Revolutionising the process of software development

Justyna Petke

Centre for Research in Evolution, Search and Testing
University College London

CREST

Genetic Improvement of Software

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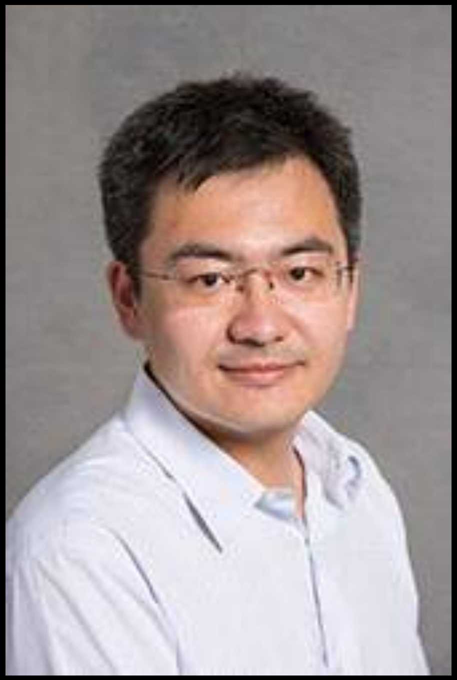
Thank you



Mark Harman Yue Jia Alexandru Marginean

CREST

What does the word "Computer" mean?

Oxford Dictionary

"a person who makes calculations, especially with a calculating machine."

Wikipedia

"The term "computer", in use from the mid 17th century, meant "one who computes": a person performing mathematical calculations."

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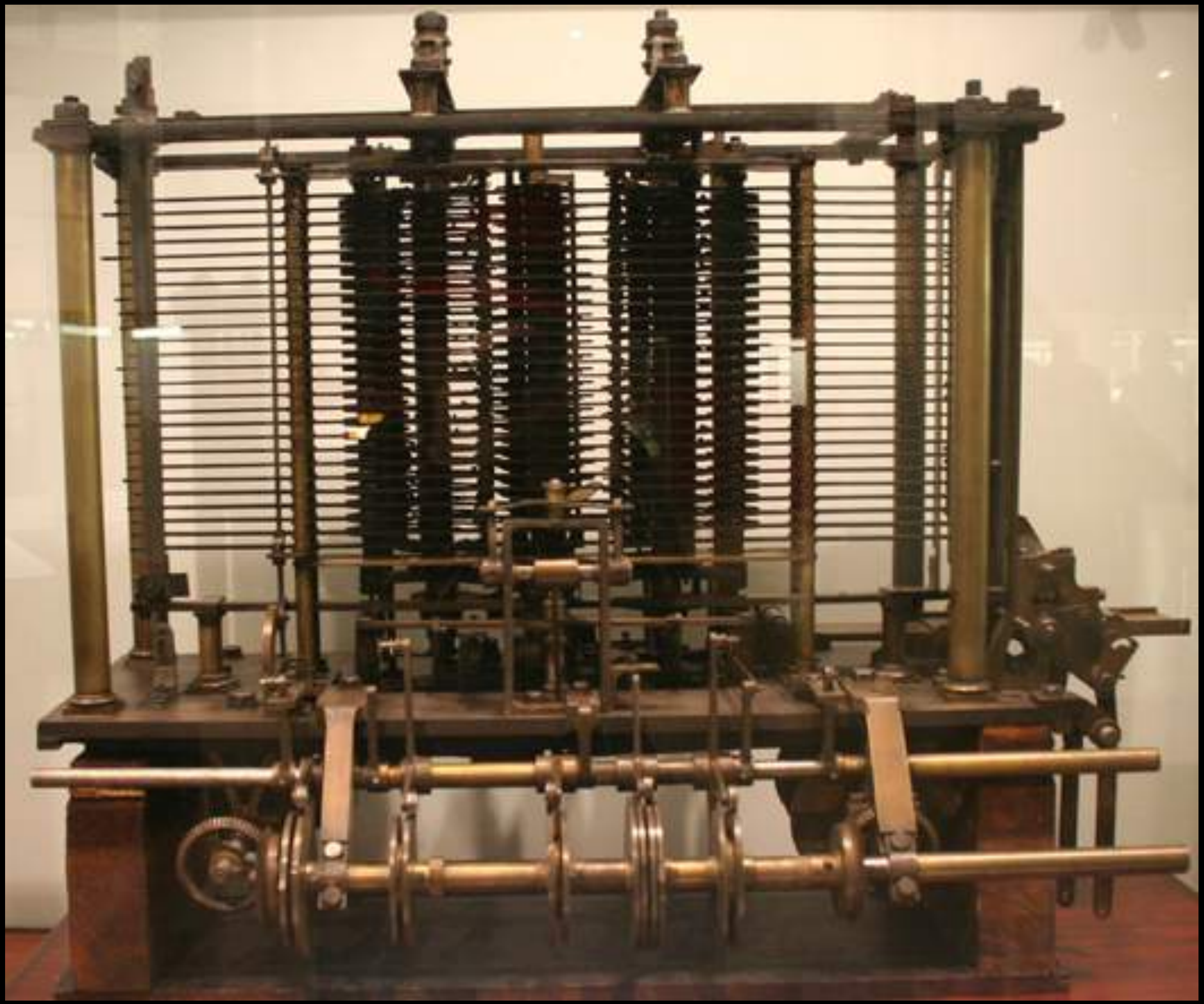
Who are the programmers

Who are the programmers

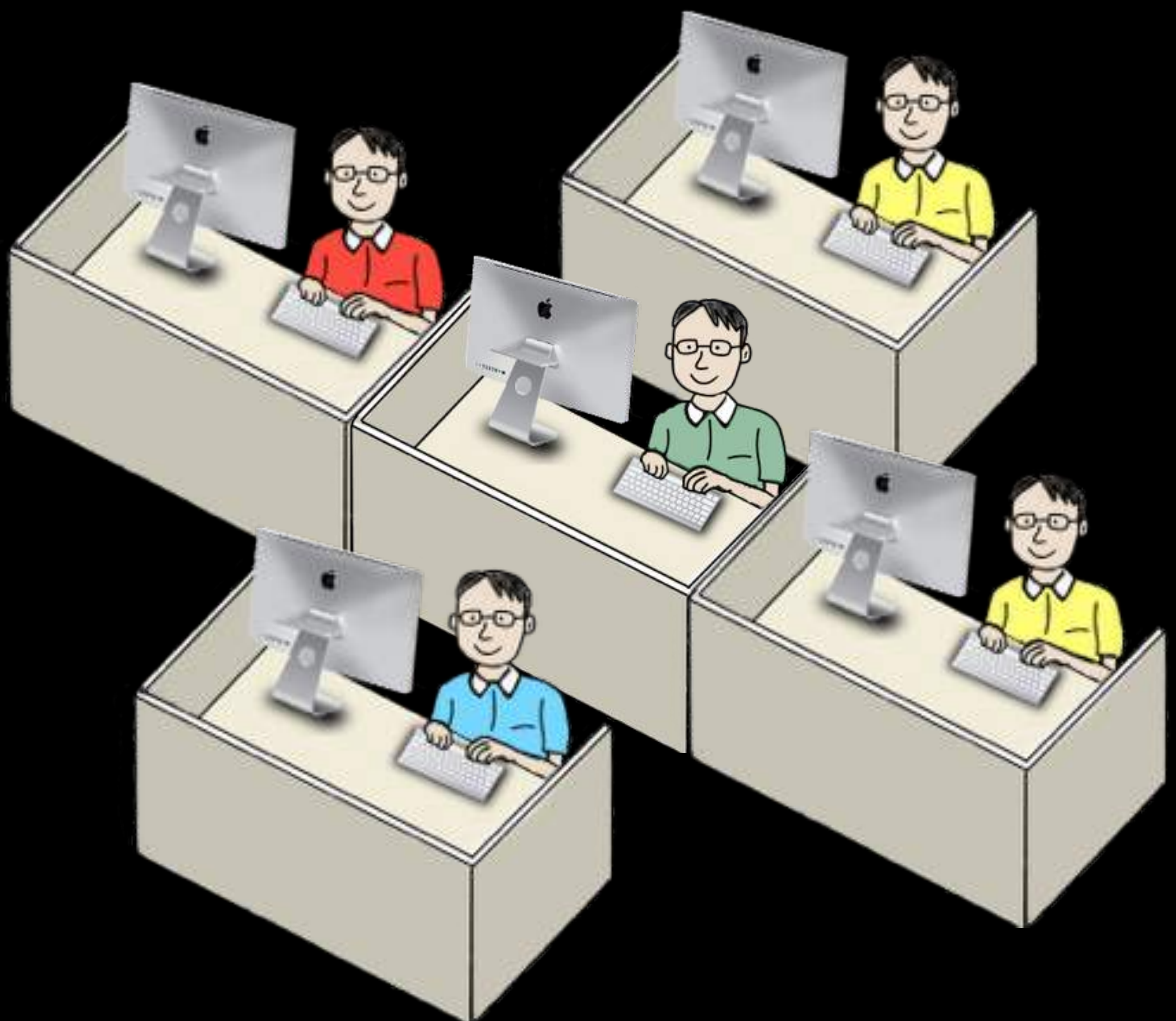


Who are the programmers

Who are the programmers

it's always been people

Who are the programers



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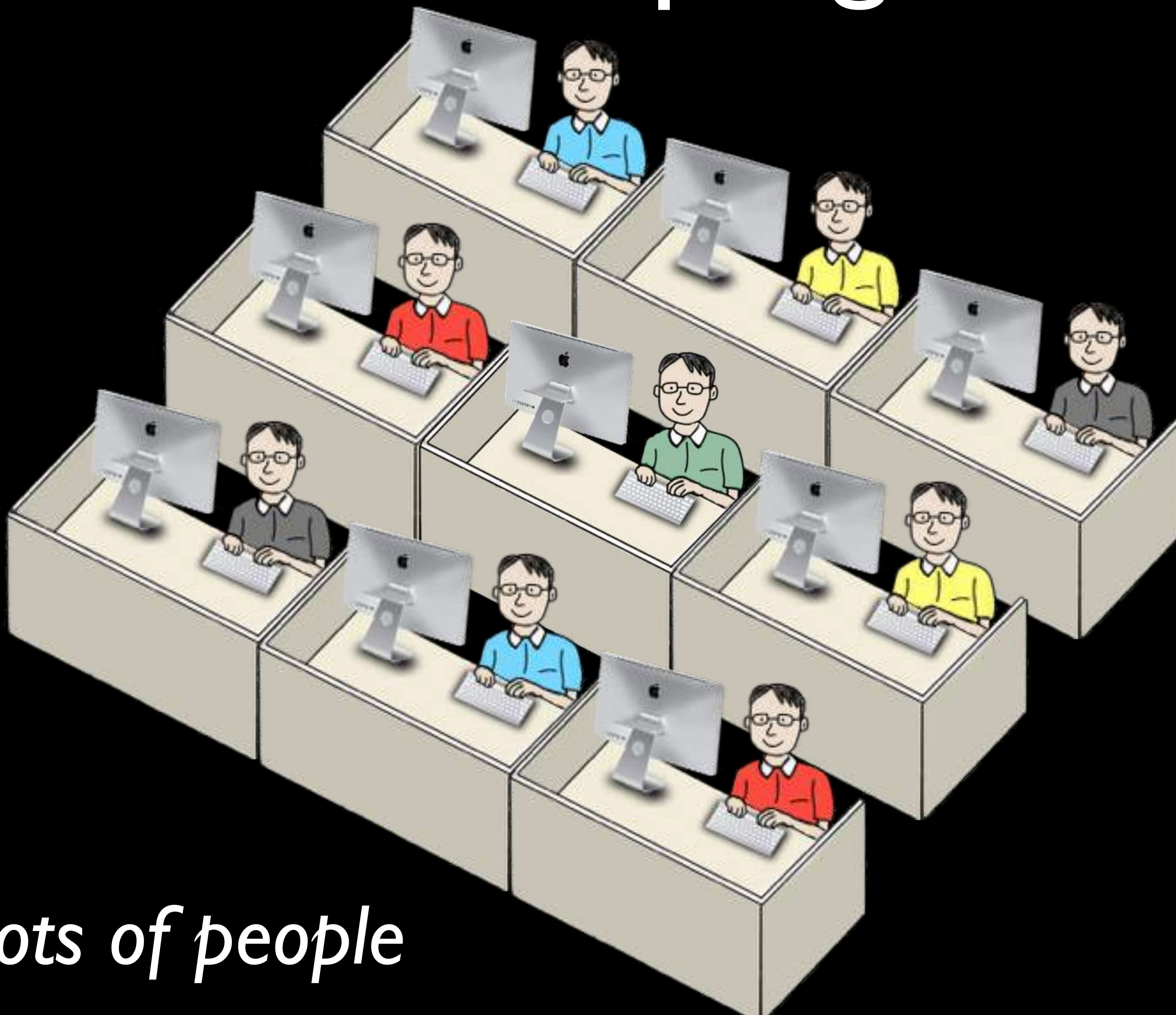
Who are the programers



lots of people

Why people?

human computers seem quaint today

will human programmers seem quaint tomorrow ?

