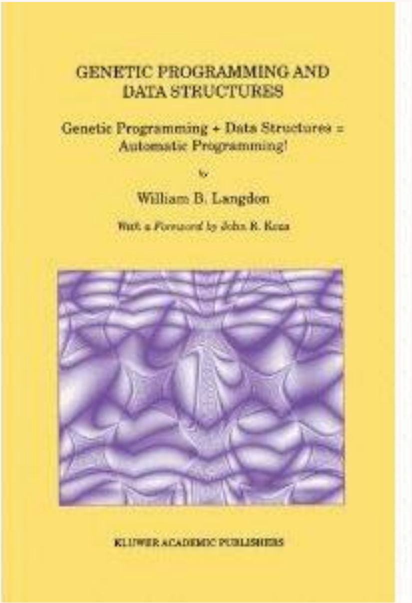
Genetic Improvement of Programs

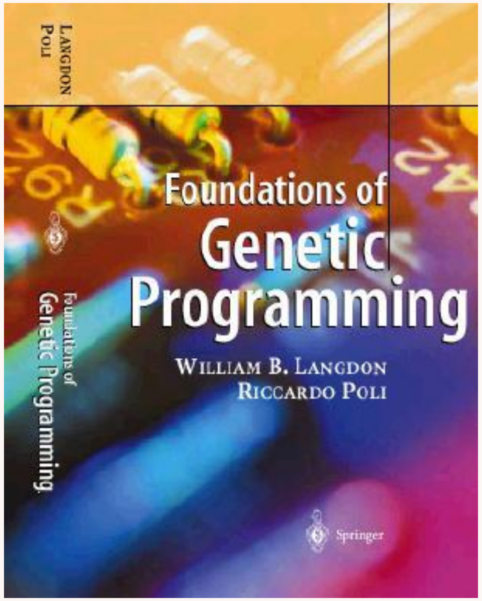
MENDEL 2012 Soft-Computing Conference

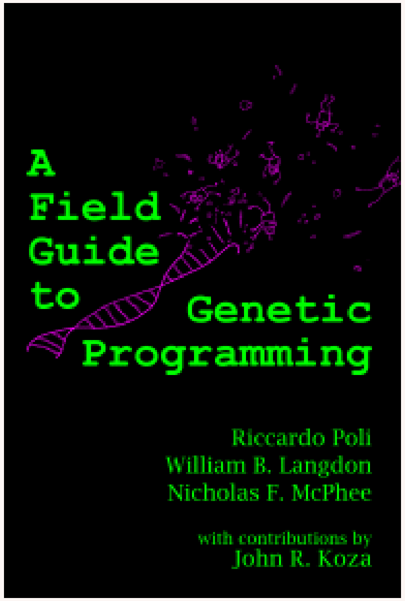
W. B. Langdon

CREST

Department of Computer Science







29.6.2012

Genetic Programming to Improve Software

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Computer Science, UCL, London

UCL

GISMO: Genetic Improvement of Software for Multiple Objectives

Genetic Improvement of Programs

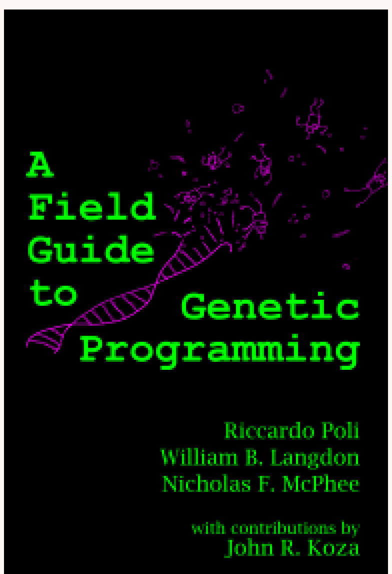
- Why
- Background
  - What is Genetic Programming
  - GP to improve human written programs
- Examples
  - Demonstration systems, automatic bug fixing
  - Evolving code for a new environment
- Implications

When to Automatically Improve Software

- When to use GP to create source code
  - Small. E.g. glue between systems “mashup”
  - Hard problems. Many skills needed.
  - Multiple conflicting ill specified non-functional requirements
- GP as tool. GP tries many possible options. Leave software designer to choose between best.

Genetic Programming

- A population of randomly created programs
  - whose 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.



