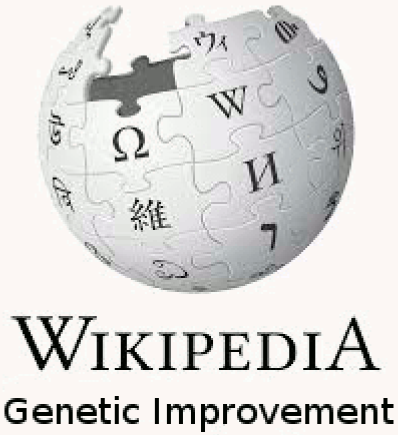
Emergent and Self-Adaptive Systems: Theory and Practice

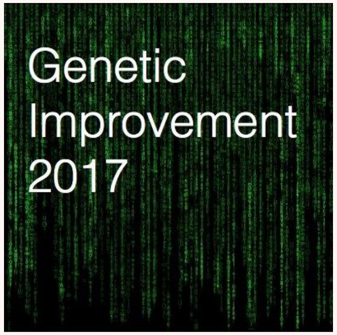
Data Science Institute, University of Lancaster, 19-20th Oct 2017

Genetic Improvement

W. B. Langdon

Computer Science, University College, London





Starting in 2015 annual workshops on GI

A Comprehensive Survey, IEEE TEVC

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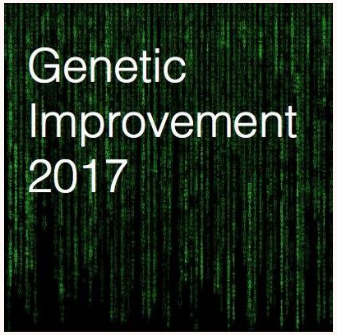

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A Comprehensive Survey, IEEE TEVC

Genetic Improvement of Programs

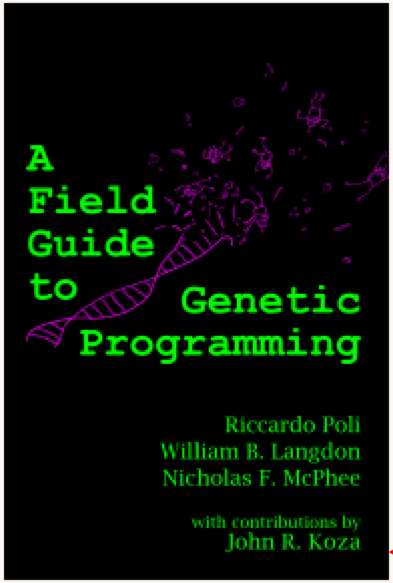
- What is Genetic Improvement
- What has Genetic Improvement done
  - Technology behind automatic bug fixing
  - Improvement of existing code: speedup, transplanting, program adaptation
- Goals of Genetic Improvement
  - more automated/higher level programming
- What can GI do for Emergent and Self-Adaptive Systems?

What is Genetic Improvement

Genetic Improvement

Use GP to evolve a population of computer programs

- Start with representation of human written code
- Programs’ fitness is determined by running them
- Better programs are selected to be parents
- New generation of programs are created by randomly combining above average parents or by mutation.
- Repeat generations until solution found.



A Field Guide to Genetic Programming

Riccardo Poli
William B. Langdon
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with contributions by
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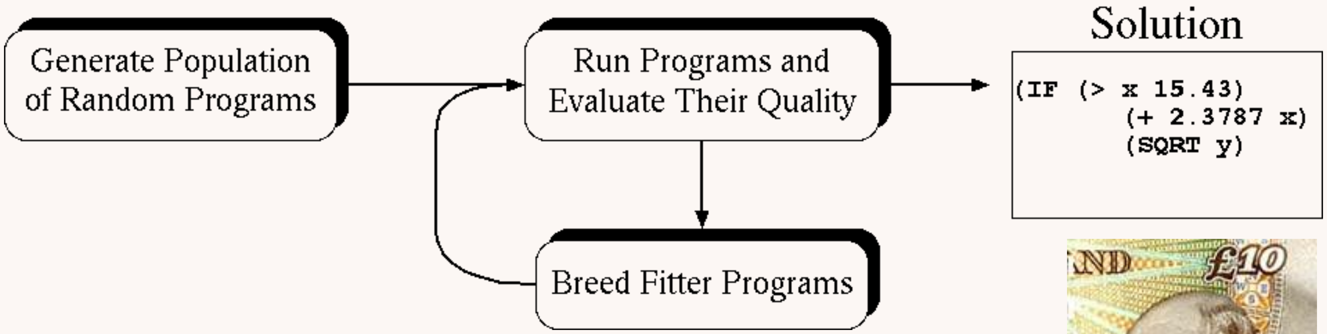