programming is changing

Functional Requirements

Non-Functional Requirements

Requirements

Functional Requirements

functionality of the Program

Non-Functional Requirements

Execution Time

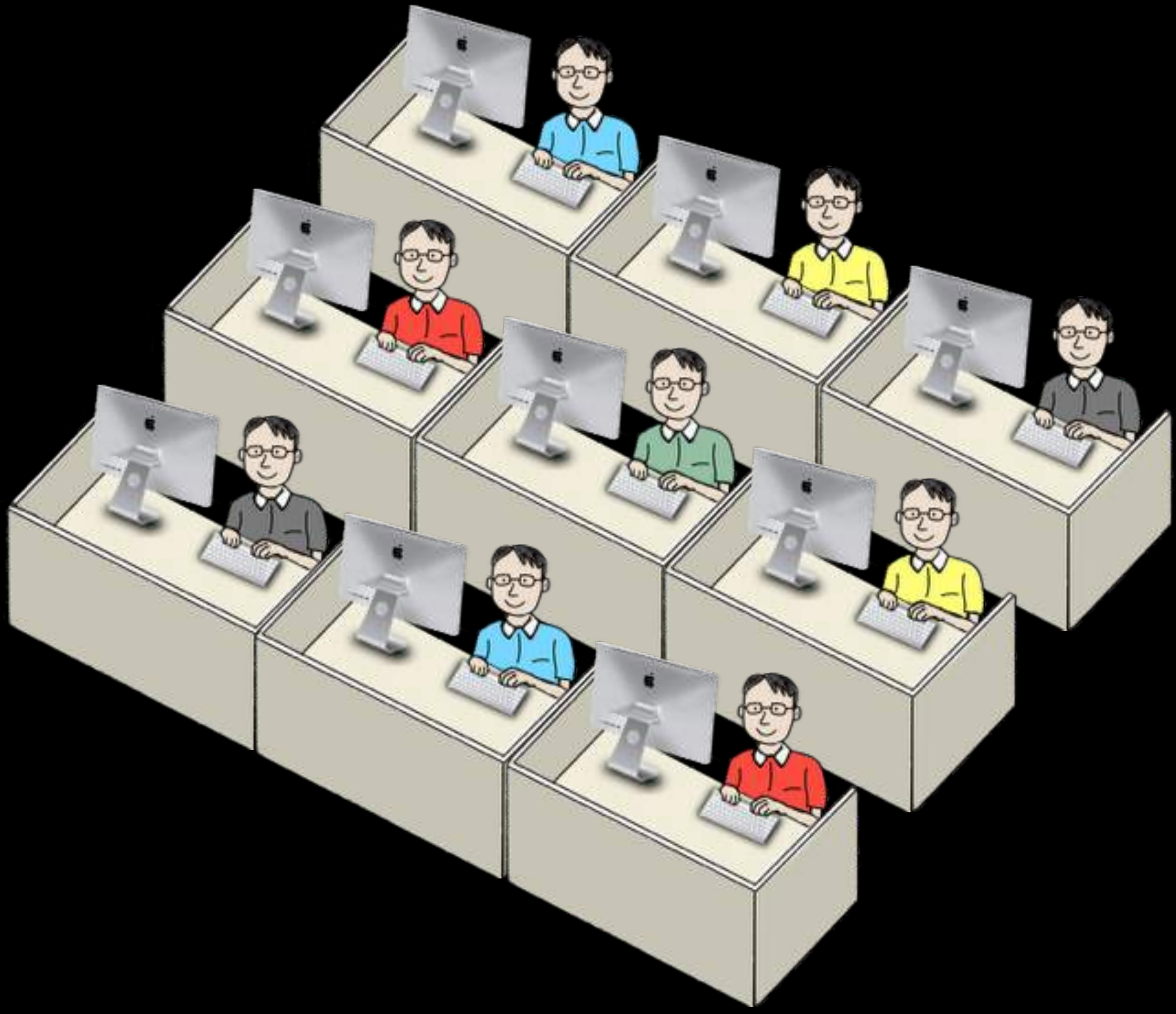
Memory

Bandwidth

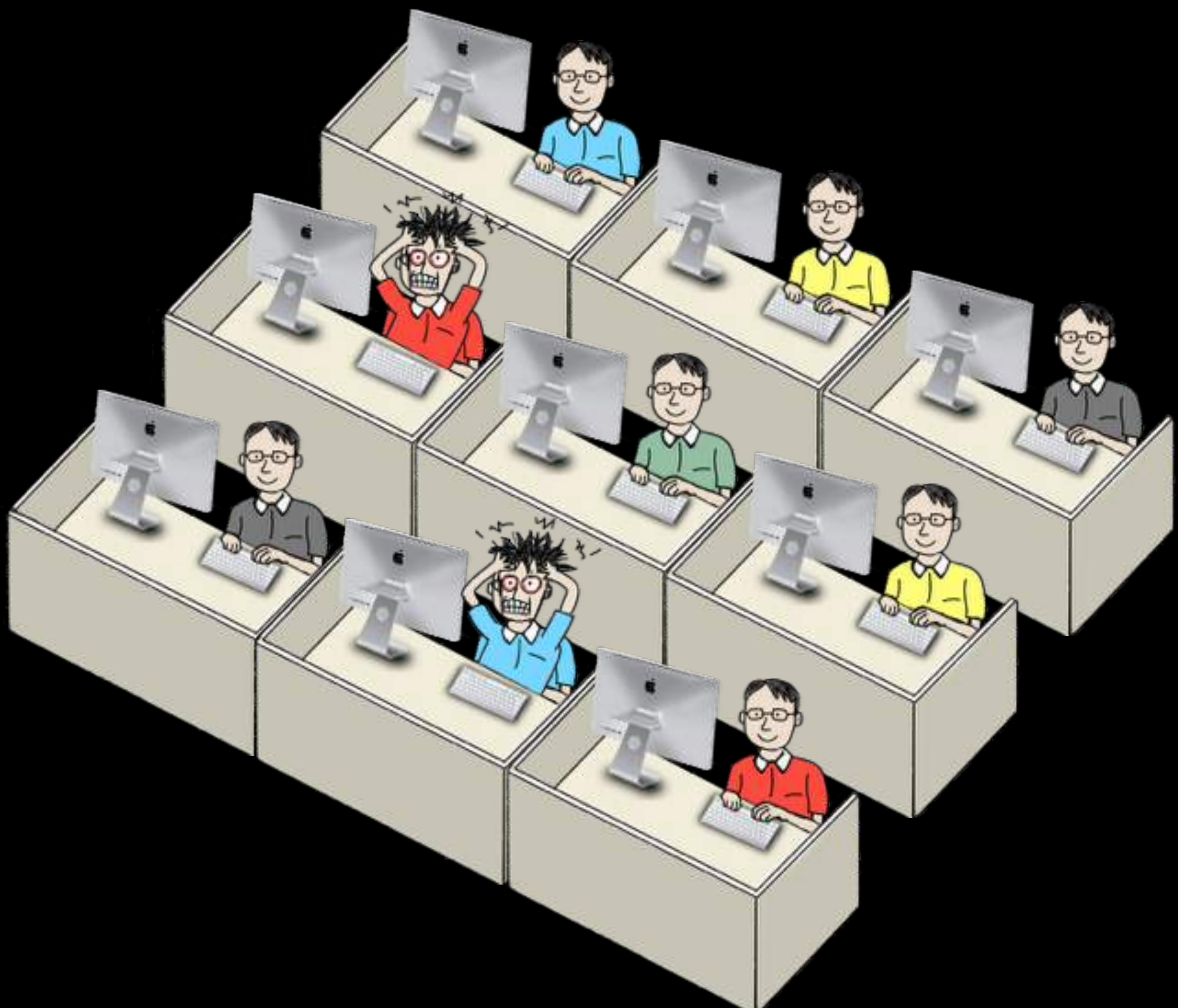
Energy

Size

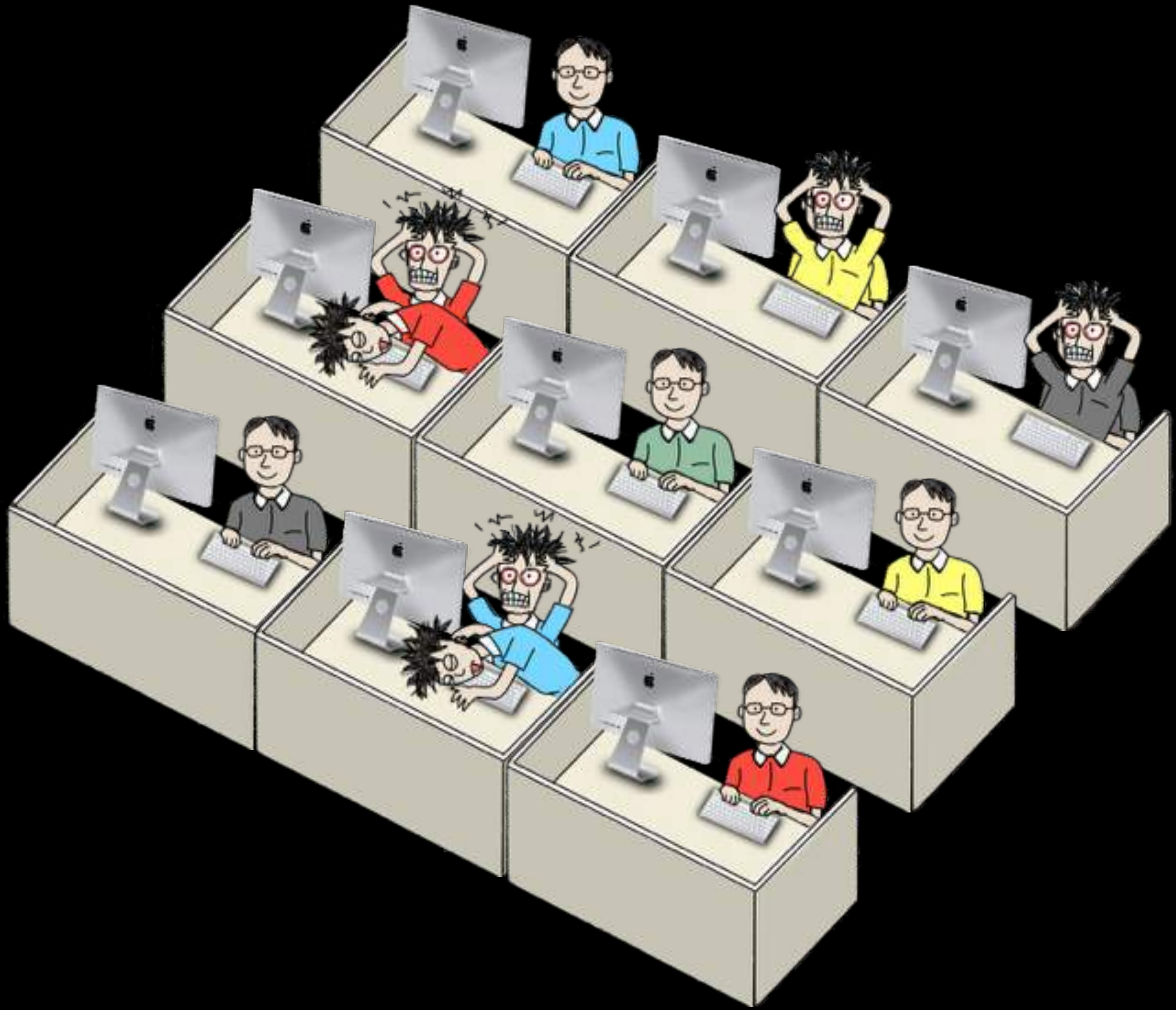
Software Design Process



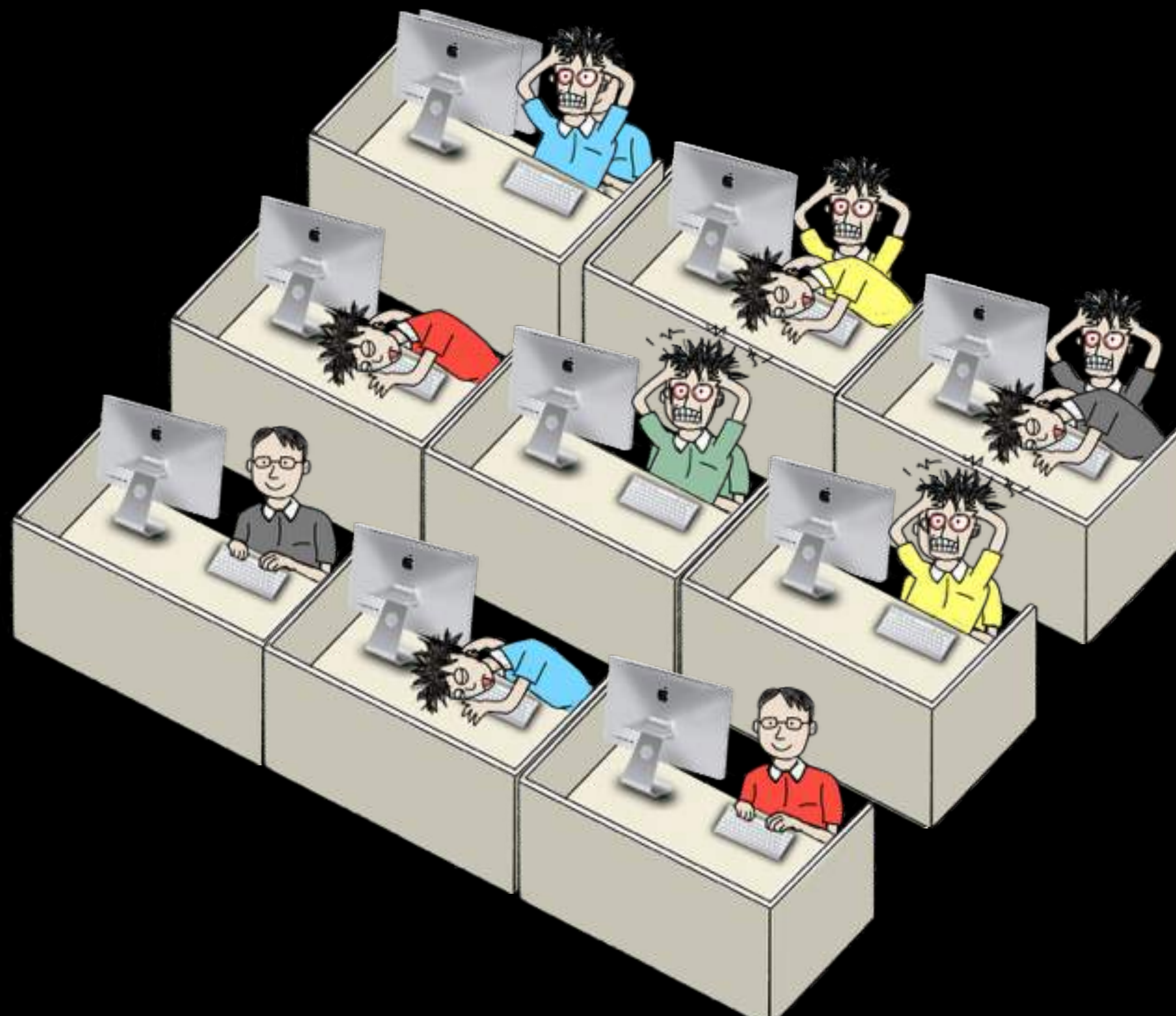
Software Design Process



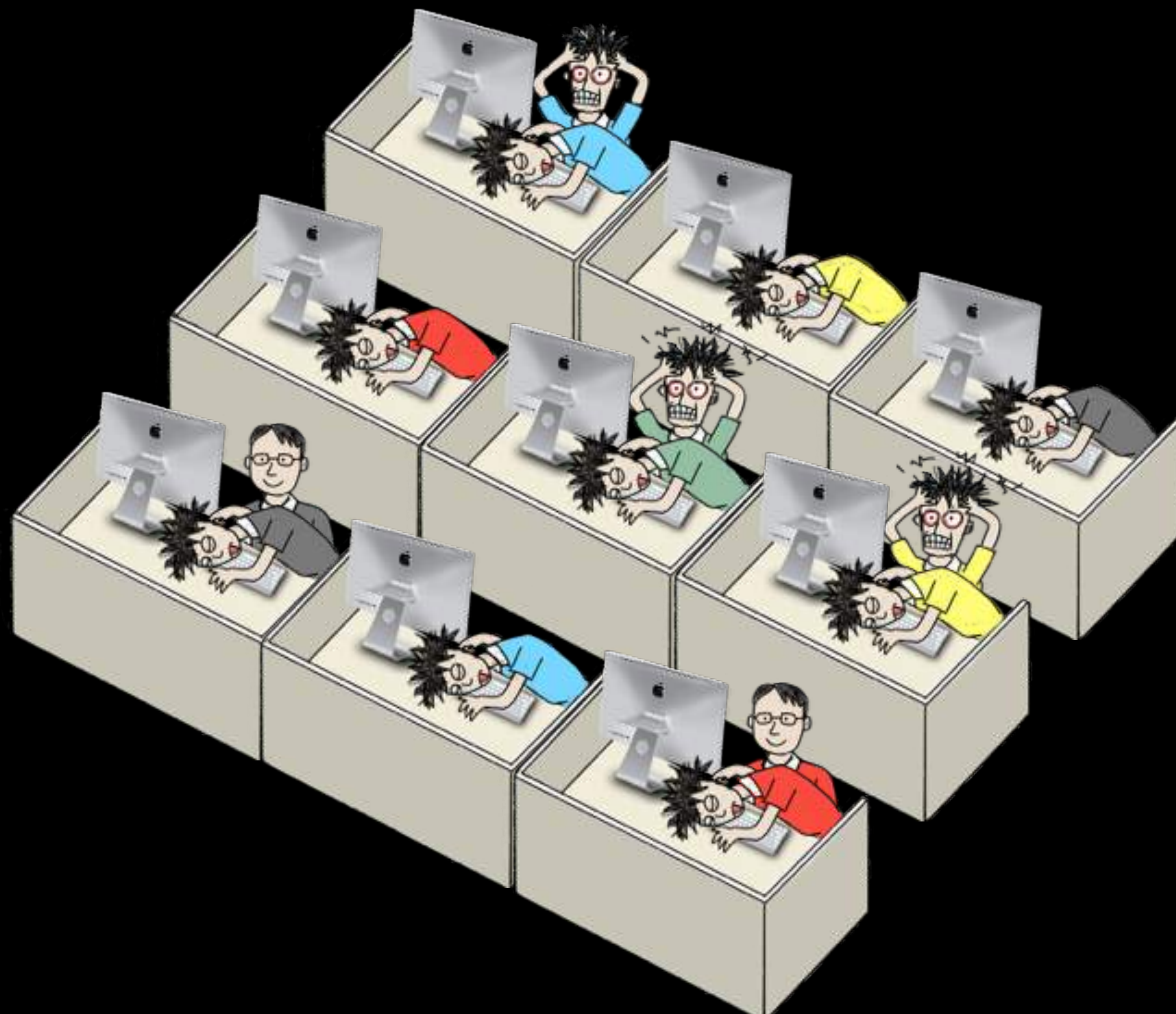
