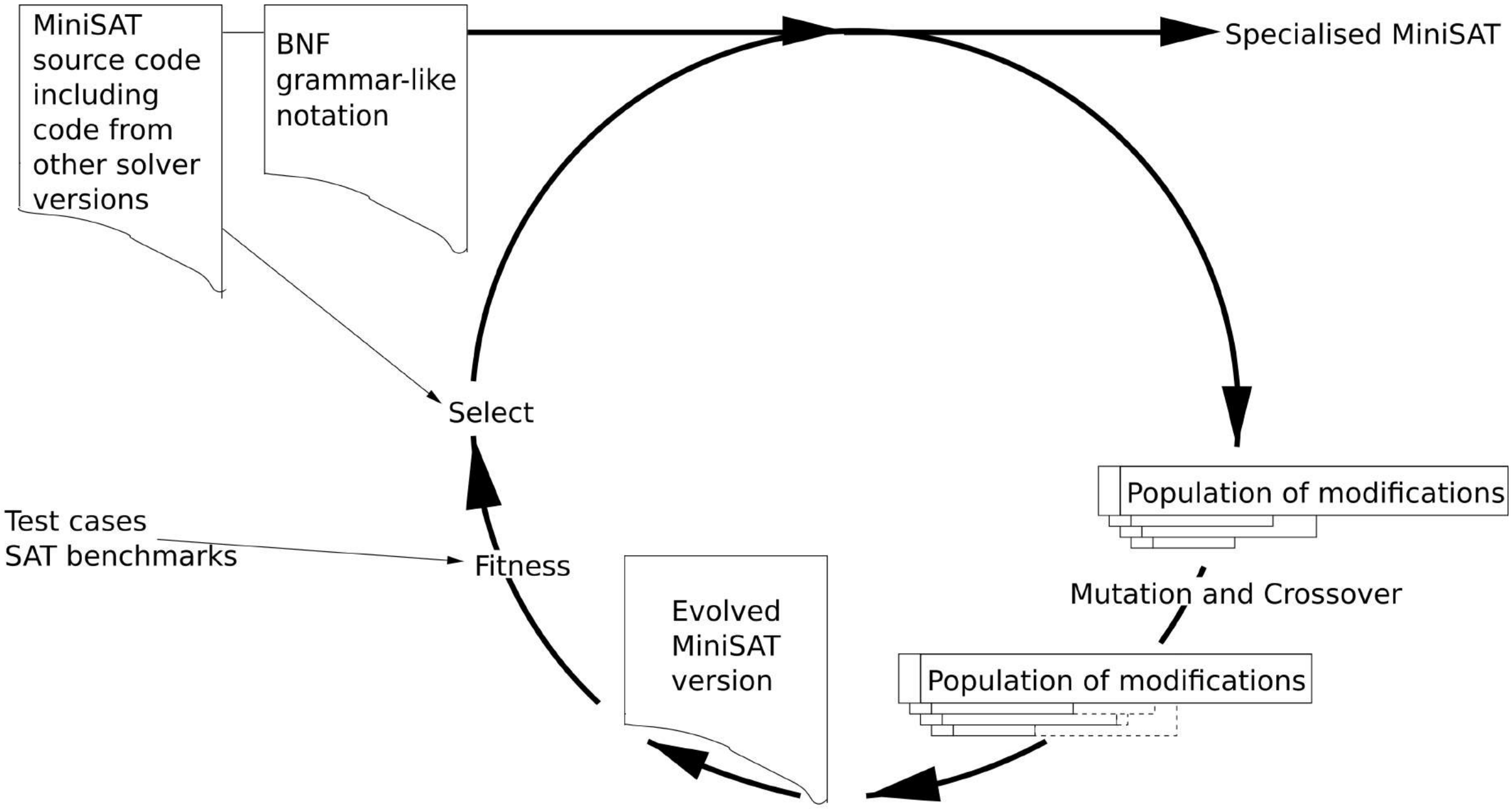
Specialising MiniSAT Using GI

the framework



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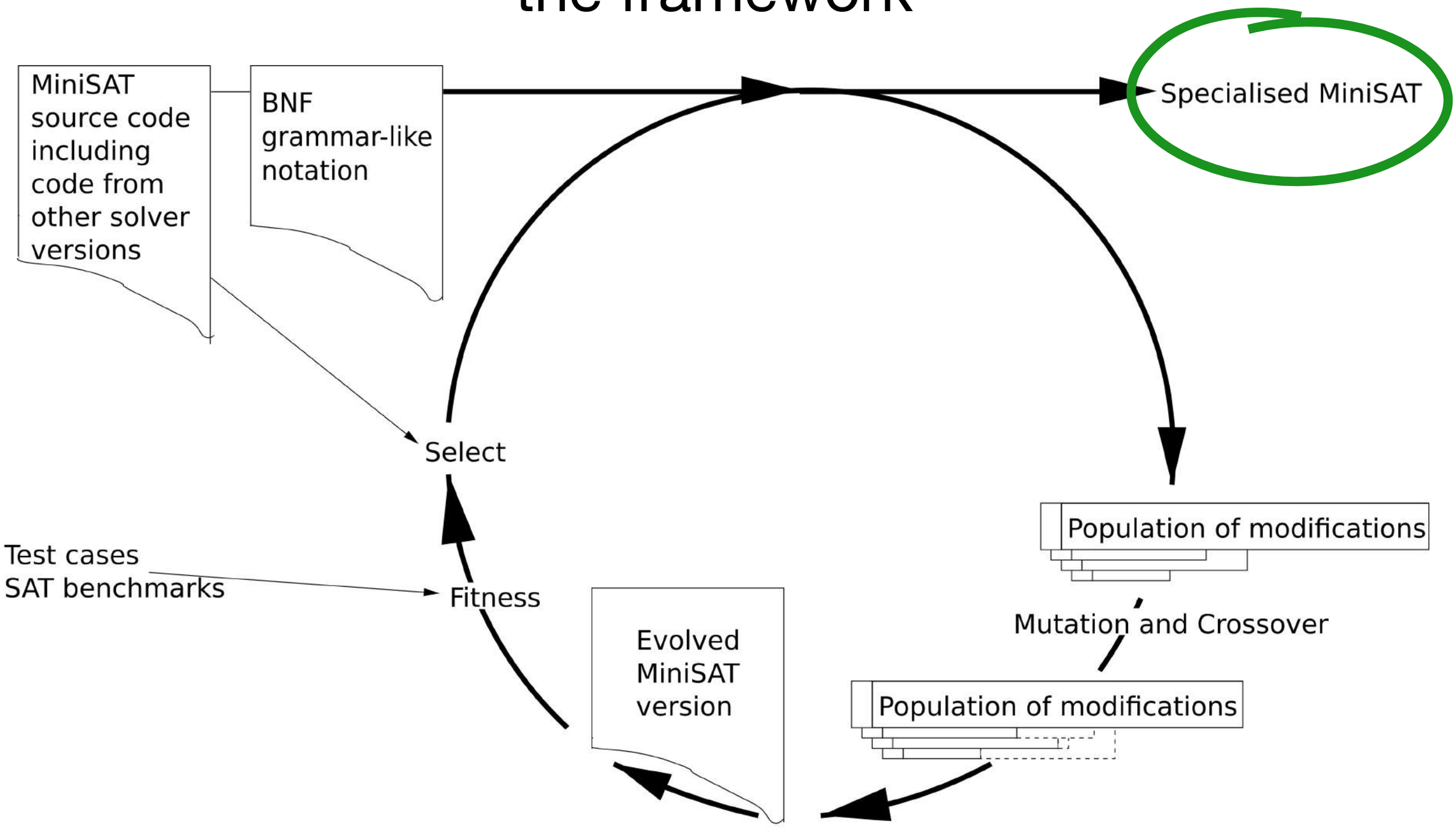
Specialising MiniSAT Using GI

the framework



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Specialising MiniSAT Using GI

filtering step

Mutations in best individuals are often independent

Greedy approach used to combine best individuals

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Results

Improved MiniSAT's performance by 17% by specialising to the set of benchmarks from the Combinatorial Interaction Testing domain