Generate Population of Random Programs

Run Programs and Evaluate Their Quality

Breed Fitter Programs

Solution

```
(IF (> x 15.43)
      (+ 2.3787 x)
      (SQRT y)
```

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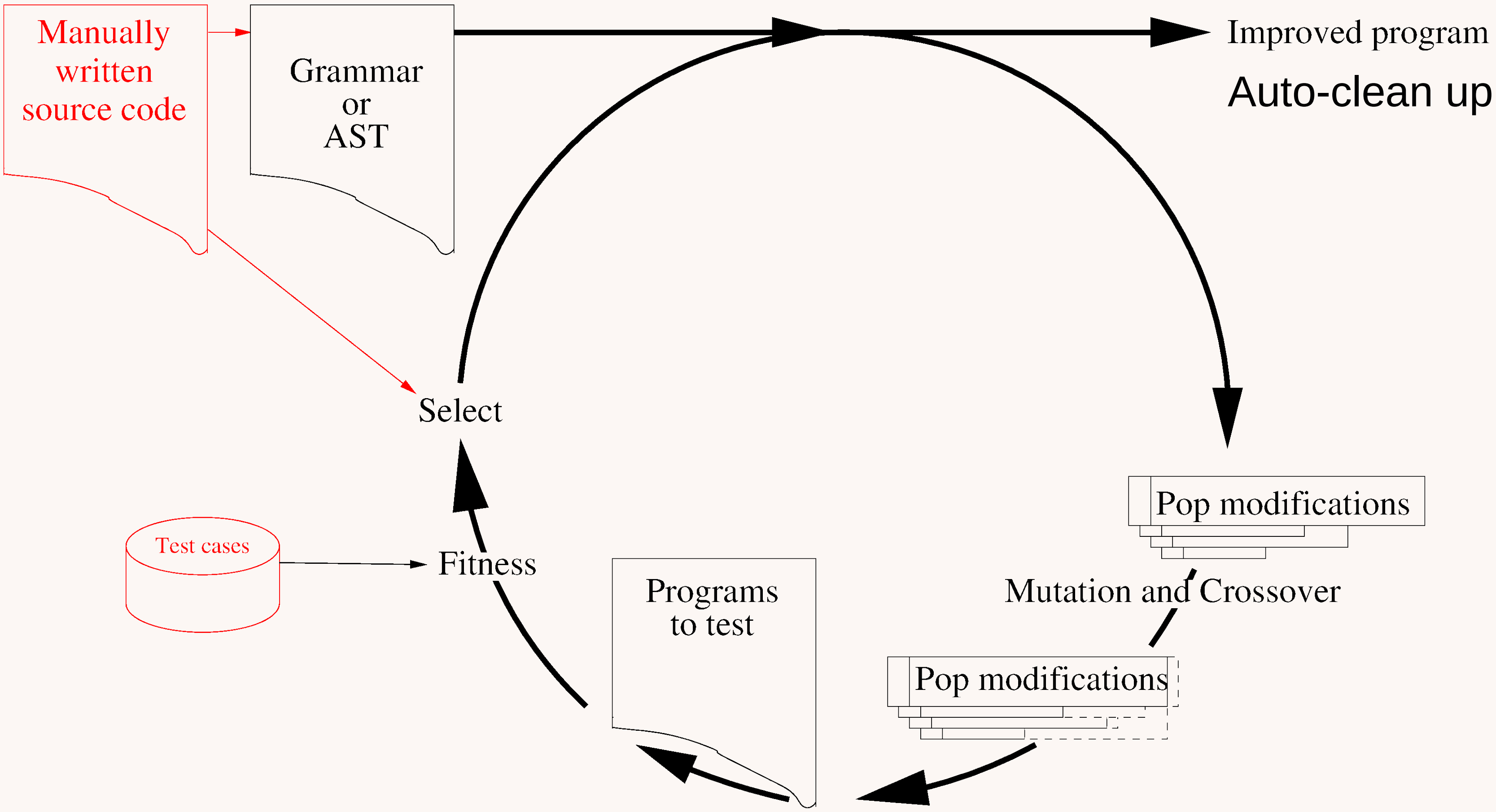
Free E-book kindle