Software Design Process



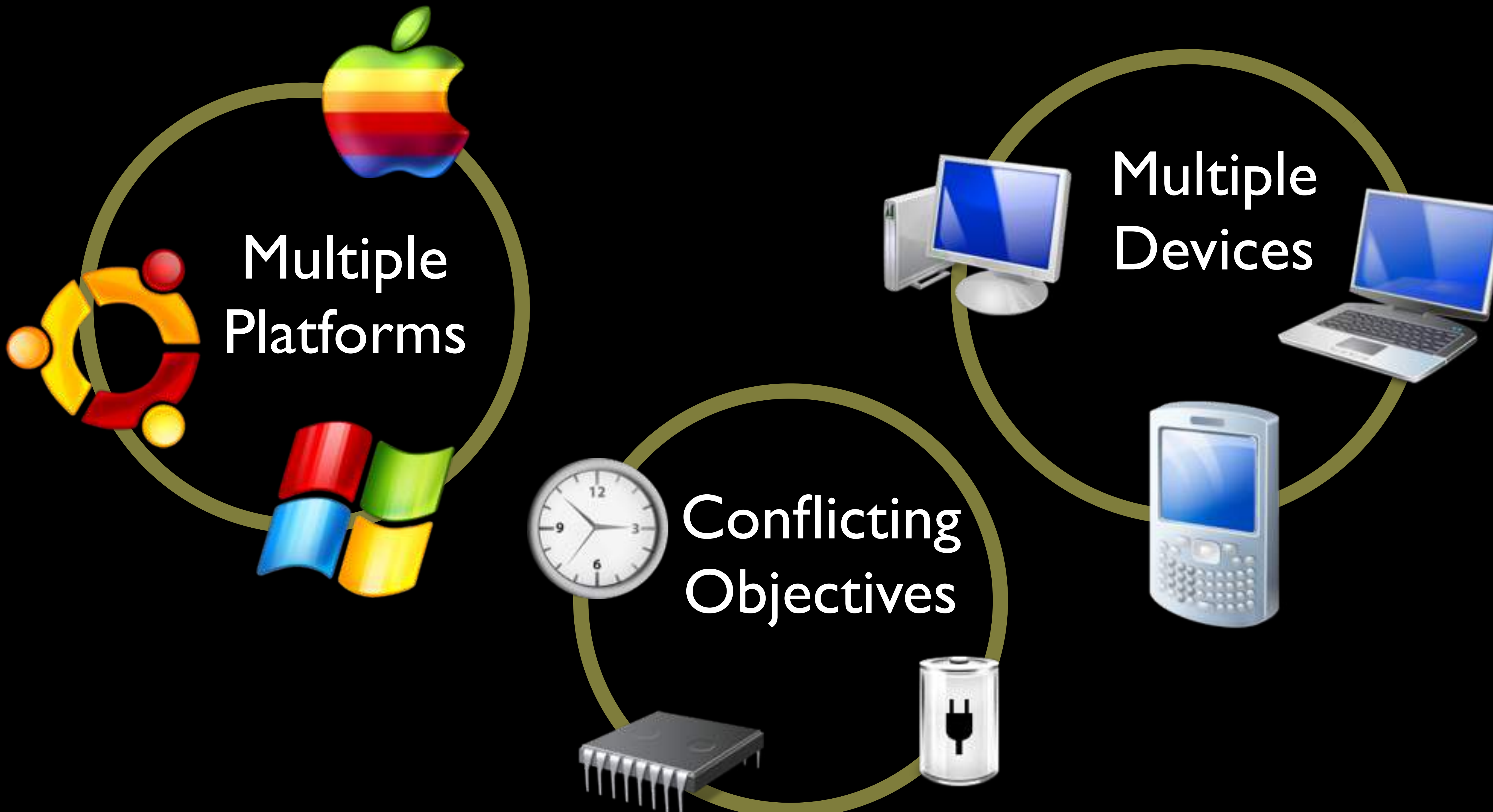
Software Design Process



Software Design Process



Multiplicity



Which requirements must be human coded ?

Functional Requirements

humans have to define these

Non-Functional Requirements

Which requirements are essential to human ?

Functional Requirements

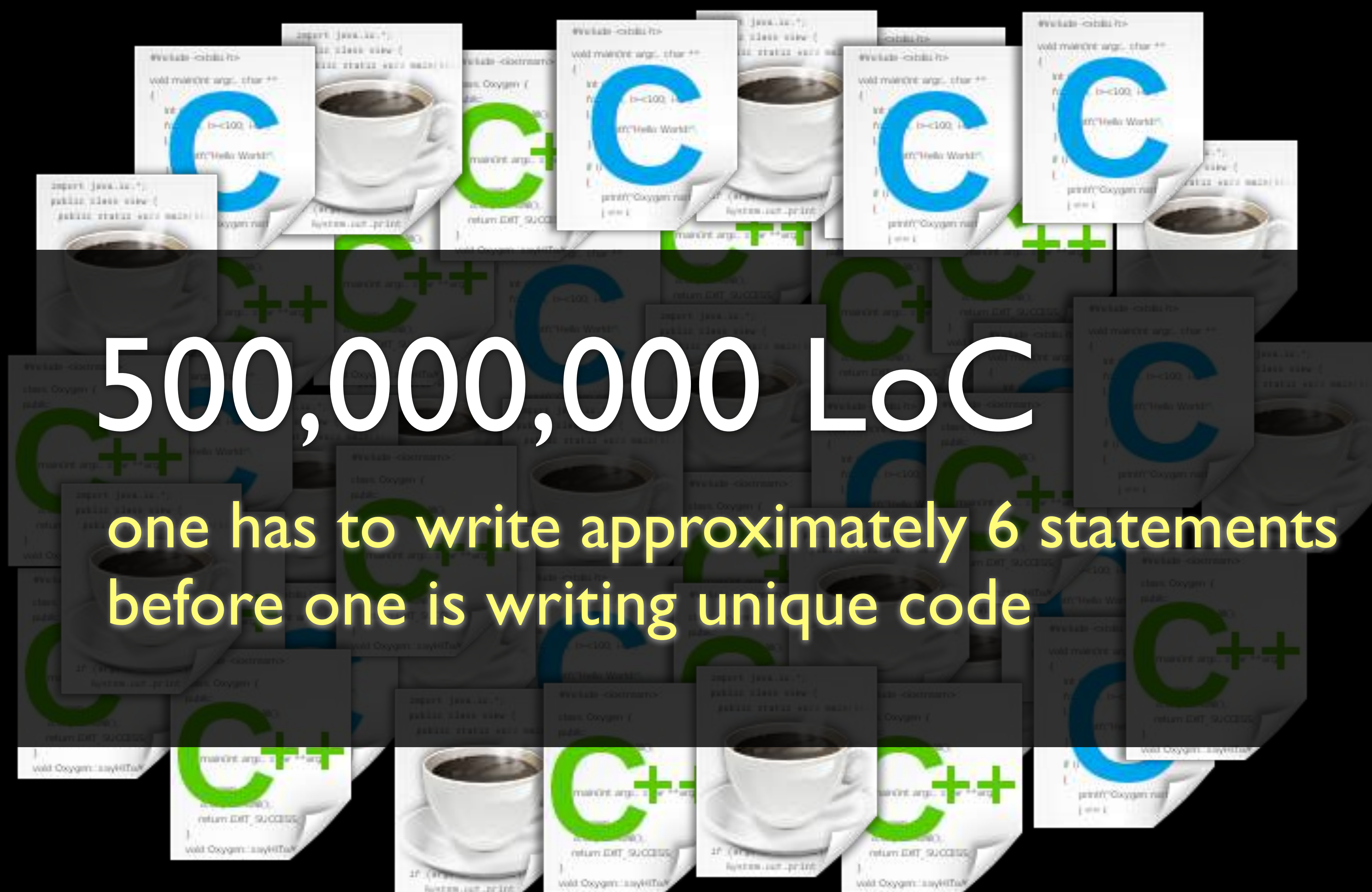
Non-Functional Requirements

humans have to define these

we can optimise these

Can it work ?