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Reducing Energy Consumption Using Genetic Improvement

“Reducing Energy Consumption Using Genetic Improvement”; Bobby R. Bruce, Justyna Petke & Mark Harman; 27th International Genetic and Evolutionary Computation Conference (GECCO 2015)

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Reducing Energy Consumption Using Genetic Improvement

up to 25% energy consumption reduction achieved when specialising for different application domains

MiniSAT Satisfiability Solver

"Reducing Energy Consumption Using Genetic Improvement"; Bobby R. Bruce, Justyna Petke & Mark Harman; 27th International Genetic and Evolutionary Computation Conference (GECCO 2015)

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Specialising Software Using GI

Petke et al.,Transactions on Software Engineering (TSE) 2017

up to 3% improvement
achieved when
specialising for different
application domains

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A few findings

Both problem-specific and general changes were produced by GI

Modifying the crossover/mutation rates has had no significant impact on the results

No obvious increase in the fitness value between generations has been observed

In some cases allowing GI to let slightly faulty versions to go to the next generation helped GI in finding an improved software version

Interactions between various mutations have been observed

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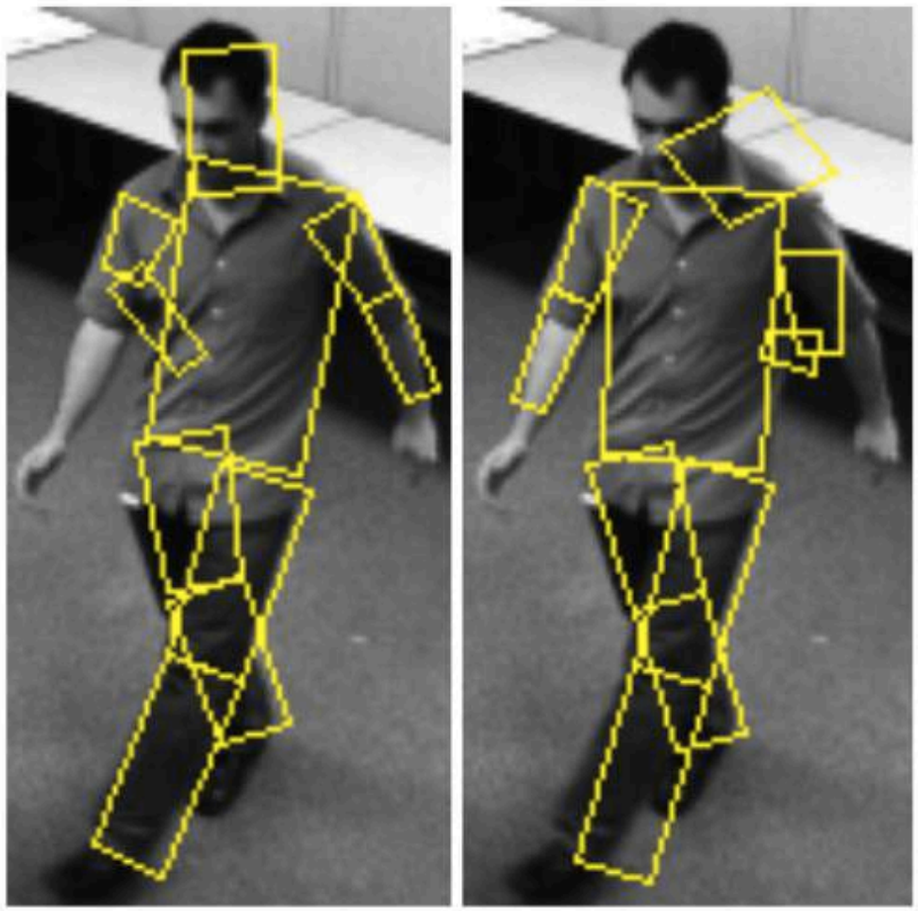
Reducing Energy Consumption Using Genetic Improvement

original picture produced by body-tracking software



picture produced by software variant with 33% energy consumption reduction

Bobby R. Bruce, Justyna Petke, Mark Harman, and Earl T. Barr “Approximate Oracles and Synergy in Software Energy Search Spaces”, IEEE Transactions on Software Engineering (TSE 2017)