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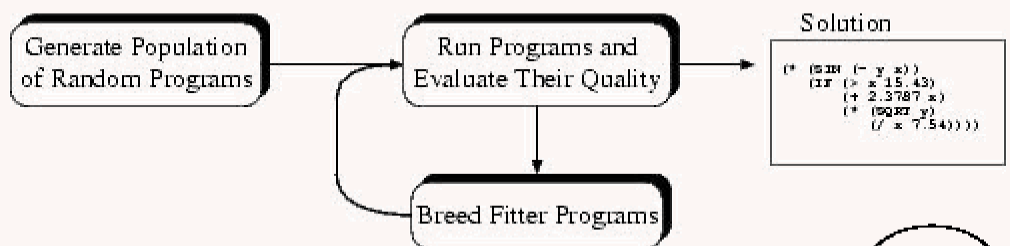
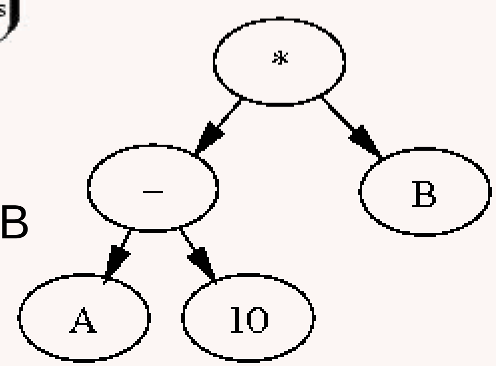
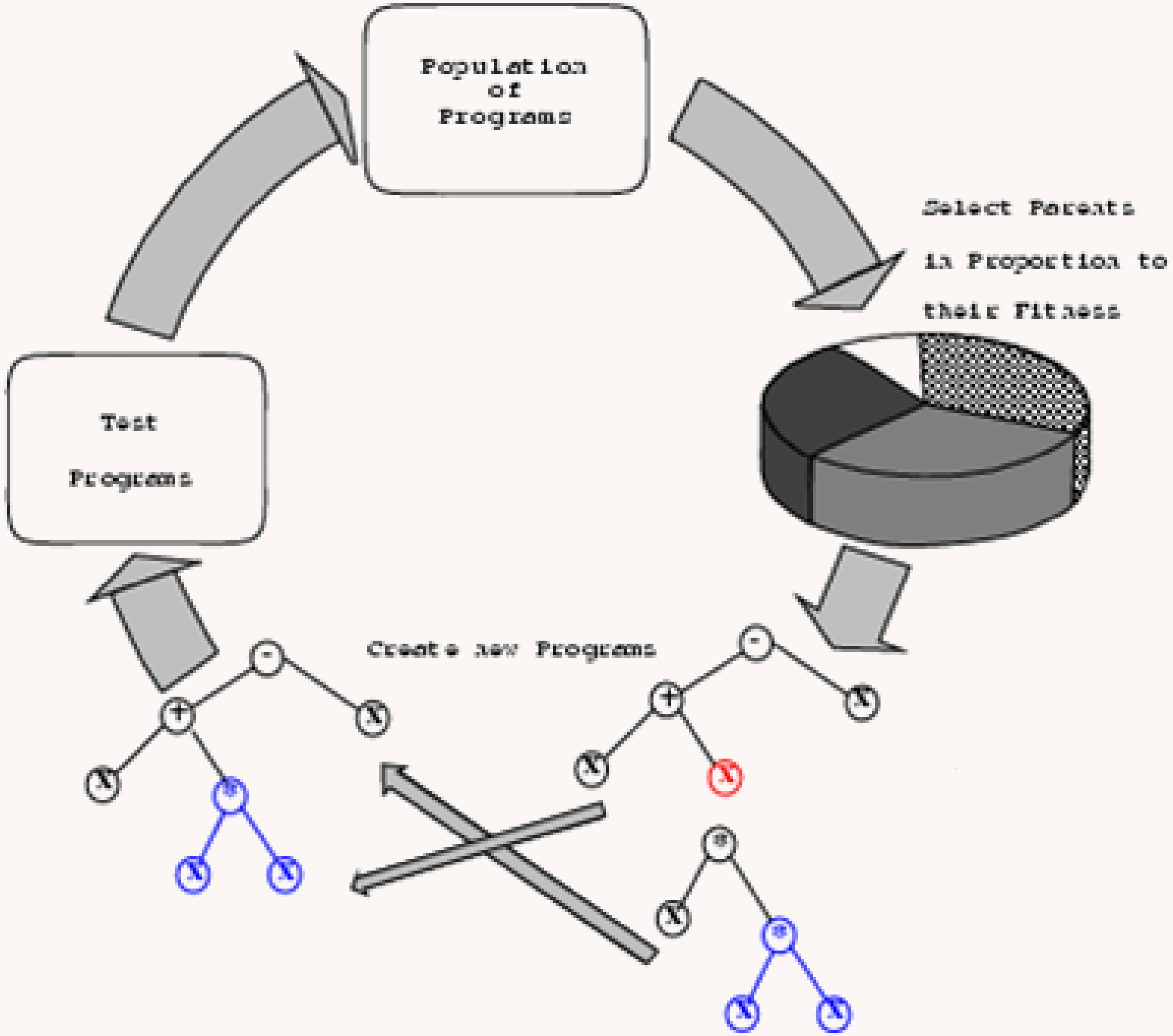