Charles Darwin 1809-1882

Typical GI Evolutionary Cycle



GI Automatic Coding

- Genetic Improvement does not start from zero
- Use existing system
  - Source of non-random code
  - Use existing code as test “Oracle”. (Program is its own functional specification)
  - Can always compare against previous version
  - Easier to tell if better than if closer to poorly defined goal functionality.
- Testing scales (sort of). Hybrid with “proof” systems

What has
Genetic Improvement done

GP Automatic Bug Fixing

- Run code: example to reproduce bug, a few tests to show fixed code still works.
- Search for replacement C statement within program which fixes bug. Fault location tool
- Real bugs in real programs (mostly C/C++ or Java).
  - Multiple prizes and best papers, including:
  - 1st prize Human-Competitive [ICSE] Gold Humie
- In daily use: Iceland health clinic [GI-2017]

GI to Speed up human written programs

- Bowtie2 ×70 [IEEE TEVC 2015]
- GPGPU BarraCUDA [BioData Mining]
  - In use since 2015. 3000 downloads from SF
  - On real data speed up to 3 times (arXiv.org)
  - Commercial use by Lab7 (in BioBuilds 2015)
  - Ported by IBM to their Power8
  - Cambridge Epigenetix

GTX 1080 21x faster than bwameth (twin core CPU)

Microsoft Azure GPU cloud

GI to
Reduce Resource Consumption

- Energy reduction [GECCO 2015a,SSBSE] particularly for mobile computing [GI-2017]
- RAM memory reduction [GECCO 2015b]
- Reduce run time [pknotsRG,OpenCV, RNAfold]
- Choose better library [SSBSE-2017]
- Improve library [SSBSE 2014,2016]

GI to Improve functionality

- Transplanting C++ [Marginean SSBSE’15, ISSTA’15]

  E.g. graph layout into Kate, H.264 into VLC, awarded Gold Humie, 26hours CPU v. 20days
- Autoporting
  – gzip to GPU [CEC 2010], RNAfold to SSE [GI-2017]
- Better RNA structure prediction
- Improving GPU shaders [2011]