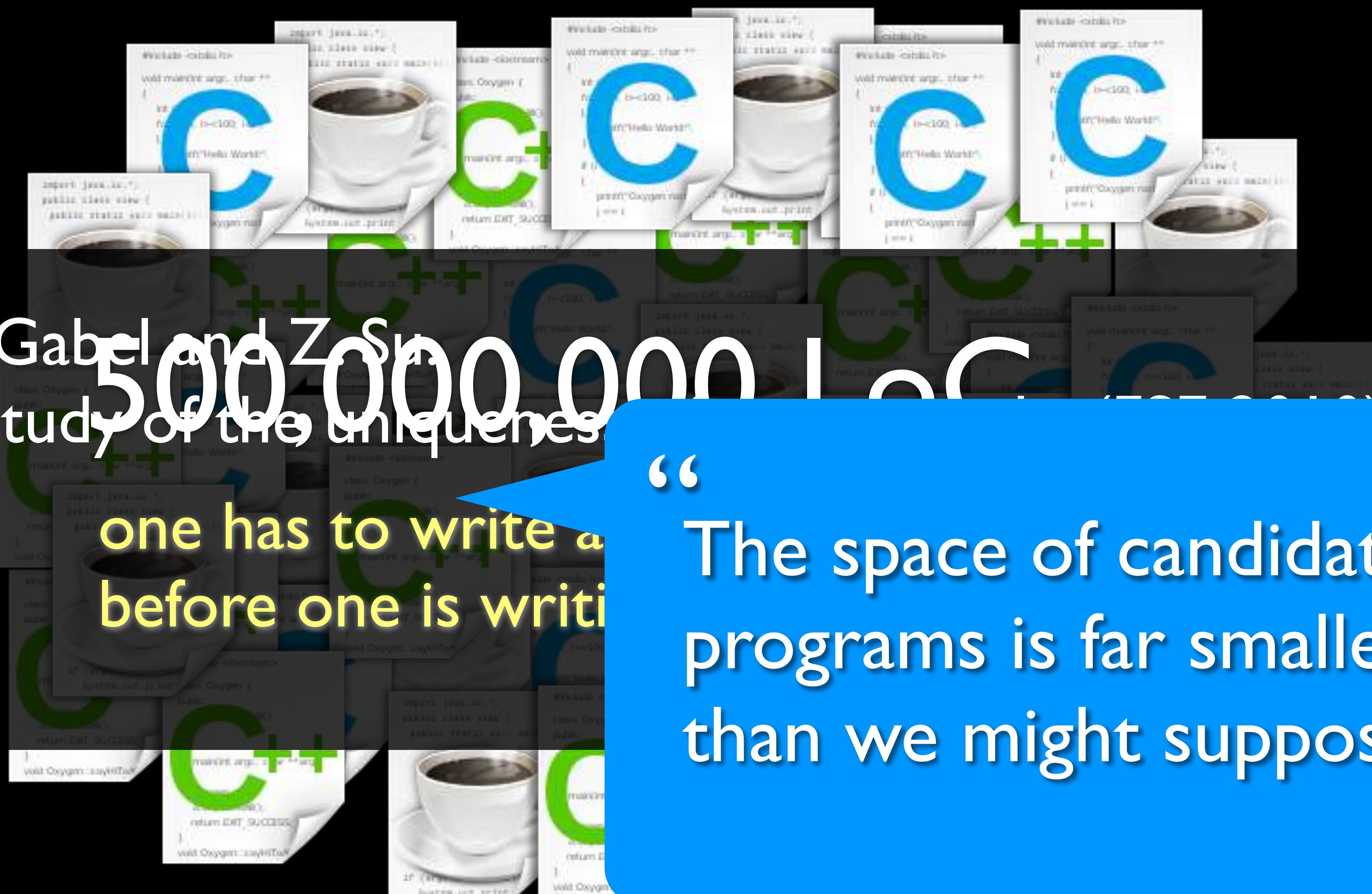
Software Uniqueness



500,000,000 LoC

one has to write approximately 6 statements
before one is writing unique code

Software Uniqueness



M. Gabel and Z. Su.

A study of the uniquenes

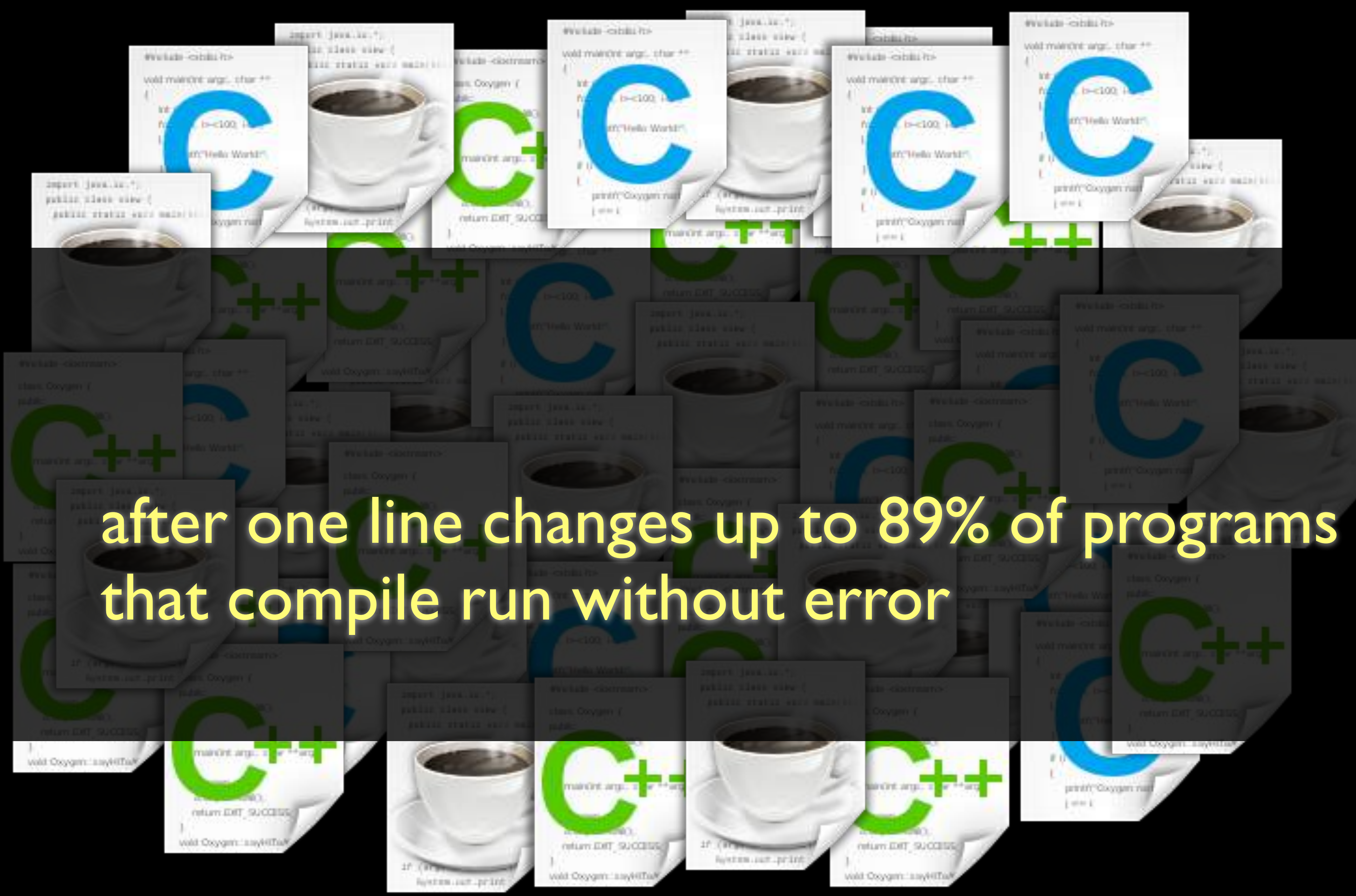
500 000 000 LoC

one has to write a

before one is writi

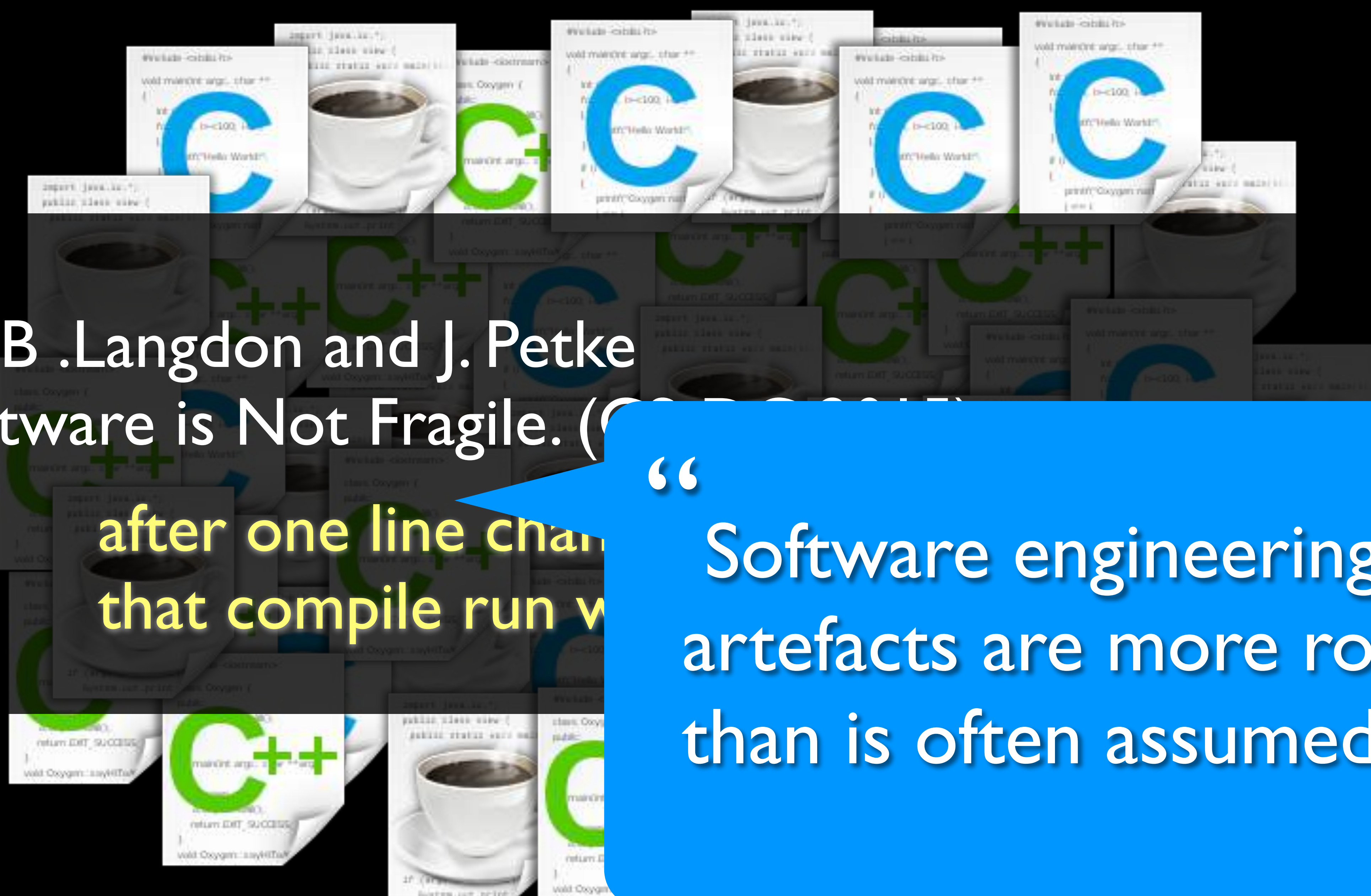
"The space of candidate programs is far smaller than we might suppose."

Software Robustness



after one line changes up to 89% of programs that compile run without error

Software Robustness



W. B .Langdon and J. Petke
Software is Not Fragile. (

after one line cha
that compile run w

“Software engineering artefacts are more robust than is often assumed.”

Non-Functional
Requirements

How can we optimise
these ?

Genetic Improvement

The GISMOE challenge: Constructing the Pareto Program Surface Using Genetic Programming to Find Better Programs

Mark Harman[1], William B. Langdon[1], Yue Jia[1], David R. White[2], Andrea Arcuri[3], John A. Clark[4]
[1]CREST Centre, University College London, Gower Street, London, WC1E 6BT, UK.
[2]School of Computing Science, University of Glasgow, Glasgow, G12 8QQ, Scotland, UK.
[3]Simula Research Laboratory, P. O. Box 134, 1325 Lysaker, Norway.
[4]Department of Computer Science, University of York, Deramore Lane, York, YO10 5GH, UK.

ABSTRACT

Optimising programs for non-functional properties such as speed, size, throughput, power consumption and bandwidth can be demanding; pity the poor programmer who is asked to cater for them all at once! We set out an alternate vision for a new kind of software development environment inspired by recent results from Search Based Software Engineering (SBSE). Given an input program that satisfies the functional requirements, the proposed programming environment will automatically generate a set of candidate program implementations, all of which share functionality, but each of which differ in their non-functional trade offs. The software designer navigates this diverse Pareto surface of candidate implementations, gaining insight into the trade offs and selecting solutions for different platforms and environments, thereby stretching beyond the reach of current

Keywords

SBSE, Search Based Optimization, Compilation, Non-functional Properties, Genetic Programming, Pareto Surface.

1. INTRODUCTION

Humans find it hard to develop systems that balance many competing and conflicting non-functional objectives. Even meeting a single objective, such as execution time, requires automated support in the form of compiler optimisation. However, though most compilers can optimise compiled code for both speed and size, the programmer may find themselves making arbitrary choices when such objective are in conflict with one another.

Furthermore, speed and size are but two of many objectives that the next generation of software systems will have

http://www.cs.ucl.ac.uk/staff/ucacbbl/gismo/

Which requirements are essential to human ?

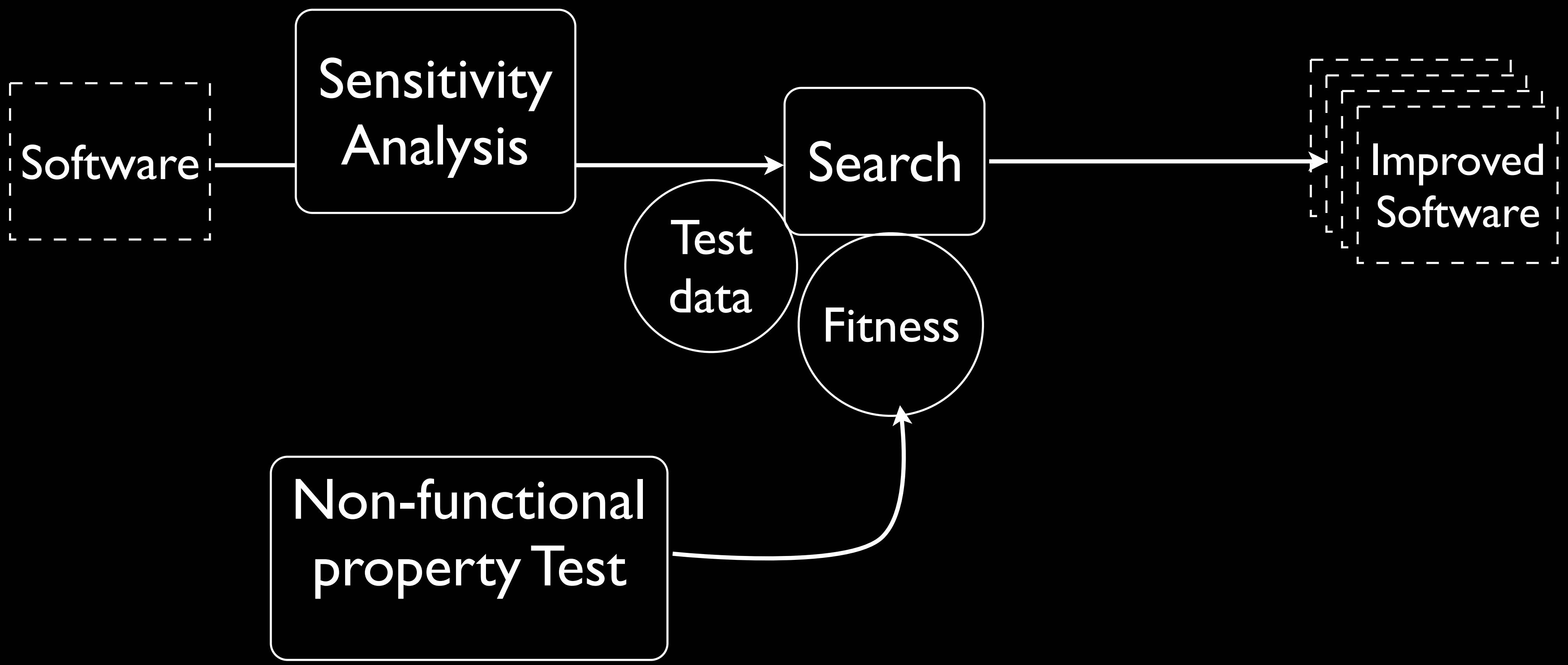
Functional Requirements

humans have to define these

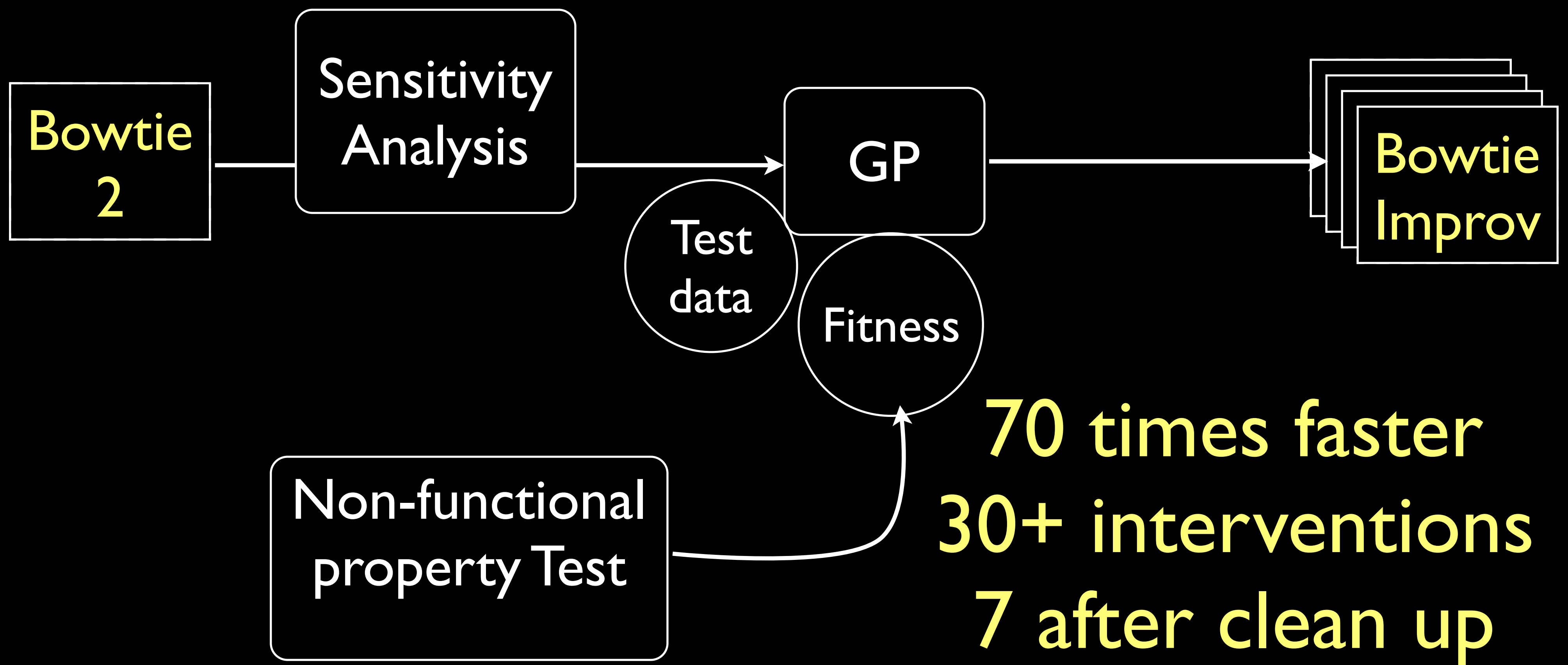
Non-Functional Requirements

we can optimise these

Genetic Improvement Framework



Efficiency Improvement



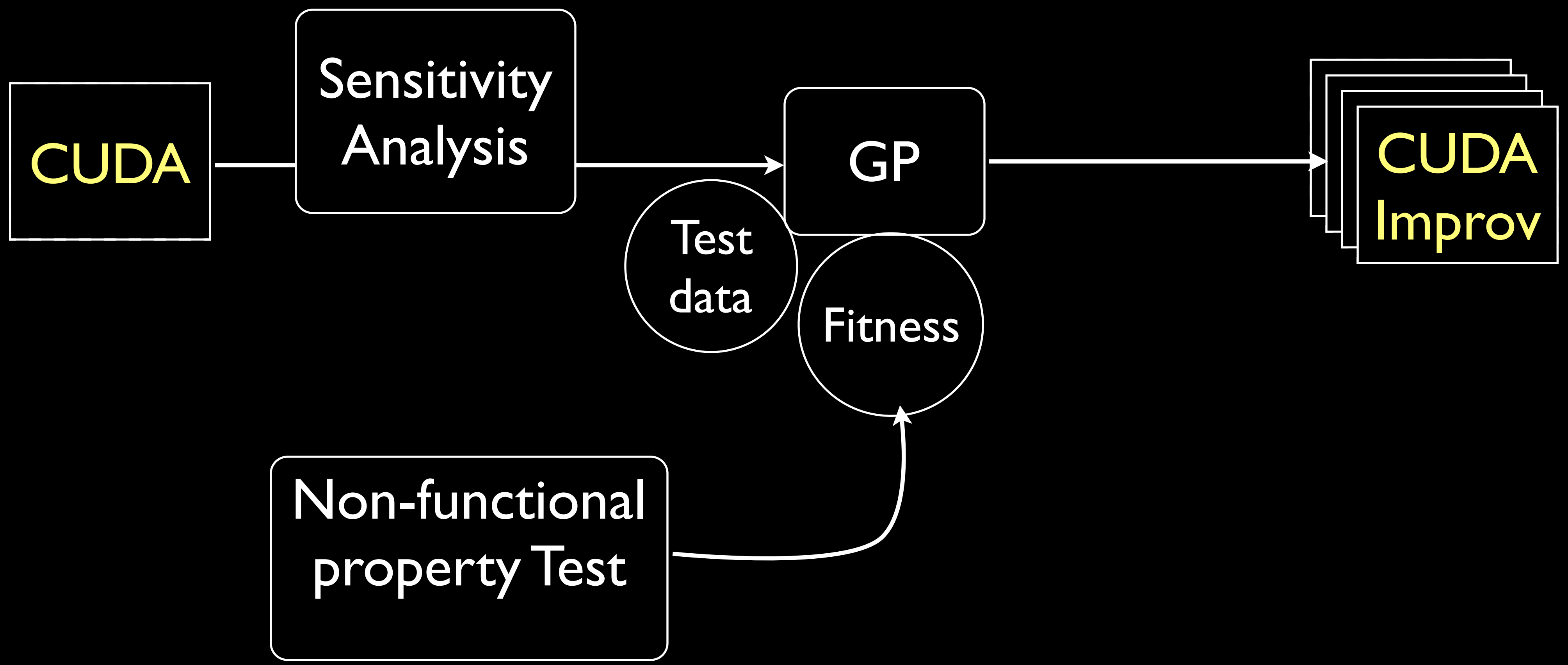
70 times faster
30+ interventions
7 after clean up
slight semantic improvement