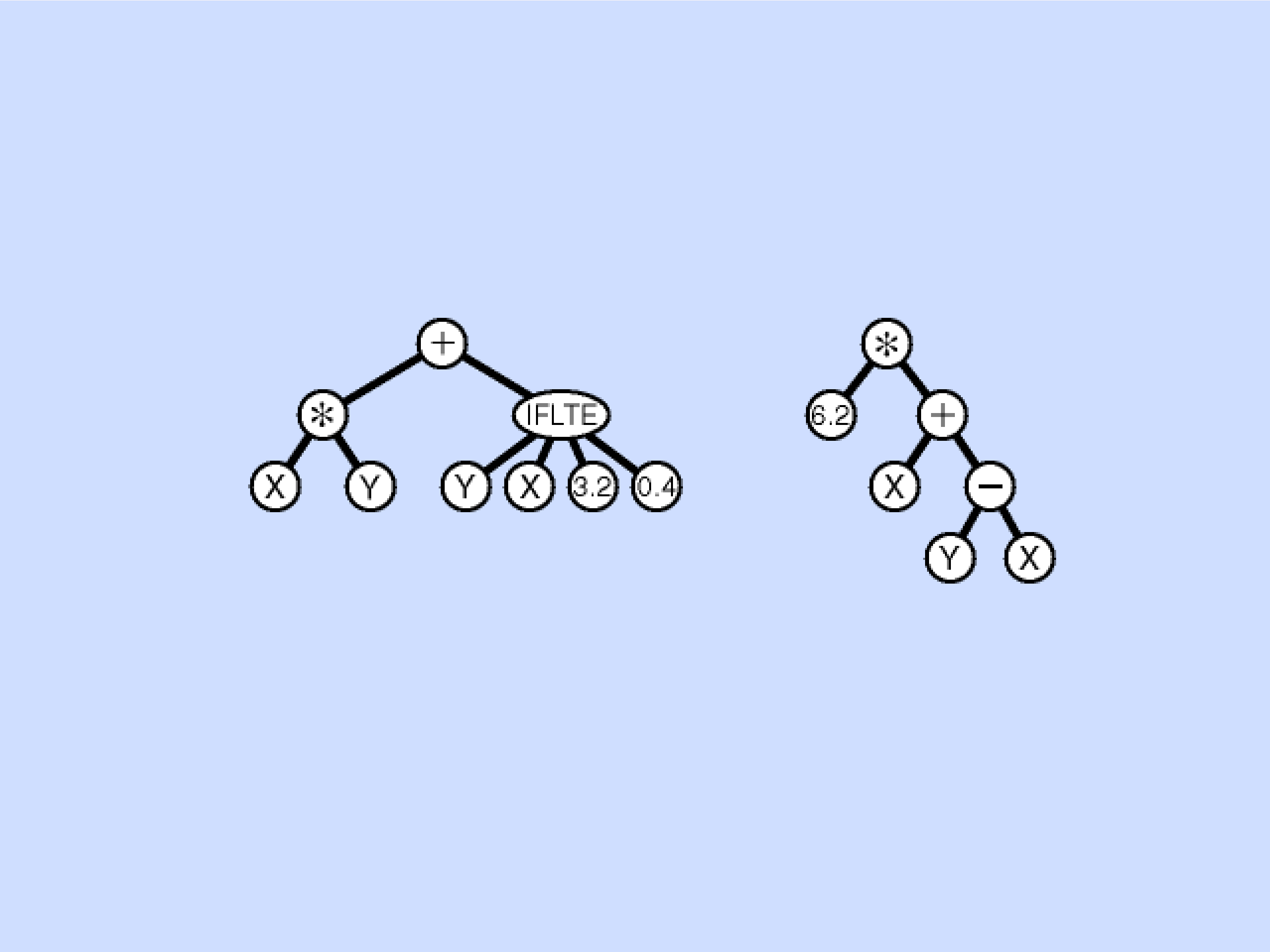
Tree (A-10)*B



GP Generational Cycle



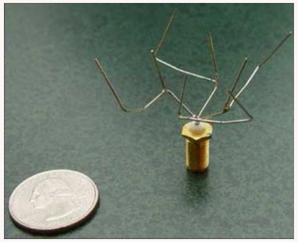
Creating new programs - Crossover

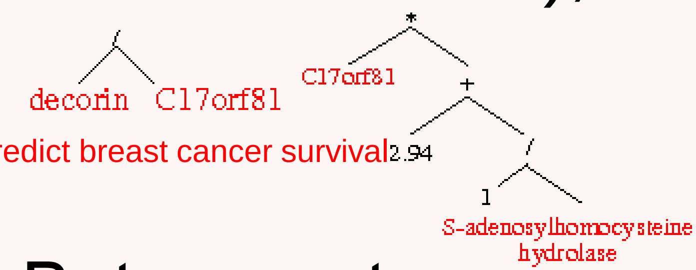


Movie

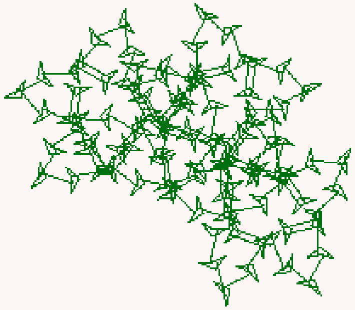
Some applications of Genetic Programming

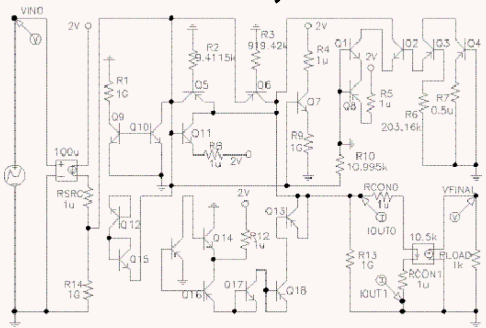
- Most GP generates solutions, e.g.:
  - data modelling,
  - chemical industry: soft sensors,
  - design (circuits, lenses, NASA satellite aerial),
  - image processing,
  - predicting steel hardness,