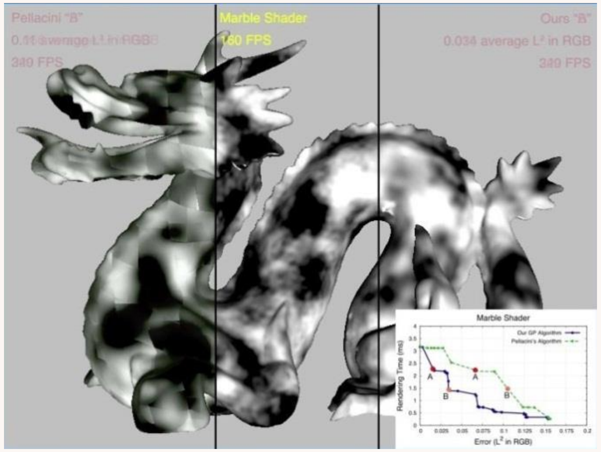


Fig 1. number of core papers on genetic improvement

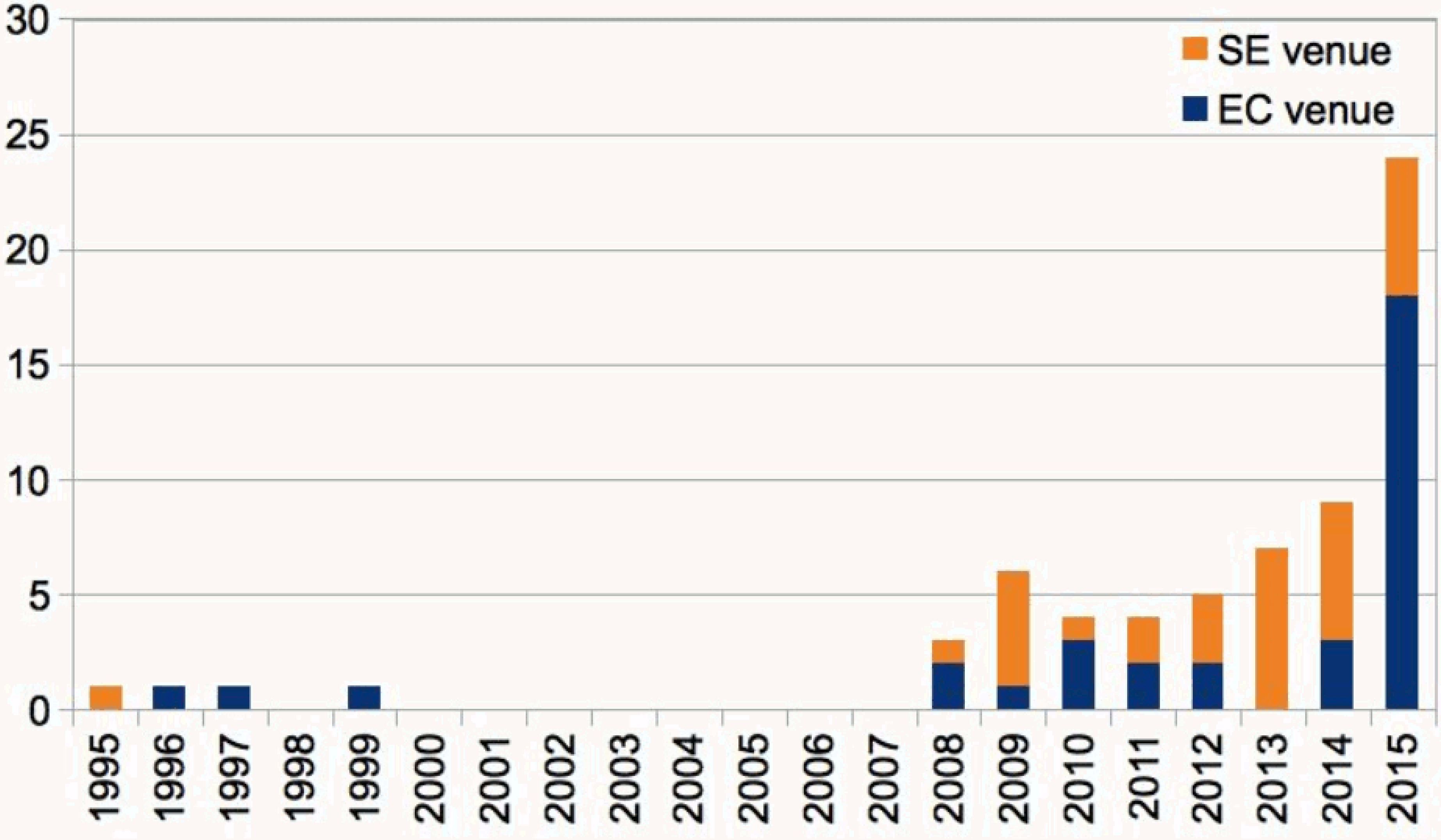
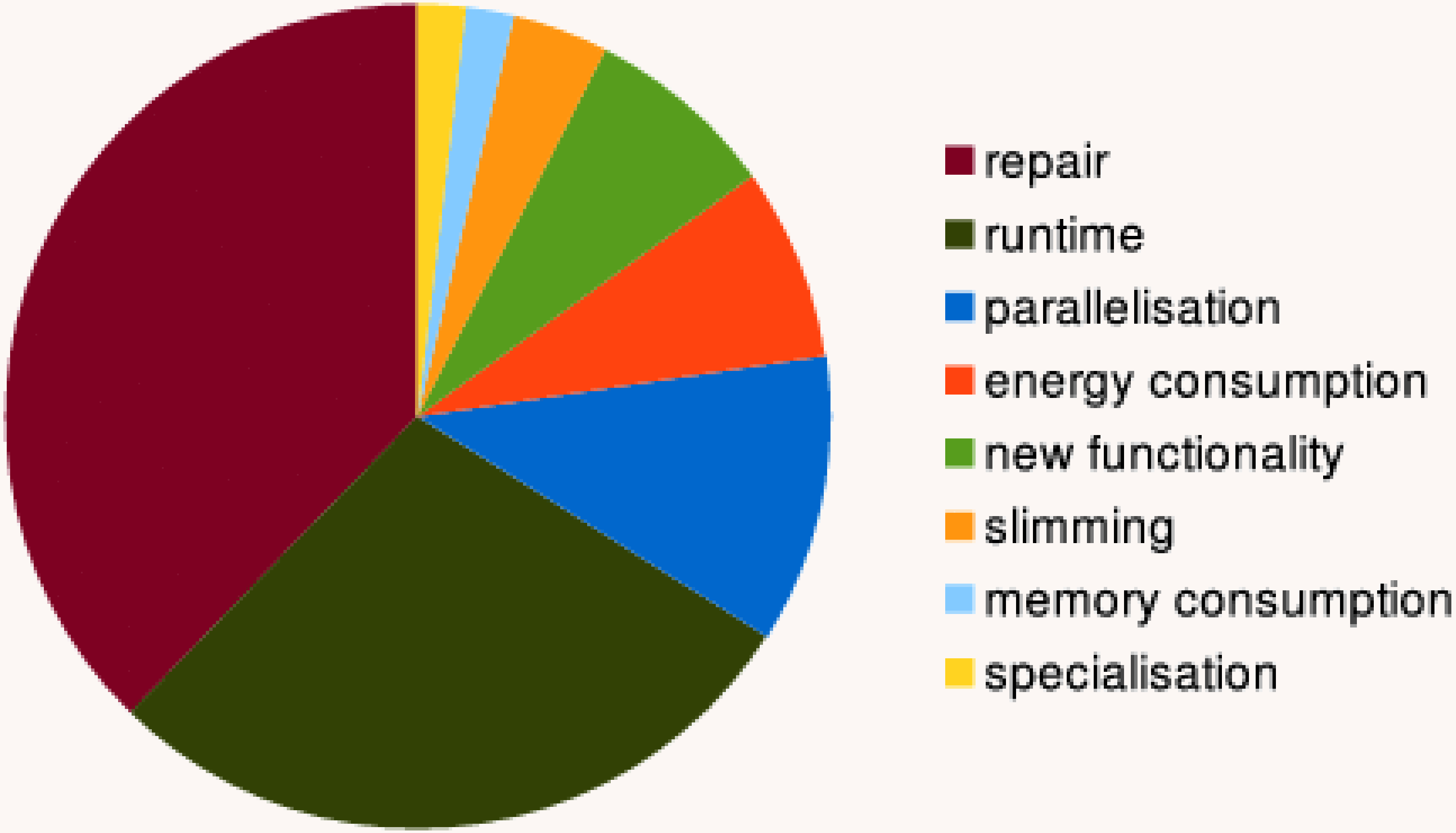


