Evolving sqrt $\sqrt{}$ into $1/x$ via software data maintenance

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and
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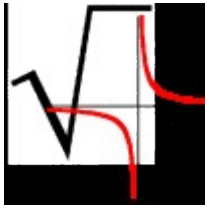
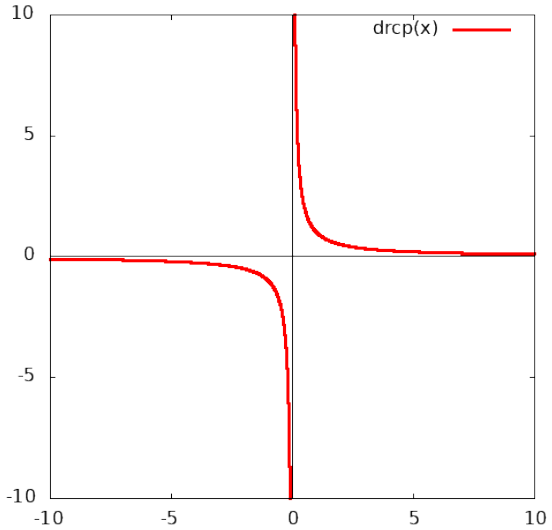


Genetic Improvement via Data

- Different type of Genetic Improvement
- Optimise embedded constants, i.e. data
  1. GI on data to evolve new or better functionality
  2. Same functionality, but better (e.g. use less energy)
- Why
  1. Minimal code changes may be more acceptable?
  2. Easier route into GI: use your favourite optimisation tool on numbers inside program source code.
     - The objective measure is based on how existing program behaves with new data inside it.
     - Eg optimise internal parameters, answer x% better

Why Reciprocal $\frac{1}{x}$

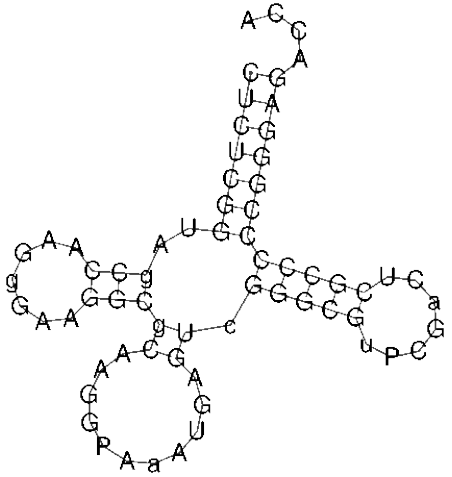


- Example of Genetic Improvement on data
- On hardware with slow division (possibly mote computing IoT) multiplication by GI double precision reciprocal could be faster

$a \times \text{drcp}(b)$ could be quicker than $\frac{a}{b}$

Genetic Improvement via Data

- New functionality via data changes
  - RNAfold better predictions [EuroGP 2018]
  - New maths functions, e.g. convert $\sqrt{x}$ into $1/x$
- In future can you improve software (e.g. faster) whilst keeping old behaviour?