W. B. Langdon and M. Harman
Optimising Existing Software with Genetic Programming.
Transactions on Evolutionary Computation (TEC) 2015

Mutation	Source file	Line (type)	Orig. code	New code
replaced	bt2_io.cpp	622 (for2)	i < offsLenSampled	i < this->_nPat
replaced	sa_rescomb.cpp	50 (for2)	i < satup_->offs.size()	0
di				
replaced	aligner_swsse_ee_u8 .cpp	707	vh = _mm_max_epu8(vh, vf);	vmax = vlo;
deleted	aligner_swsse_ee_u8 .cpp	766	pvFStore += 4;	
replaced	aligner_swsse_ee_u8 .cpp	772	_mm_store_si128(pv HStore, vh);	vh = _mm_max_epu8(vh, vf);
deleted	aligner_swsse_ee_u8 .cpp	778	ve = _mm_max_epu8(ve, vh);	

Runtime reduction from 12 days to 4 hours

Efficiency Improvement



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

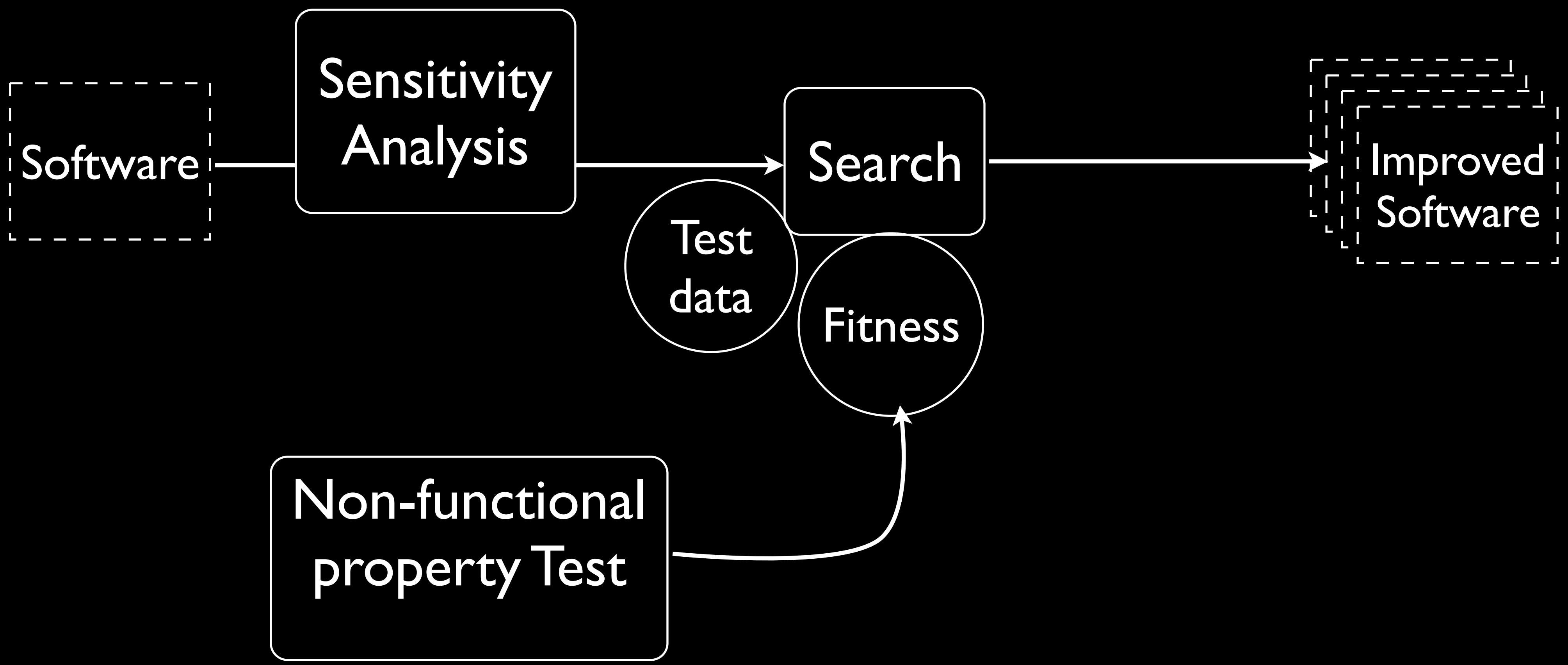
Efficiency Improvement

Challenge: Use genetic improvement to improve program efficiency of a state-of-the-art bioinformatics program for DNA sequence mapping called BarraCUDA, consisting of 8,000+ lines of code.

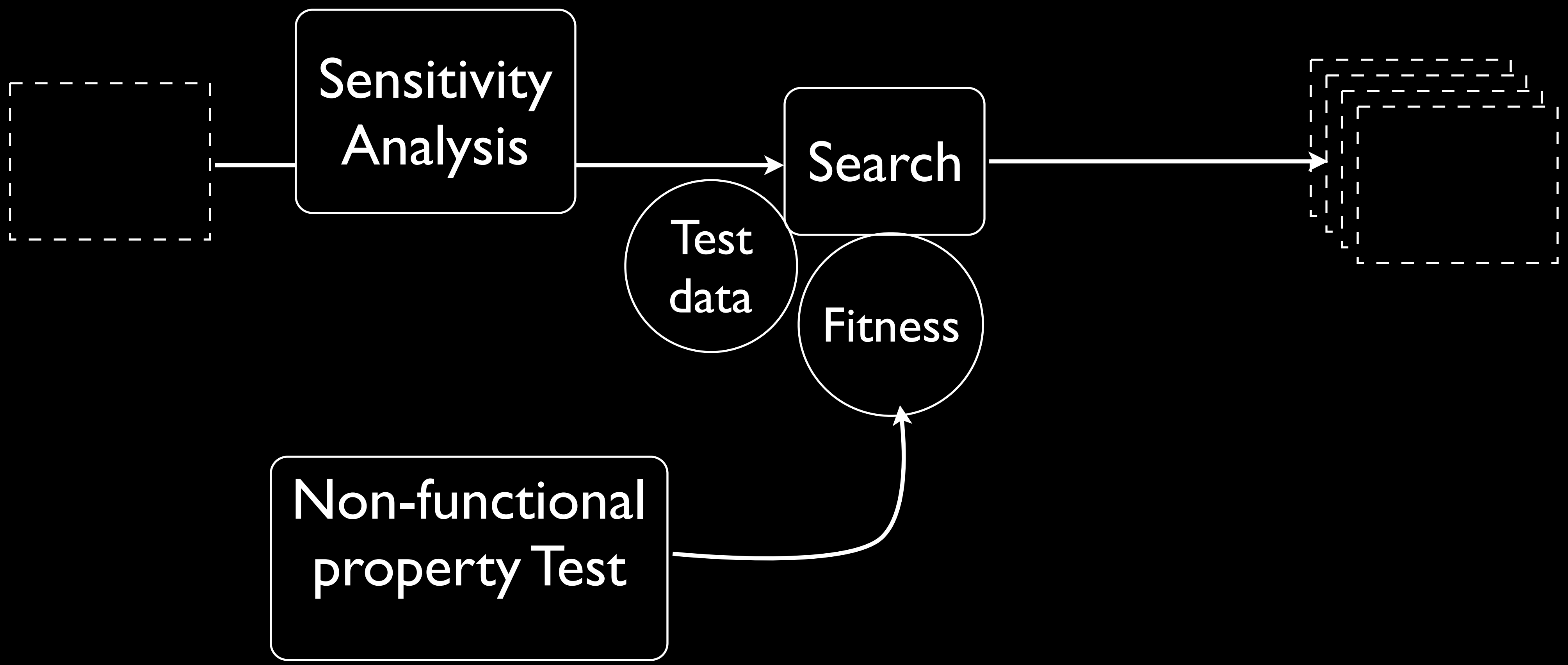
Results: The improved version of BarraCUDA is up to 3x faster than the original on large real-world datasets. The new version has been adopted into development and has been downloaded over 1,000 times so far. Ported by IBM to one of their super computers and adopted by Lab7.

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

Genetic Improvement Framework



Software Specialisation with Transplants



Genetic and Evolutionary Computation Conference

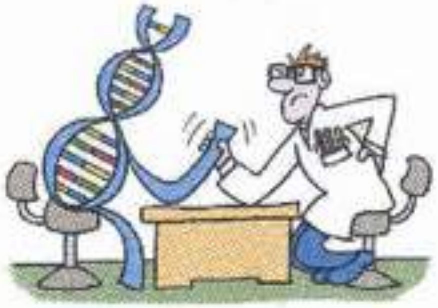
July 12-16, 2014
Vancouver, British Columbia

GECCO

Winners of the
2014 Humies Silver Award:

Justyna Petke, Mark Harman,
William B. Langdon, Westley Weimer

Using Genetic Improvement and Code Transplants to Specialize a C++ Program to a Problem Class



Association for Computing Machinery

sigevo

Question

Can we improve the efficiency of an already highly-optimised piece of software using genetic programming?

Motivation for choosing a SAT solver

Bounded Model Checking

Planning

Software Verification

Automatic Test Pattern Generation

Combinational Equivalence Checking

Combinatorial Interaction Testing

and many other applications..

Motivation for choosing a SAT solver

MiniSAT-hack track in SAT solver competitions

Contributions

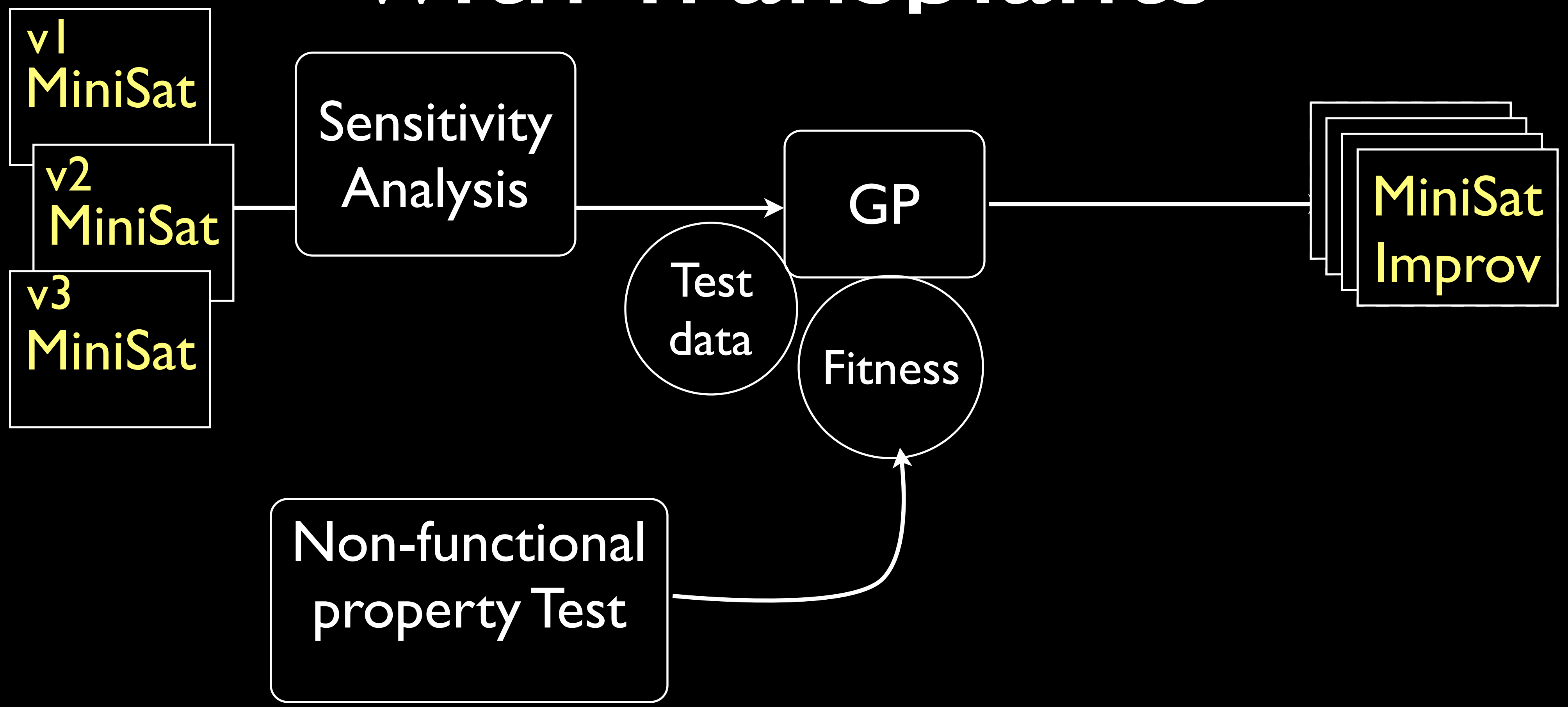
Introduction of multi-donor software transplantation