Fig 3. software applications of empirical studies in core papers on genetic improvement



Where is Genetic Improvement Headed

Goals of Genetic Improvement

- Totally automatic programming still distant
- Intermediate GI as stepping stone to higher level programming. Programmer says what needs to be done by test cases.
- Program assembled from existing(perhaps open source) code or more automated bag-of-parts software product lines
- Automatic customisation, per user versions, many (30184) version computing

GI Automatic Coding

- Genetic Improvement may also allow us to trade improvement in one aspect against loss in another.
  - E.g. reduce accuracy but faster execution
  - (Can sometimes improve both)
- Customise per user (dreaming smart phone)
- Predict what user will want to next.
  - E.g. yesterday read news page at 8:30 so today load it into cache before they reach underground tube station.

Automatic Testing

- Software quality continues to be dominated by the cost of manual effort
- Existing test suites are often run automatically
- Evolution can automatically create test cases (goal: code coverage) but still lacks knowledge of the correct answer (known as the test oracle problem).

Automatic Oracle Generation

- Current automatic oracles are crude:
  - did the program terminate? Did it crash?
- Given huge number of existing open source test suites [SBST 2017], can Machine Learning:
  - infer the answer expected of a test case?
  - could Machine Learning get close or give plausible answers?
  - Reject non-plausible answers?

Potential GI Links to Emergent and Self Adaptive Systems

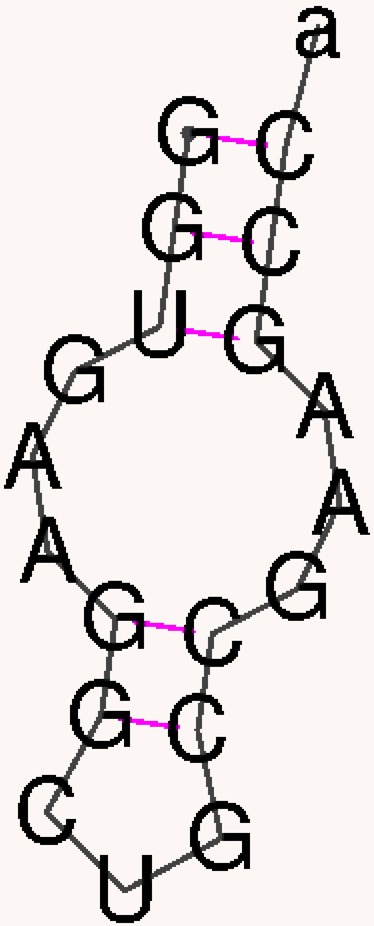
Genetic Improvement in Emergent and Self-adaptive Systems

- ECSELR adapt Java code via JVM
  - Evolution runs inside the Java Virtual Machine
  - Tune distributed www online video services in response to changes in user geographic load
- Adaptation: detect and repair buffer overruns [failure-oblivious computing]

  (Faster to trap invalid memory exception than test every access for end-of-buffer [ukmac 2016])

GI and Dynamic Programming

- Use evolution to adapt 50,000 parameters of dynamic programming model.
- RNAfold predicts RNA structures based on finding one with minimum energy.
- RNA is a long chain biomolecule (cf. DNA) which reduces energy by binding to self.
- Adjust parameters to fit reality



DP used in OR

Big Data and Self Adaptation?

- Deep learning needs large data, so
- What are suitable data open sources of training data to aid *adaptation* e.g. to user

1. User feedback
   - Sparse, badly structured? Apt stores?
   - 5% users are testers, instrument user
   - Dreaming smart phones
2. Bug reports/crash dumps
   - Bugzilla 200 per week (cf. Iceland health clinic)
   - Bug triage tries to discard lots of data. Can we learn from it instead?

Six impossible things before breakfast

- To have impact do something considered impossible.
- If you believe software is fragile you will not only be wrong but shut out the possibility of mutating it into something better.
- Genetic Improvement has repeatedly shown mutation need not be disastrous and can lead to great things.

Conclusions

- Genetic Improvement (GI) applying Genetic Programming to existing code
- GI for automatic bugfixing, software transplanting, performance improvement faster answers or better answers.