RNA molecule. Example of more accurate RNAfold output

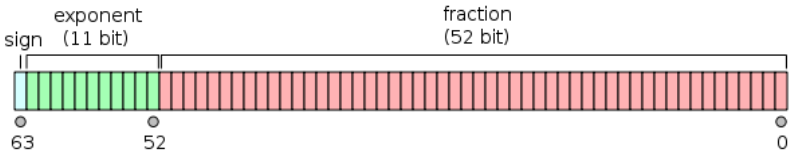
Maintaining Embedded Constants

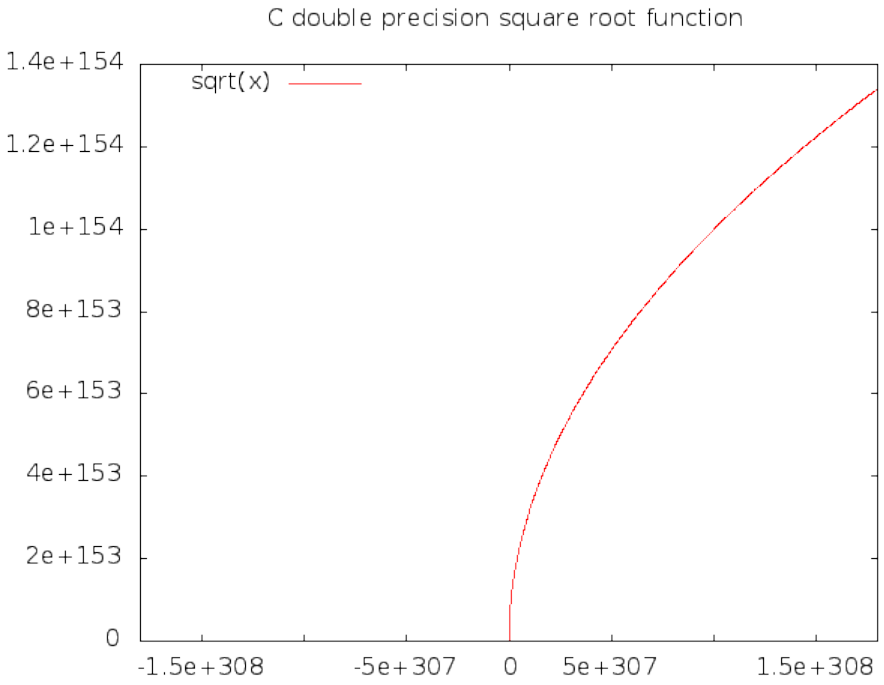
- EuroGP 2018
  - RNAfold 7000 lines of code 50000 numbers
  - On average better predictions of RNA folding.
  - Shipped since 2018 (release 2.4.7)
- Evolution plus *manual changes* to open source GNU C library double precision sqrt gives:
  - cube root
  - $\log_2$
  - invsqrt $\frac{1}{\sqrt{x}}$
  - division less division $1/x$

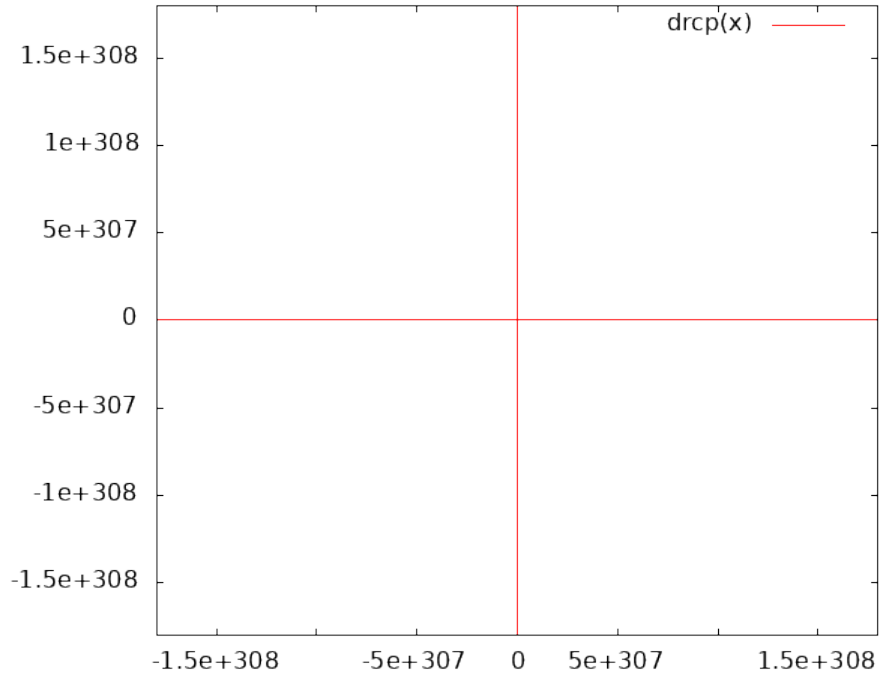
Use CMA-ES to convert sqrt into $1/x$

By updating table of 512 floats used by PowerPC code.