Contributions

Introduction of multi-donor software transplantation

Use of genetic improvement as means to specialise software

Software Specialisation with Transplants



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

Program Representation

Changes at the level of lines of source code

Each individual is composed of a list of changes

Specialised grammar used to preserve syntax

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++"
```

Code Transplants

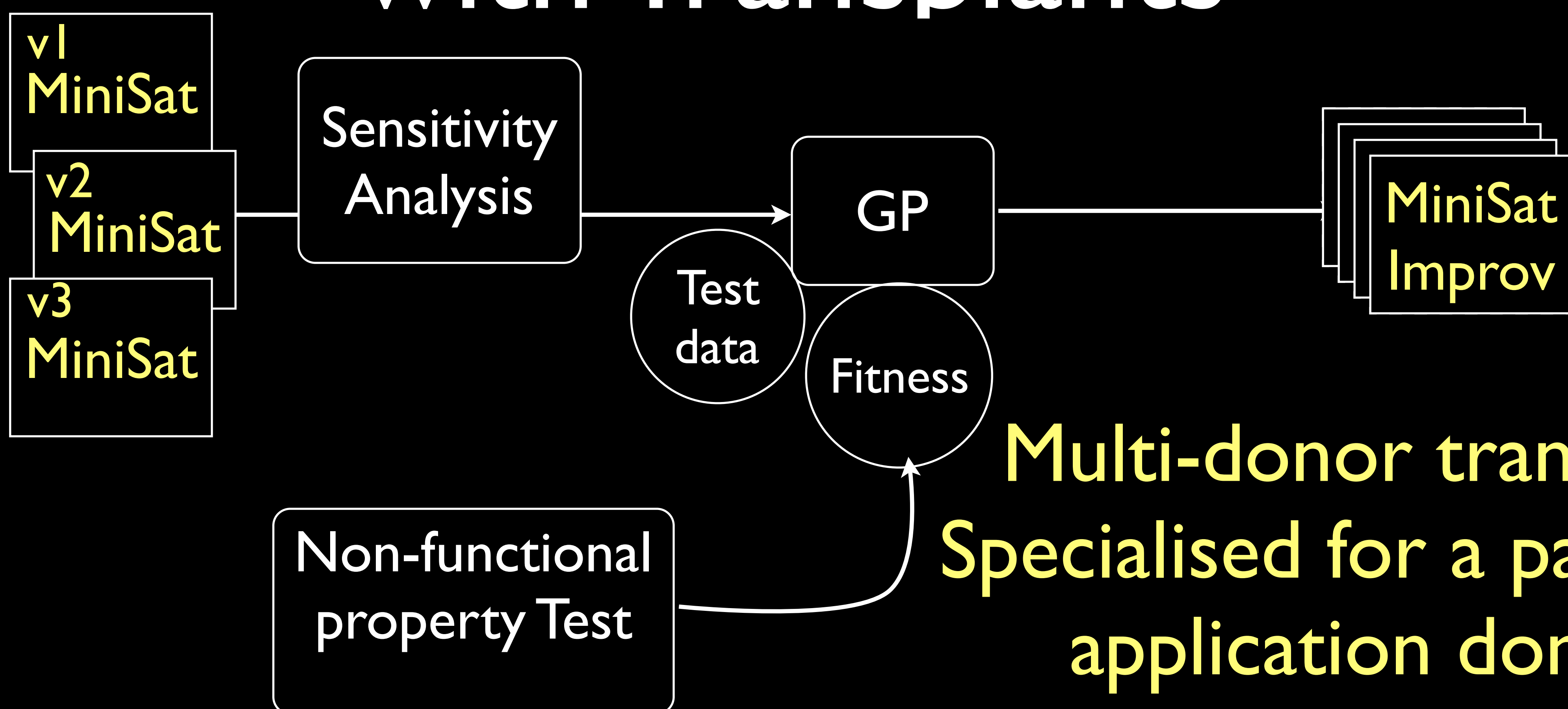
GP has access to both:

- the *host* program to be evolved
- the *donor* program(s)

Question

How much runtime improvement can we achieve?

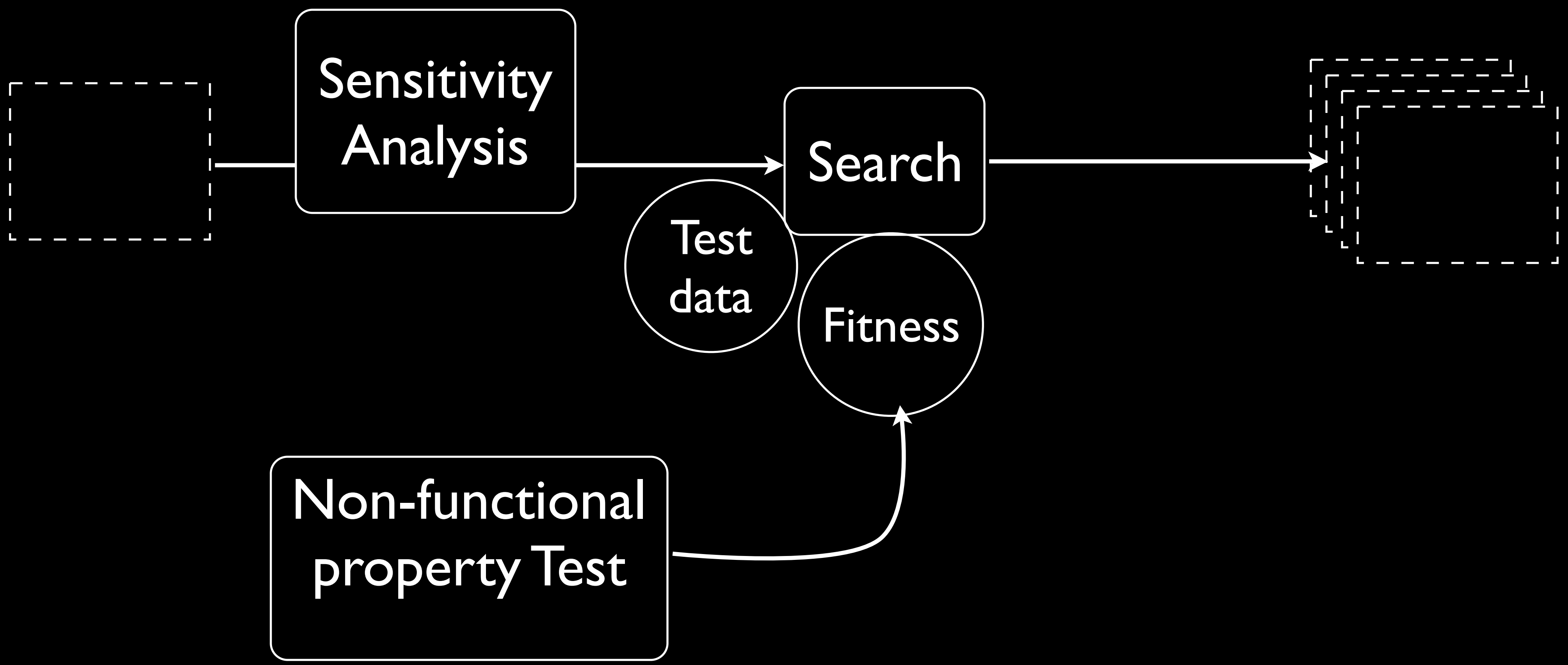
Software Specialisation with Transplants



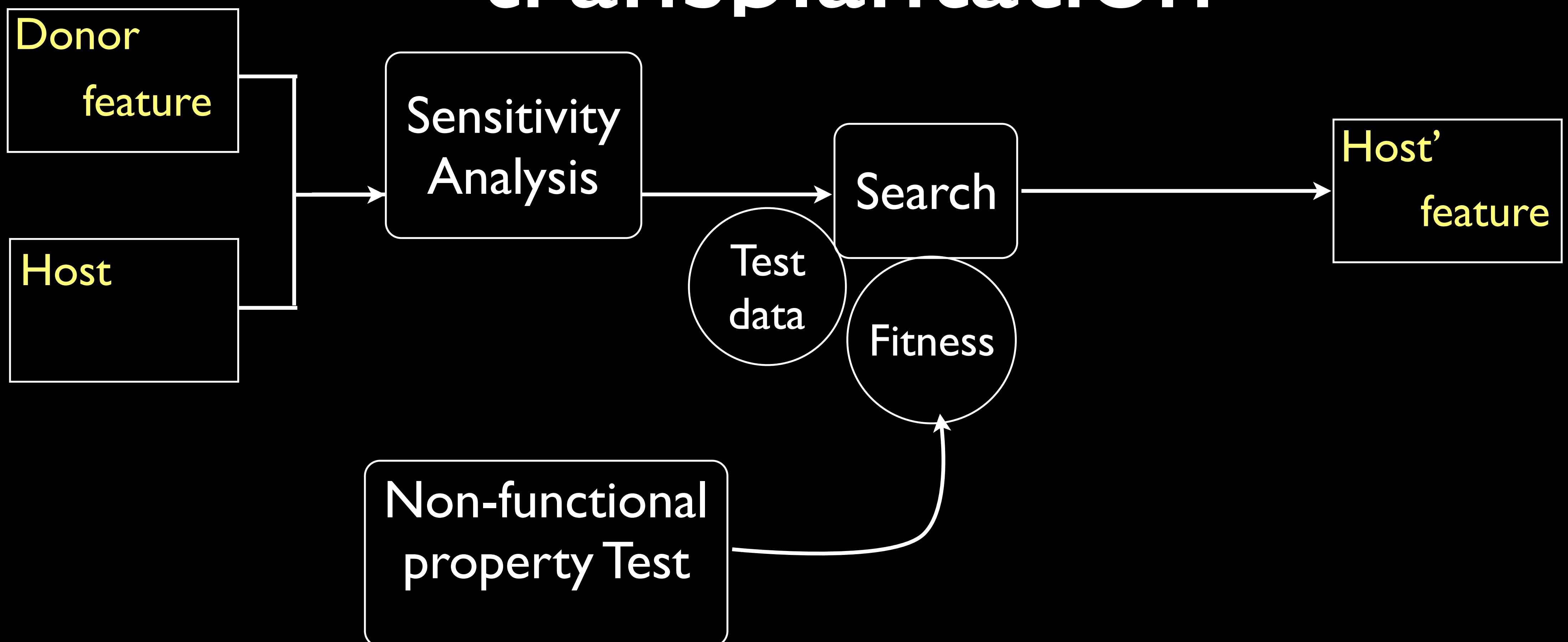
Multi-donor transplant
Specialised for a particular application domain
17% faster

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

Real-world cross-system transplantation



Real-world cross-system transplantation



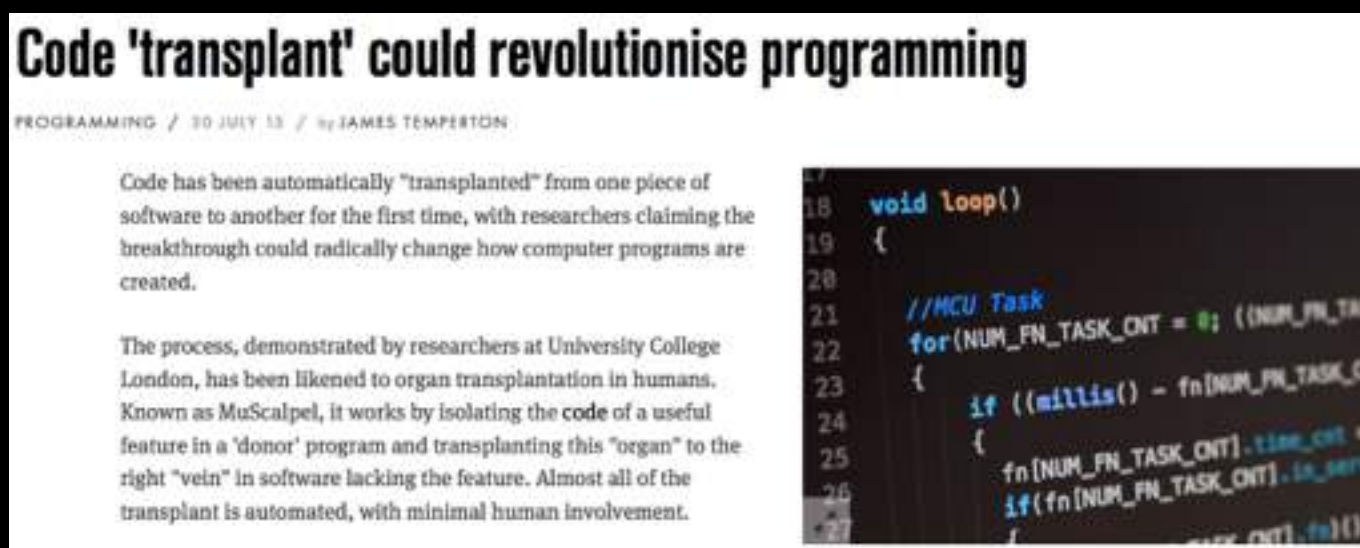
Earl T. Barr, Mark Harman, Yue Jia, Alexandru Marginean, and Justyna Petke
Automated Software Transplantation
International Symposium on Software Testing and Analysis (ISSTA) 2015

Automated Software Transplantation

E.T. Barr, M. Harman, Y. Jia, A. Marginean & J. Petke

ACM Distinguished Paper Award at ISSTA 2015

Gold 'Humie' Award Winner at GECCO 2016



Code 'transplant' could revolutionise programming

PROGRAMMING / 30 JULY 15 / by JAMES TEMPERTON

Code has been automatically "transplanted" from one piece of software to another for the first time, with researchers claiming the breakthrough could radically change how computer programs are created.

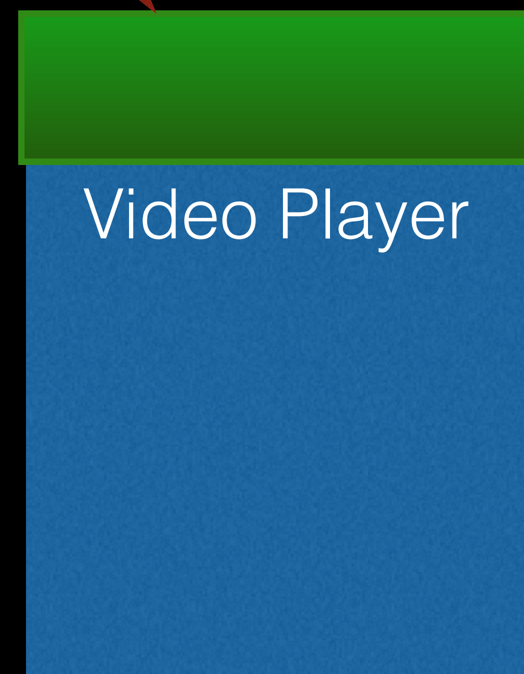
The process, demonstrated by researchers at University College London, has been likened to organ transplantation in humans. Known as MuScalpel, it works by isolating the code of a useful feature in a 'donor' program and transplanting this "organ" to the right "vein" in software lacking the feature. Almost all of the transplant is automated, with minimal human involvement.