  BarraCUDA 3,095 sourceforge downloads (26 months).

  Commercial use by Lab7 (in BioBuilds Nov2015)

  IBM Power8. RNAfold
- Future GI, test oracles. Do impossible things
- Software is not fragile

  break it, bend it, Evolve it

Charles Darwin 1809-1882

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Genetic Improvement

Genetic Improvement 2017

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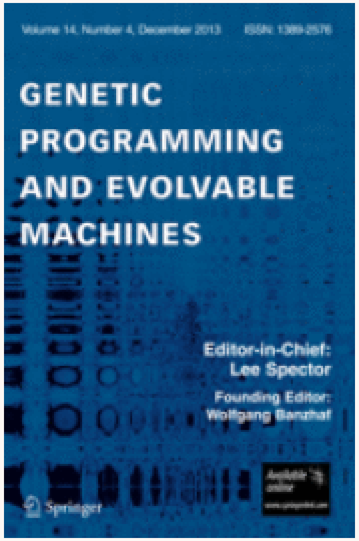
End



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GI special issue

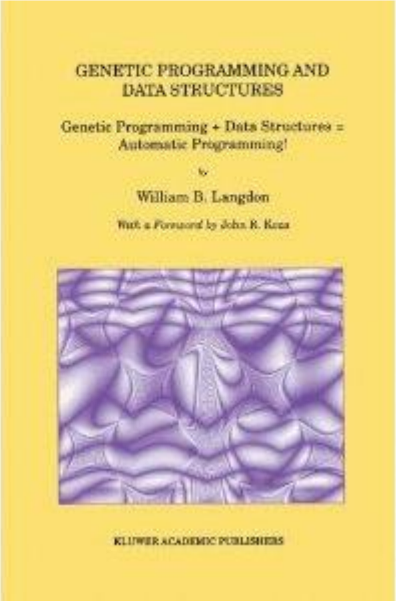
http://www.cs.ucl.ac.uk/staff/W.Langdon/ http://www.epsrc.ac.uk/ EPSRC

Genetic Improvement

W. B. Langdon

CREST

Department of Computer Science



GENETIC PROGRAMMING AND DATA STRUCTURES

Genetic Programming + Data Structures = Automatic Programming!

by

William B. Langdon

With a Foreword by John R. Koza

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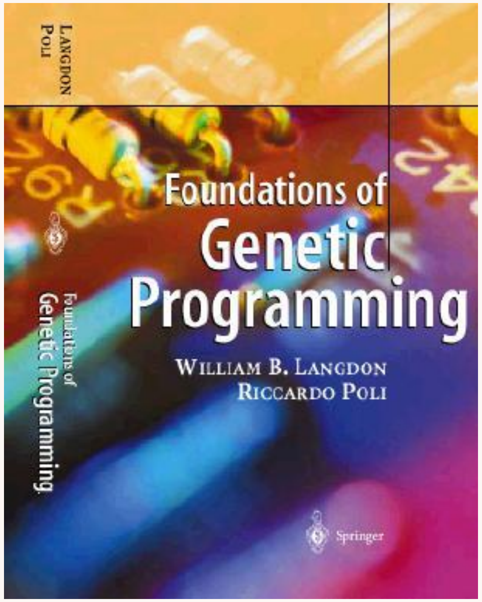
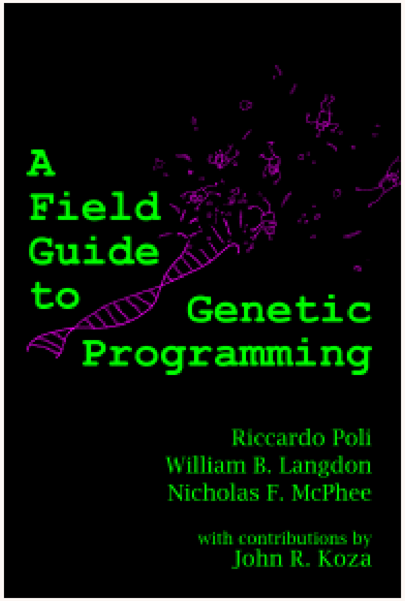