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Reducing Energy Consumption Using Genetic Improvement

A few findings:

The number of effective modifications in the GI search space is scarce, but increases 15-fold if approximation is allowed

Pairings of effective modifications often do not produce a positive effect

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Automated Software Transplantation

Idea: add a new feature to the software by transplanting it from a different piece of software

“Automated Software Transplantation”; Earl T. Barr, Mark Harman, Yue Jia, Alexandru Marginean & Justyna Petke; 24th International Symposium on Software Testing and Analysis (ISSTA 2015)

ACM SIGSOFT Distinguished Paper Award Winner

Gold `Humie’ Winner at GECCO 2016

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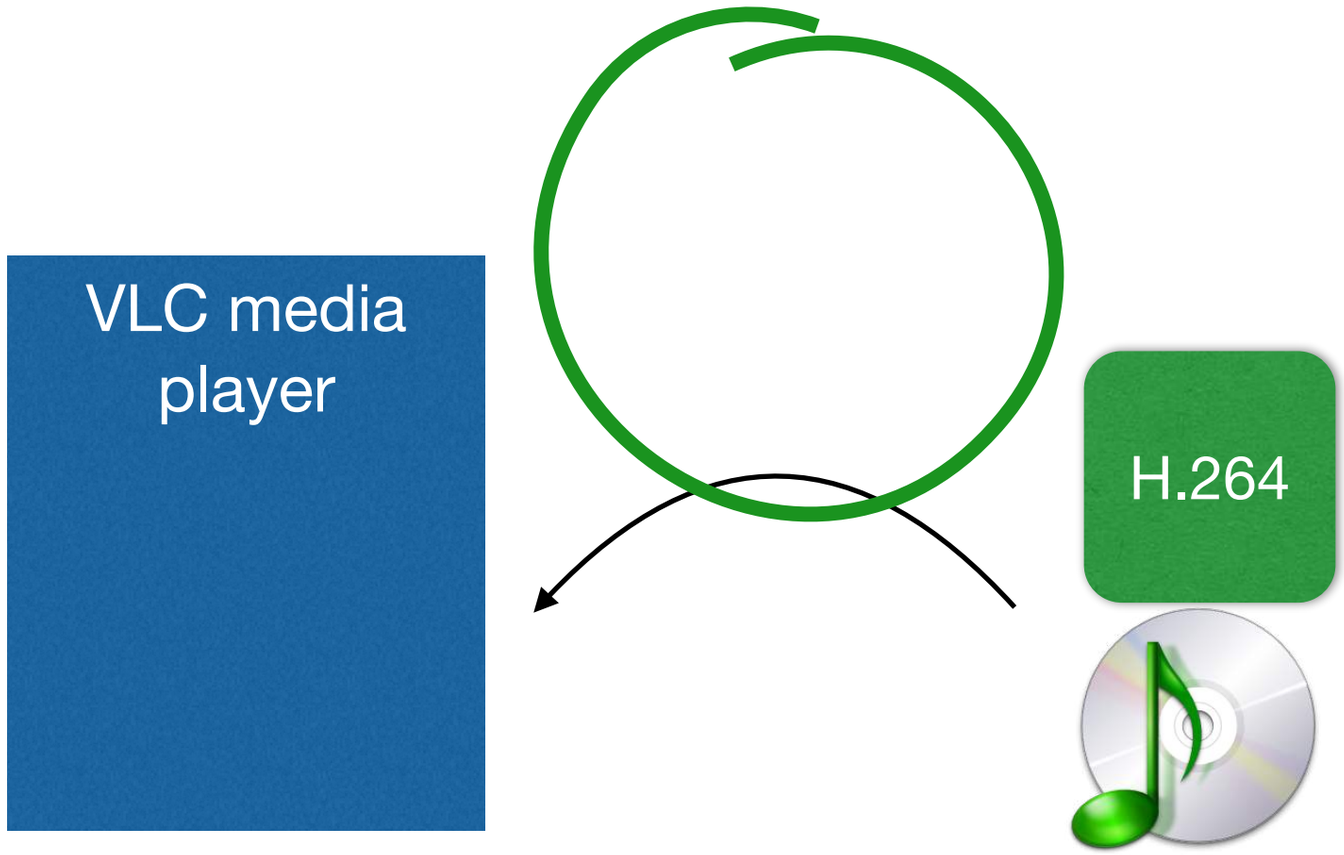
Automated Software Transplantation