IEEE 754 Double Precision





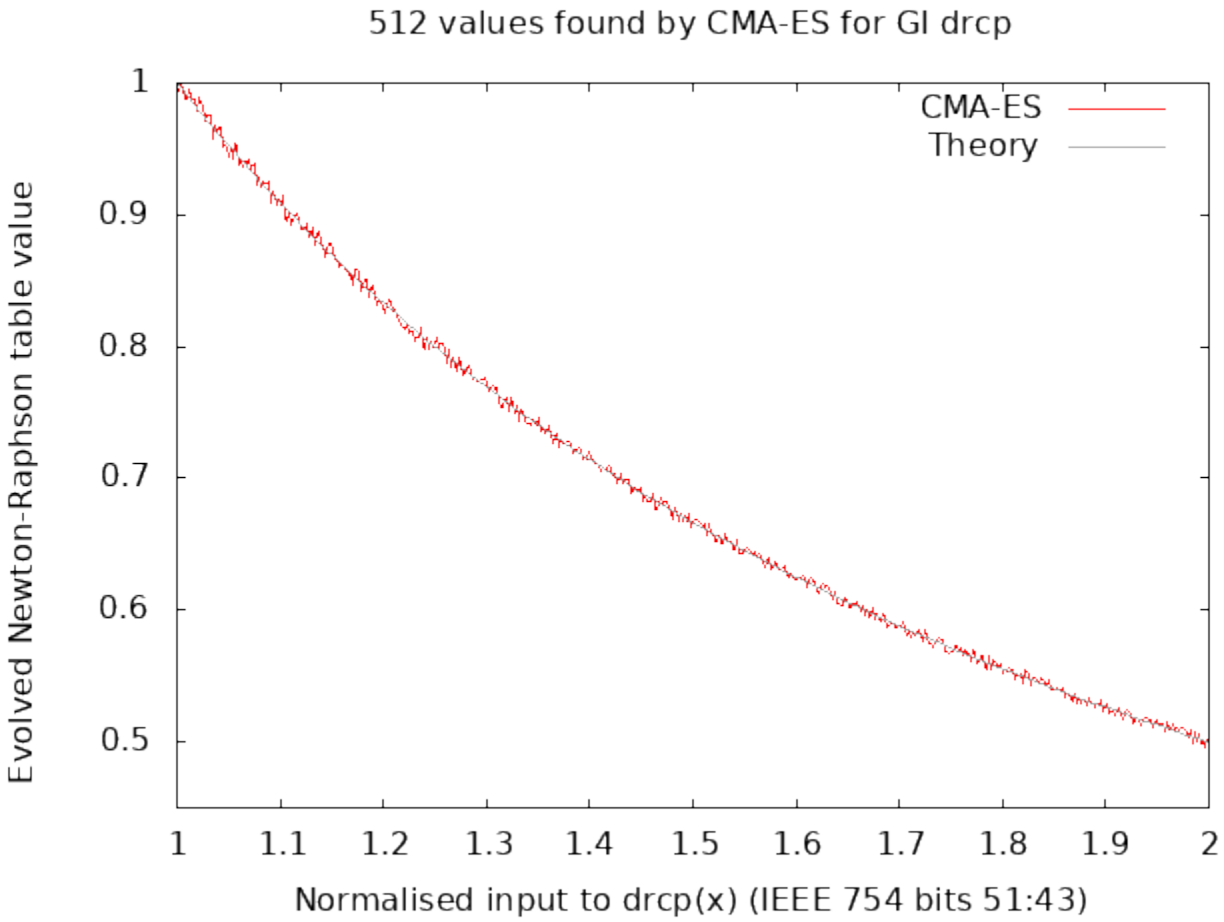


GNU C library sqrt $\sqrt{x}$ converted to $1/x$

- sqrt puts normalised input x into 512 bins
- Each bin holds a start point for Newton-Raphson
- Run CMA-ES per bin (total ≥512 times)
  - Seed with square root data
  - Run drcp code with CMA-ES generated value to give c='drcp'(x). Inverting c should give x
  - Fitness based on difference | 1/c – x |

    x takes 3 test values: smallest, mid, max in bin
- Usually all differences smallest possible
- else run CMA-ES again

CMA-ES



CMA-ES finds good values for all Newton-Raphson bins

Evolved drcp $\frac{1}{x}$

Evolved double reciprocal drcp tested many thousands of times

- It works!
  - Always within DBL_EPSILON (2^{-52}, $2.2\ 10^{-16}$)
    - I.e. smallest possible difference still visible in double precision arithmetic
  - Almost always gives best possible double
- Easy. (six seconds)
- You can do better.