over 2,000 shares of article in WIRED.CO.UK

coverage in BBC WORLD SERVICE Click

Why A ansplantation?

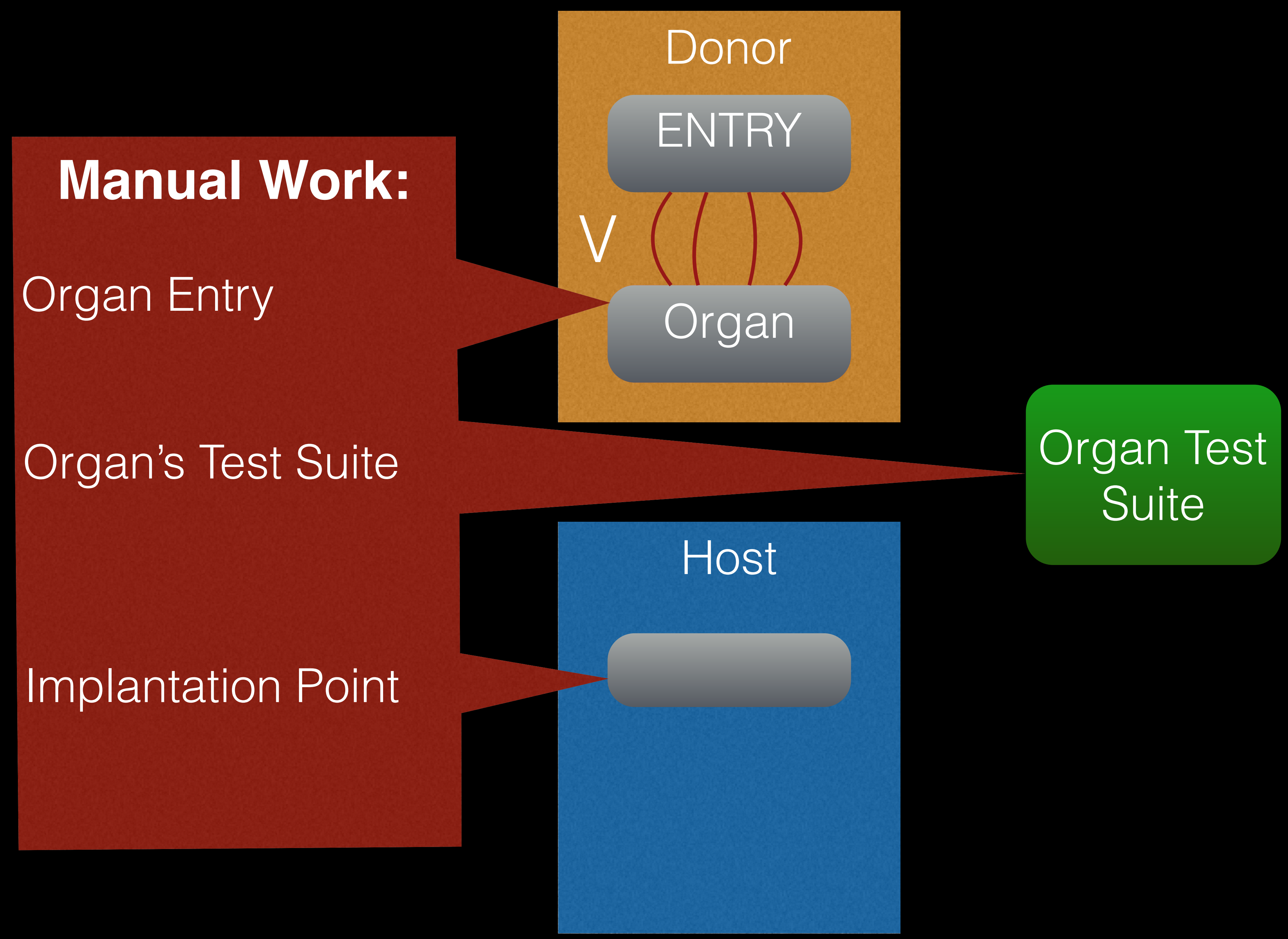
~100 players



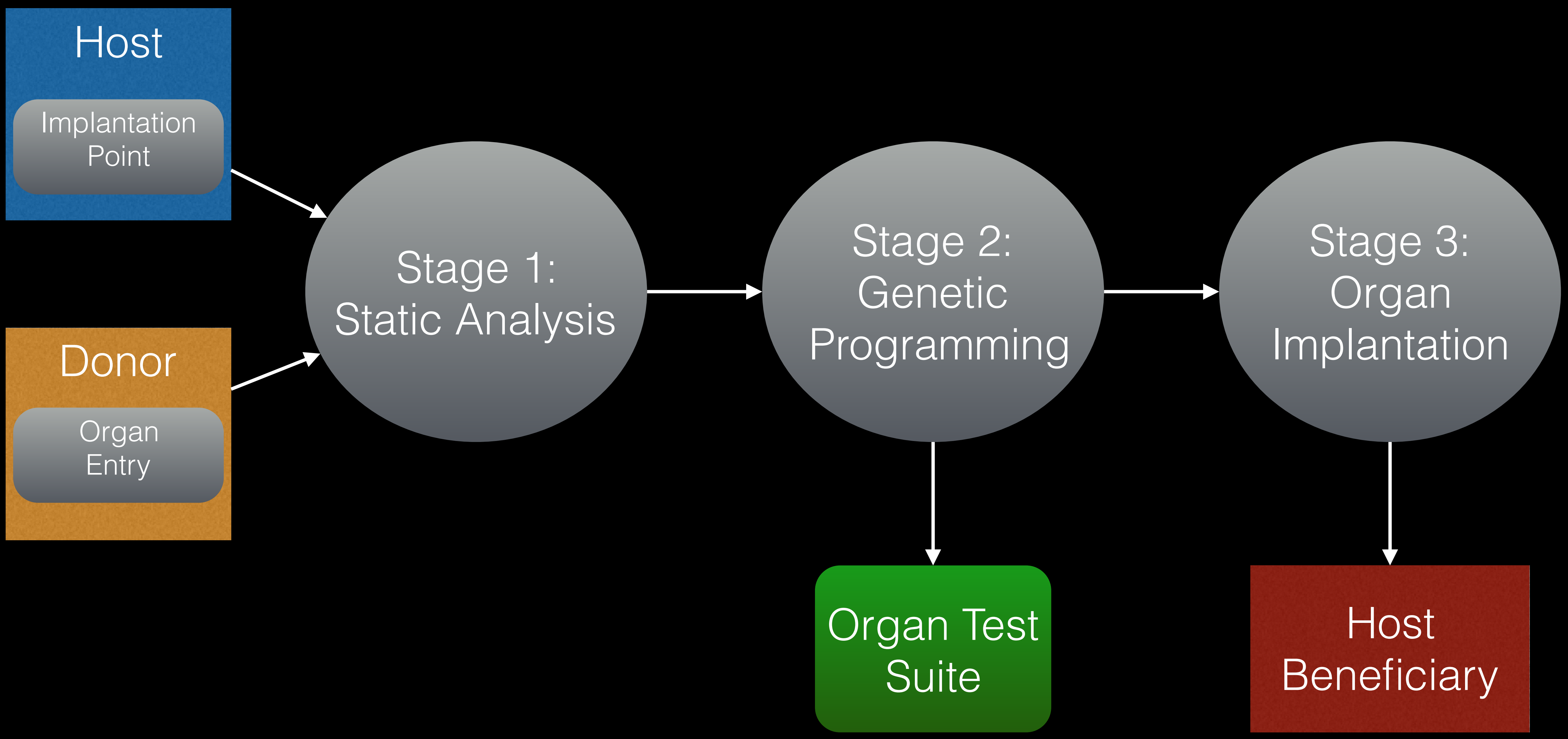
Check open source repositories

~~Start from scratch~~

Automated Software Transplantation



µTrans


Host
Implantation Point
Donor
Organ Entry
Stage 1: Static Analysis
Stage 2: Genetic Programming
Stage 3: Organ Implantation
Organ Test Suite
Host Beneficiary

Subjects

Subjects	Type	Size KLOC
Idct	Donor	2.3
Mytar	Donor	0.4
Cflow	Donor	25
Webserver	Donor	1.7
TuxCrypt	Donor	2.7
Pidgin	Host	363
Cflow	Host	25
SoX	Host	43
	Case Study	
x264	Donor	63
VLC	Host	422

Minimal size: 0.4k

Max size: 422k

Average Donor:16k

Average Host: 213k

Experimental Methodology and Setup

Host

Implantation Point

Organ Test Suite

Donor

OE

64 bit Ubuntu 14.10
16 GB RAM
8 threads

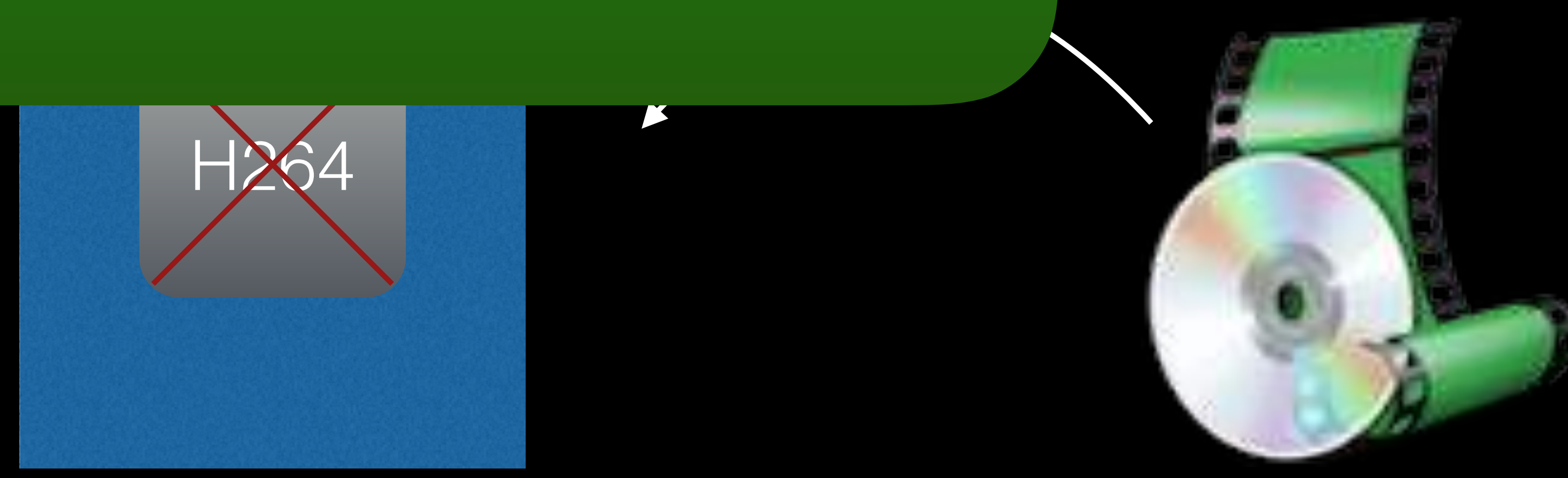
Empirical Study

in 12 out of 15 experiments
we successfully autotransplanted
new functionality

Case Study

			Acceptance
H.264			100%

within 26 hours performed a task
that took developers
an avg of 20 days of elapsed time



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.

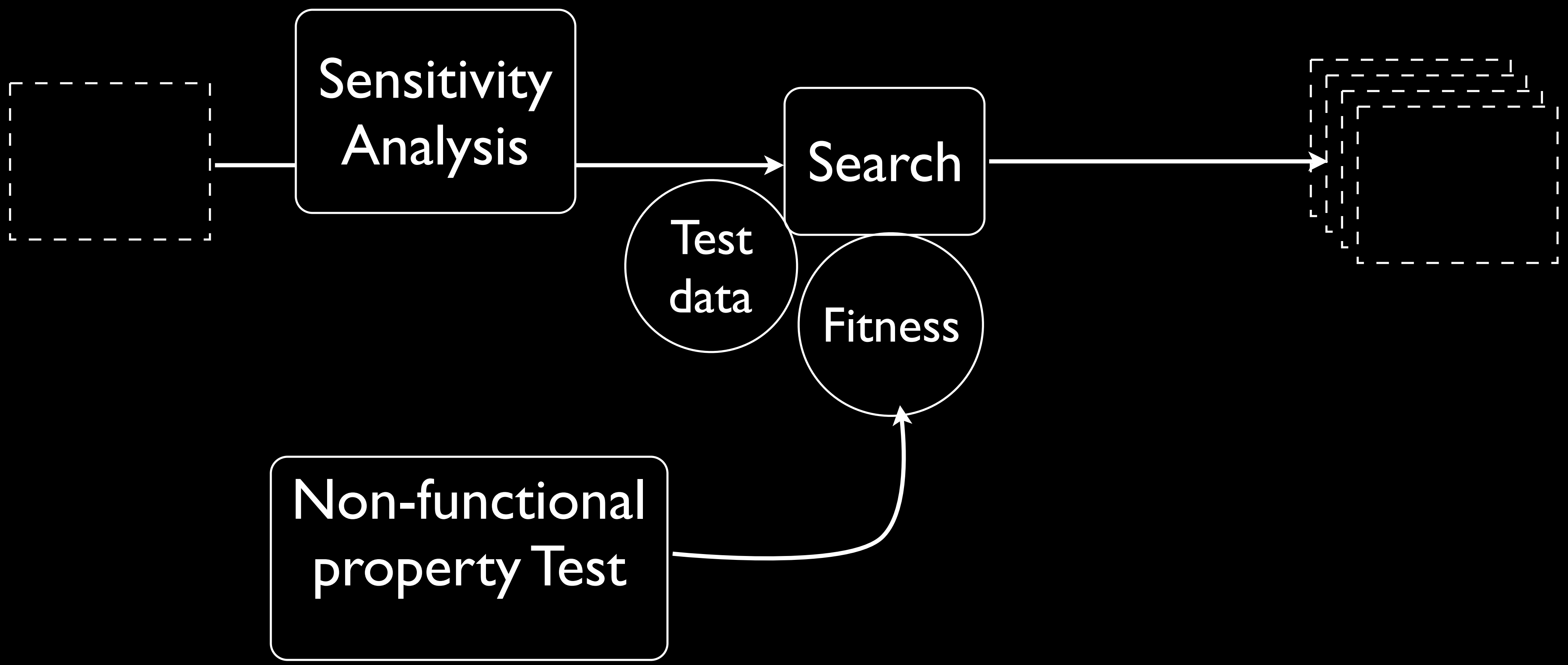
This website contains the source for muScalpel, muScalpel in binary form, and the data sets, including test suites, that underlie our experiments. To facilitate replicating our results, we have written a sequence of **scripts** that run a *single* run of each of our experiments. The name of the script 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

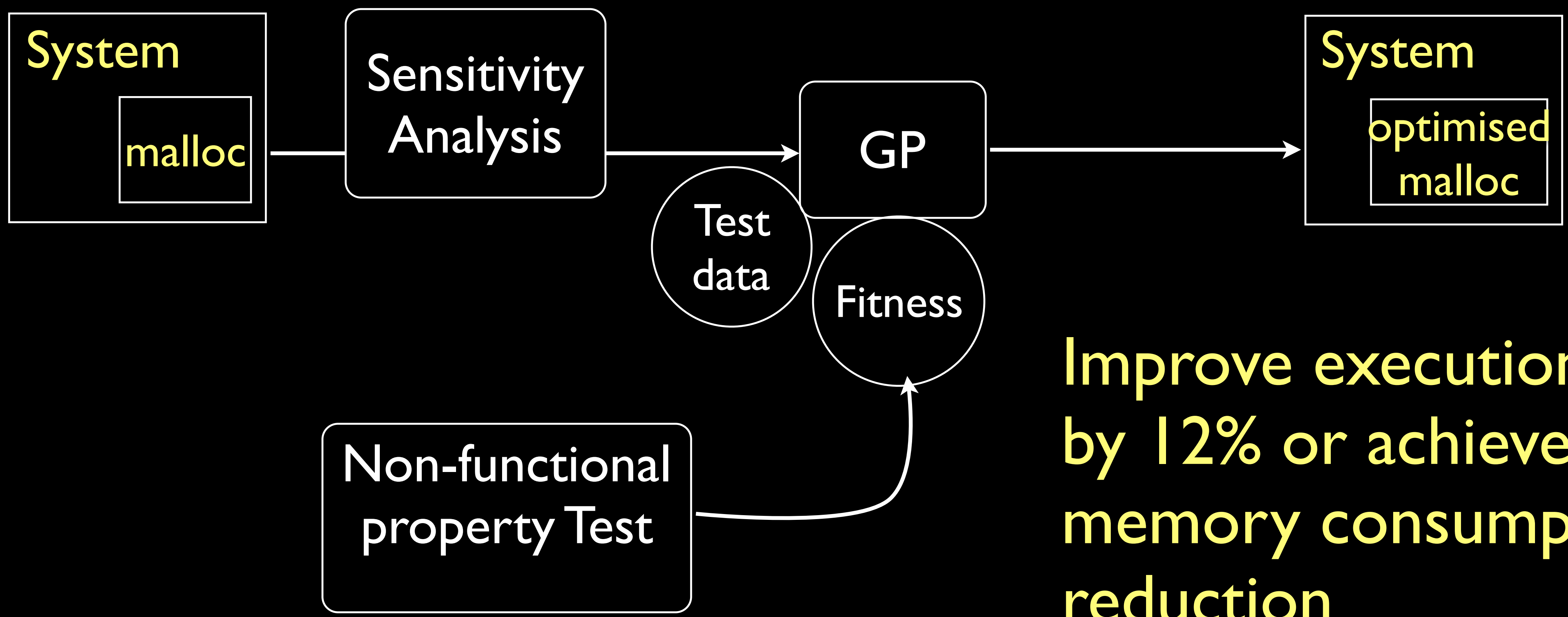
- Link to a script that runs all our experiments, as submitted to ISSTA 2015 artifact evaluation track. Here we also provide a dockerized version of our experiments.
  - **All experiments:** : Download

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

Memory vs speed trade offs



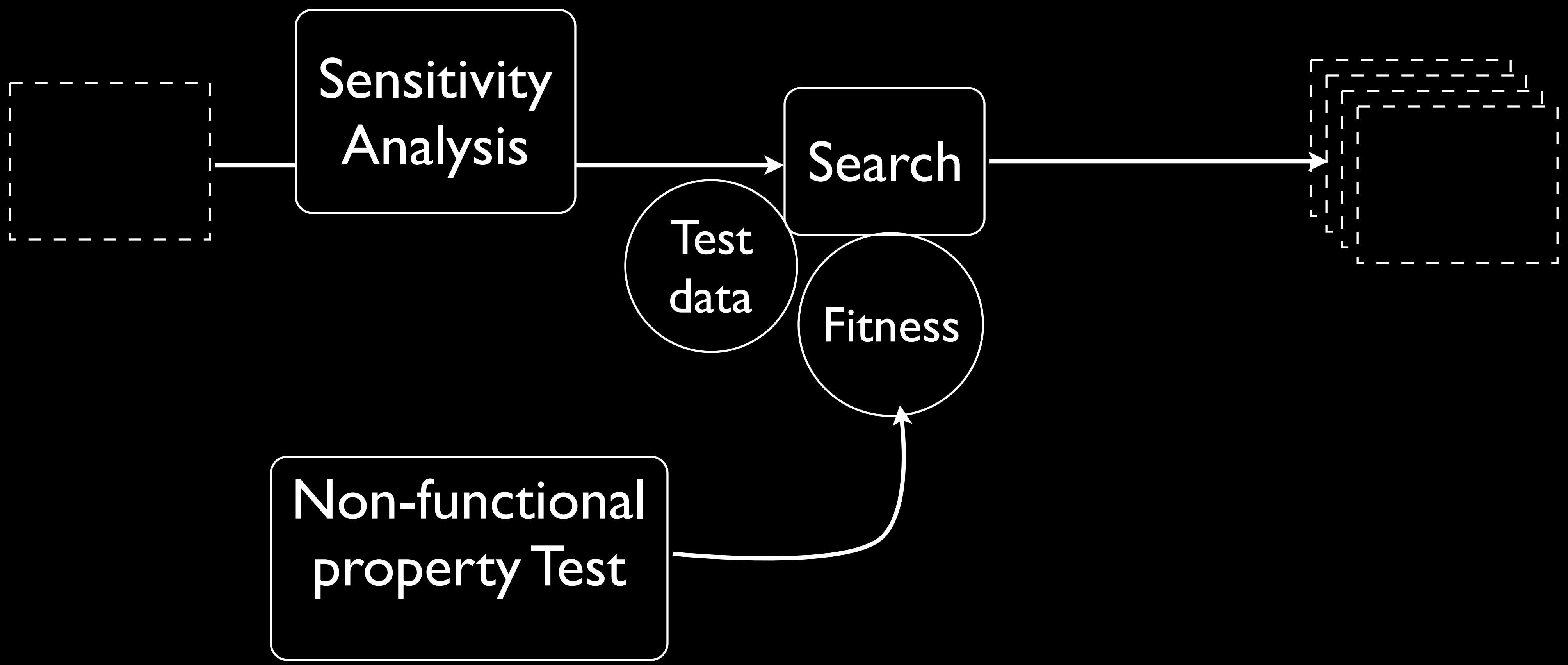
Memory vs speed trade offs



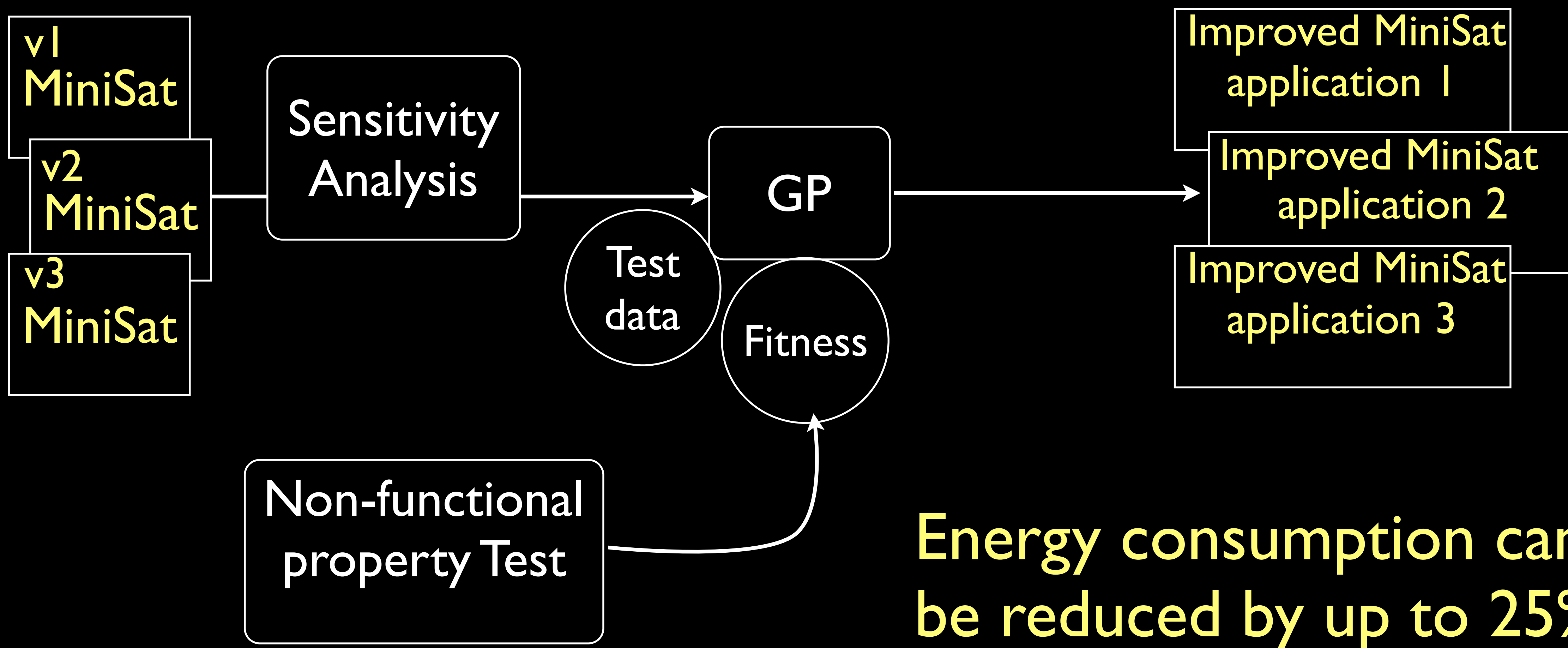