Transplanted the H.264 video encoding functionality in 26 h of computation time
(compared with estimated 20 days of human effort)

Justyna Petke, UCL

Appeared at ISSTA 2015

- Overview
- Preprint
- MuScalpel
- Subjects
- Test Suites
- Artifact Evaluation
- SSBSE 2015

muScalpel

Implemented in TXL and C, muScalpel realizes μTrans and comprises 28k SLoCs, of which 16k is TXL, and 12k is C. muScalpel implements a custom version of GP. Unlike conventional GP, which creates an initial population from individuals that contain multiple statements, muScalpel generates an initial population of individuals with just 1 statement, uniformly selected. muScalpel's underlying assumption is that our organs need very few of the statements in their donor. Starting from one LOC gives muScalpel the possibility to find small solutions quickly. muScalpel focuses on evolving the organ's vein. muScalpel also inherits the limitations of TXL, such as its stack limit which precludes parsing large programs and its default C grammar's inability to properly handle preprocessor directives.

As we all know, software is often difficult to build and run, due to dependencies on its development environment and target platform. muScalpel is no exception. Please keep in mind that we built and ran muScalpel only on 64-bit Ubuntu 14.04 LTS machine, with 16 GB RAM, SSD and 8 physical cores, with its TXL v10.6a-64 (14.7.13), gcc-4.8, cflow (GNU cflow) 1.4 installed. Any other configurations may have affect on the results of the replication of our experiments.

This website contains the source for muScalpel, muScalpel in binary form, and the data sets, including test suites, that underlie our experiments. To facilitate replicating our results, we have written a sequence of **scripts** that run a *single* run of each of our experiments. The name of the script identifies the experiment. We have worked hard to make each script bullet-proof and have it thoroughly check your environment for its dependencies and tell you what, if anything, is missing. Despite our best efforts, you may still encounter problems. If that happens, please contact us so we can work with you to resolve them.

Experiment Scripts

- Link to a script that runs all our experiments, as submitted to ISSTA 2015 artifact evaluation track. Here we also provide a dockerized version of our experiments.
  - **All experiments:** : Download

http://crest.cs.ucl.ac.uk/autotransplantation/MuScalpel.html

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Genetic Improvement Frameworks

Gin https://github.com/gintool/gin

PyGGI https://github.com/coinse/pyggi

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Gin 

An extensible and modifiable toolbox for GI experimentation

Automatically transforms, builds, and tests Java projects

Supports automated test-generation & source code profiling

Scales to large real-world projects

Alexander E. I. Brownlee, Justyna Petke, Brad Alexander, Earl T. Barr, Markus Wagner, David R. White: “Gin: genetic improvement research made easy”, Genetic and Evolutionary Computation Conference (GECCO 2019)

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Gin 

Automated profiling to link tests with methods

Dynamic class loading and test case execution

Compilation & test execution performed entirely within memory to improve performance

Support for Maven & Gradle projects

Automated test case generation & runtime manipulation

Detailed reports on JUnit test results

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Gin 

Changes at the line & statement level

Supports expression-level changes

Supports constrained edits to nodes of the same type

Changes: Delete, Replace, Copy, Swap, Move

Gin 

First results:

case study on Gson (with added GP implementation)