Automatic Software Maintenance

- In a world addicted to software, maintenance is the dominant cost of computing.
- Need to keep parameters up to date. E.g.
  - New science, new laws or regulations, new users, new user expectations
  - Change of load, new hardware (e.g. bigger RAM memory), auto port to new devices/phones
  - Search can be fast (total CMA-ES runtime 6 secs)
- Little SBSE research
- Great scope for automation

Summary: Genetic Improvement on Data

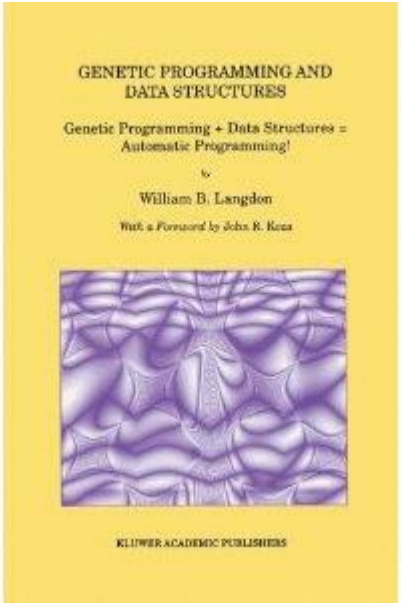
- Problem of maintaining data in code ignored
- GI can optimize data in programs
  - Use your own favourite optimiser on parameters numbers embedded in source code, with your objective: battery life, faster, better predictions, etc., etc.
- Rapidly generated maths (cbrt, $\log_2$, $\frac{1}{\sqrt{x}}$, $1/x$)
  - Replication package GitHub Replication_GI_Division_Free_Division
- Software is not fragile

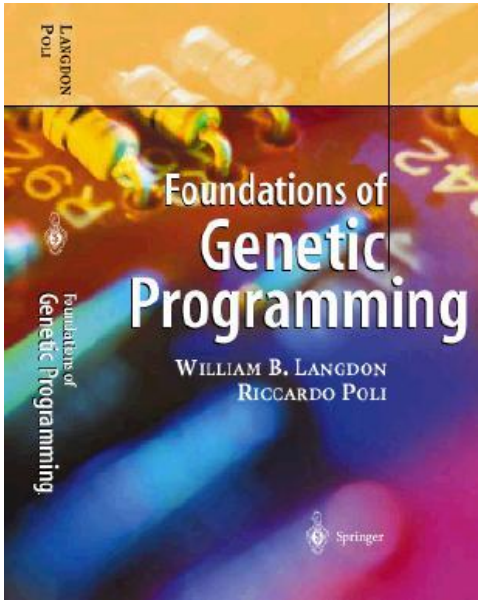
END

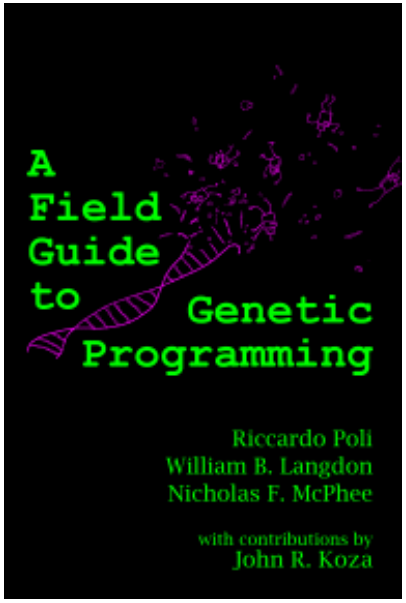
W. B. Langdon YouTube videos
https://www.youtube.com/channel/UChebBvv66dPOcElWk6ht4OA