Improve execution time by 12% or achieve a 21% memory consumption reduction

Fan Wu, Westley Weimer, Mark Harman, Yue Jia and Jens Krinke
Deep Parameter Optimisation
Genetic and Evolutionary Computation Conference (GECCO) 2015

Reducing Energy Consumption



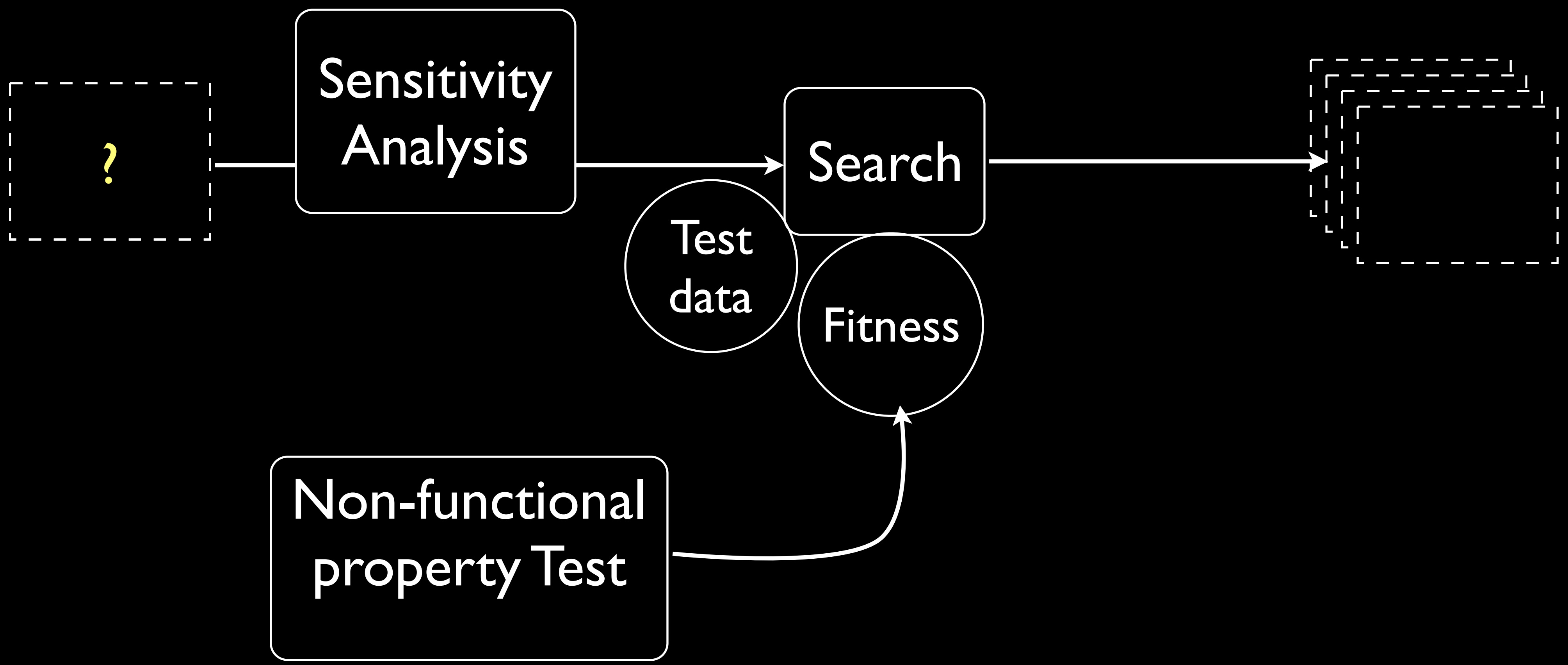
Reducing Energy Consumption



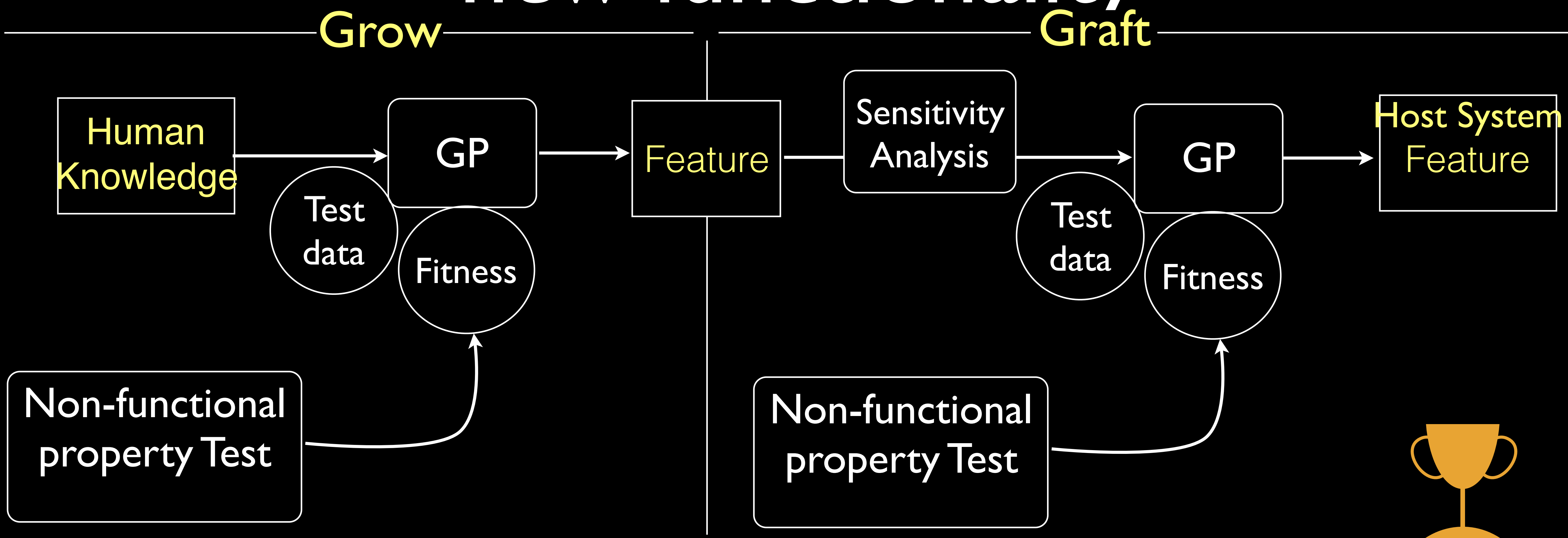
Energy consumption can be reduced by up to 25%

Bobby R. Bruce Justyna Petke Mark Harman
Reducing Energy Consumption Using Genetic Improvement
Conference on Genetic and Evolutionary Computation (GECCO 2015)

Grow and Graft new functionality



Grow and Graft new functionality



Mark Harman, Yue Jia and Bill Langdon,
Babel Pidgin: SBSE can grow and graft entirely new functionality into a real world system
Symposium on Search-Based Software Engineering (SSBSE) 2014 (Challenge track)

Genetic Improvement Applications

Improving software efficiency

Improving energy consumption

Porting old code to new hardware

Grafting new functionality into an existing system

Specialising software for a particular problem class

Other

Genetic Improvement Visibility

First International Workshop on Genetic Improvement
at GECCO 2015, Madrid, Sp
www.geneticimprovemento

Special Session on GI http://www.wcci2016.org/

Second International Workshop on Genetic Improvement
at GECCO 2016, Denver, Colorado

Genetic Improvement of Software

geneticimprovementofsoftware.com

Functional Properties

New Feature

Functionality Improvement

Non-functional Properties

Execution Time

Memory

Energy

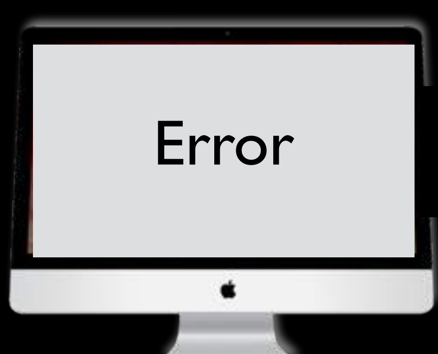
Genetic Improvement of Software

geneticimprovementofsoftware.com

Functional Properties

New Feature

Functionality Improvement



Bug Repair

Non-functional Properties

Execution Time

Memory

Bandwidth

Energy

Size

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Ada Lovelace: By Alfred Edward Chalon [Public domain], via Wikimedia Commons

Programmer: undesarchiv, B 145 Bild-F031434-0006 / Gathmann, Jens / CC-BY-SA [CC-BY-SA-3.0-de (http://creativecommons.org/licenses/by-sa/3.0/de/deed.en)], via Wikimedia Commons