Foundations of Genetic Programming

WILLIAM B. LANGDON
RICCARDO POLI

Springer



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- ECSELR adapt Java JVM
  - – Tune distributed www online video services in response to changes in user geographic load
- Testing scales (sort of)
- Adaptation: detect and repair buffer overruns
- Workshop 2014 imperial[], (SE only Dagstuhl Seminar 2013)

BNF Grammar

Configuration parameter

```
if (*lastpos!=pos_shifted)
{
#ifndef sequence_global
  *data = tmp = tex1Dfetch(sequences_array, pos_shifted);
#else
  *data = tmp = Global_sequences(global_sequences,pos_shifted);
#endif /*sequence_global*/
  *lastpos=pos_shifted;
}
```

CUDA lines 119-127

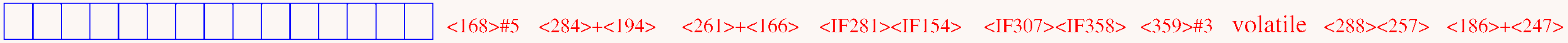
```
<119>   ::= " if" <IF_119> " \n"
<IF_119>::= "(*lastpos!=pos_shifted)"
<120>   ::= "{\n"
<121>   ::= "#ifndef sequence_global\n"
<122>   ::= "" <_122> "\n"
<_122>  ::= "*data = tmp = tex1Dfetch(sequences_array, pos_shifted);"
<123>   ::= "#else\n"
<124>   ::= "" <_124> "\n"
<_124>  ::= "*data = tmp = Global_sequences(global_sequences,pos_shifted);"
<125>   ::= "#endif\n"
<126>   ::= "" <_126> "\n"
<_126>  ::= "*lastpos=pos_shifted;"
<127>   ::= "}\n"
```

Fragment of Grammar (Total 773 rules)

Grammar rule types

- Type indicated by rule name
- Replace rule only by another of same type
- Fixed (evolution cannot change code), variable.
- statements (e.g. assignment, **Not** declaration)
- <_947> ::= "*k0 = k;"
- IF
- <_392>   ::= " if" <IF_392> " {\n"
- <IF_392>   ::= " (par==0)"
- for loops (for1, for2, for3)
- "for(" <for1_630> ";" <for2_630> ";" <for3_630> ") \n"
- ELSE
- specials

Representation



<168>#5 <284>+<194> <261>+<166> <IF281><IF154> <IF307><IF358> <359>#3 volatile <288><257> <186>+<247>

- variable length list of grammar patches.
  - no size limit, so search space is infinite
- tree like 2pt crossover.
- Mutation adds one randomly chosen grammar change
- 3 possible grammar changes:
  - Delete line of source code (or replace by “”, 0)
  - Replace with line of GPU code (same type)
  - Insert a copy of another line of kernel code

Example Mutating Grammar

```
<_947> ::= "*k0 = k;"
<_929> ::= "((int*)l0)[1] =
__shfl(((int*)&l)[1],threads_per_sequence/2,threads_per_sequence);
"
```

2 lines from grammar

```
<_947>+<_929>
```

Fragment of list of mutations

Says insert copy of line 929 before line 947

Copy of line 929

New code

```
((int*)l0)[1] =
__shfl(((int*)&l)[1],threads_per_sequence/2,threads_per_sequence);
*k0 = k;
```

Line 947

The Genetic Programming Bibliography

http://www.cs.bham.ac.uk/~wbl/biblio/

11748 references, 10000 authors

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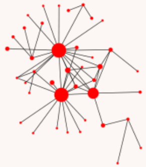

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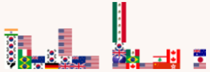
Co-authorships

Co-authorship community.
Downloads

Downloads by day



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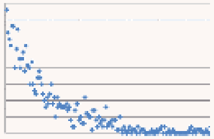

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