Genetic Programming

W. B. Langdon







Improving RNAfold parameters

EuroGP-2018

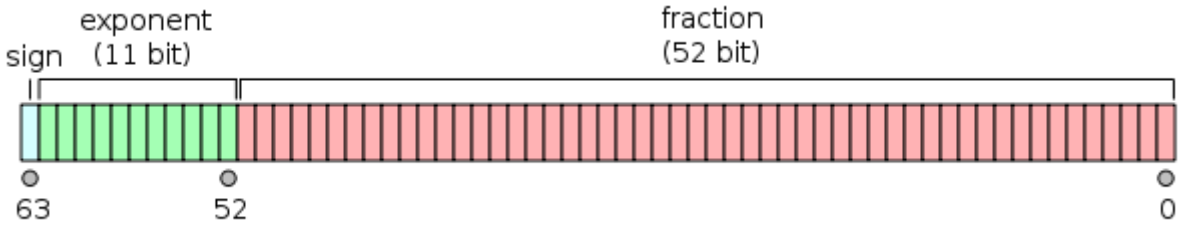
- RNAfold 7100 lines of C source code, 51521 parameters.
- Fitness correlation between prediction and true structure (MCC).
- Post evolution tidy
- 14732 (29%) parameters changed
- Holdout set significant increase in MCC
- Also better than constrained optimisation
- GI parameters rna_langdon2018.par shipped with ViennaRNA since 13 Jun 2018

Manual Changes I of 2 (old sqrt)

- Most implementations of square root use hardware support.
- GNU C library glibc 2.29 also includes Newton-Raphson iterative solution
- Trap bad values, e.g. negative
- Normalise double input to 0.5 .. 2.0
- Guaranteed convergence in three steps:
  - Update both estimate of $\sqrt{x}$ and derivative
- Apply square root to exponent, ie divide by 2

Code Changes II (for $1/x$)

- Normalise double precision input to 1.0..2
  - Update estimate of x^{-1}
  - Use reciprocal of derivative, i.e. $-x^{-2}$, directly
- Apply 1/x to exponent, i.e. negate.
- Could we use code GI to further improve?



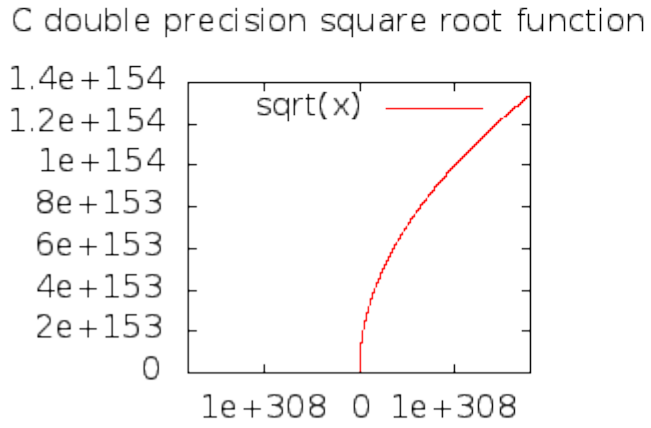
- Source code

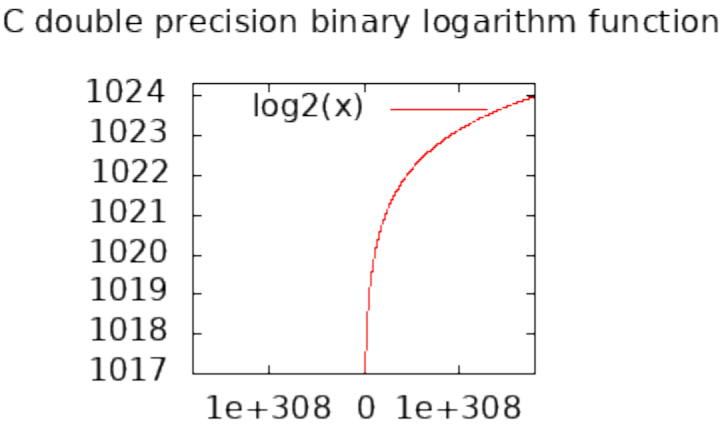
  http://www.cs.ucl.ac.uk/staff/W.Langdon/ftp/gp-code/gi_cbrt.tar.gz

Square root to $\log_2$ GECCO-2019

Frame work as sqrt to cbrt but

- Derivative known
- CMA-ES one dimension at a time (512 times) very easy





The Genetic Programming Bibliography

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13569 references, 12000 authors

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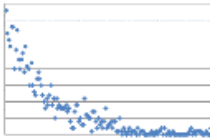

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