Gin fixed injected bugs

Gin found an edit that improved runtime

Justyna Petke, Alexander E. I. Brownlee: Software Improvement with Gin: A Case Study. Symposium on Search Based Software Engineering (SSBSE 2019)

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PyGGI 

Python General Genetic Improvement Framework

Supports line- & statement-level changes

Copy/delete/replace supported

Simple, short scripts needed to run

Gabin An, Aymeric Blot, Justyna Petke, Shin Yoo: "PyGGI 2.0: Language Independent Genetic Improvement Framework”, European Software Engineering Conference and Symposium on the Foundations of Software Engineering (ESEC/FSE 2019)
demo: https://www.youtube.com/watch?v=PxRUdlRDS40&feature=youtu.be

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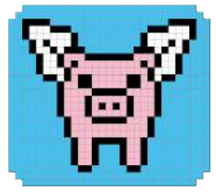
PyGGI 

XML tree representation

Supports multiple programming languages (inc. Python)

Build-in support for srcML (C++, C, C#, Java)

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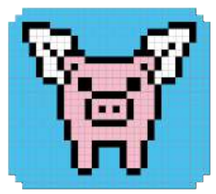
PyGGI 

Bug fixes found

Previous results on runtime improvement replicated

Gabin An, Aymeric Blot, Justyna Petke, Shin Yoo: "PyGGI 2.0: Language Independent Genetic Improvement Framework”, European Software Engineering Conference and Symposium on the Foundations of Software Engineering (ESEC/FSE 2019)
demo: https://www.youtube.com/watch?v=PxRUdlRDS40&feature=youtu.be

Genetic Improvement of Software

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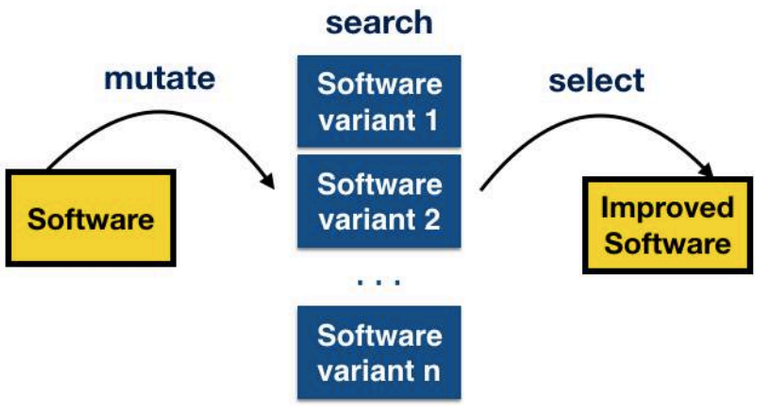
Genetic Improvement

mutates software to find an improved software version



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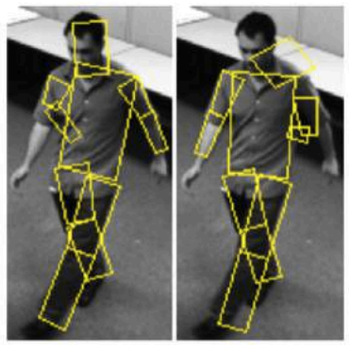
Reducing Energy Consumption Using Genetic Improvement

original picture produced by body-tracking software



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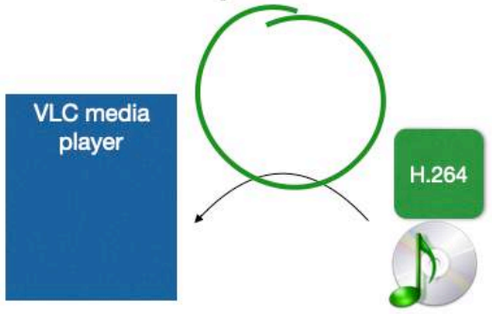

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