  - cinema “boids”, Cliff hanger, Batman returns

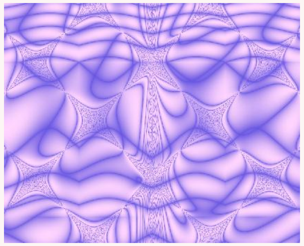


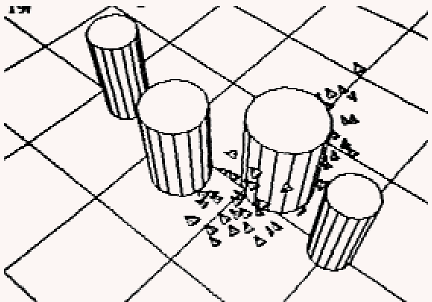


Predict breast cancer survival







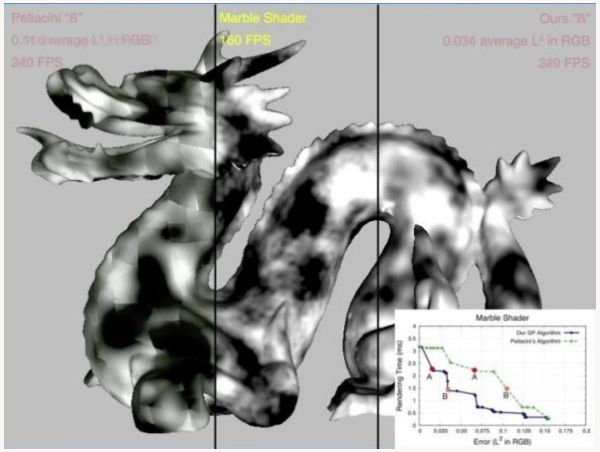


GP to Improve Human written Programs

- Gluing together existing programs to create new functionality
  - combining web services, mashup
- Tailoring for specific use
  - domain specific hash functions
  - heap management, garbage collection
  - evolving communications protocols

GP to Improve human written programs

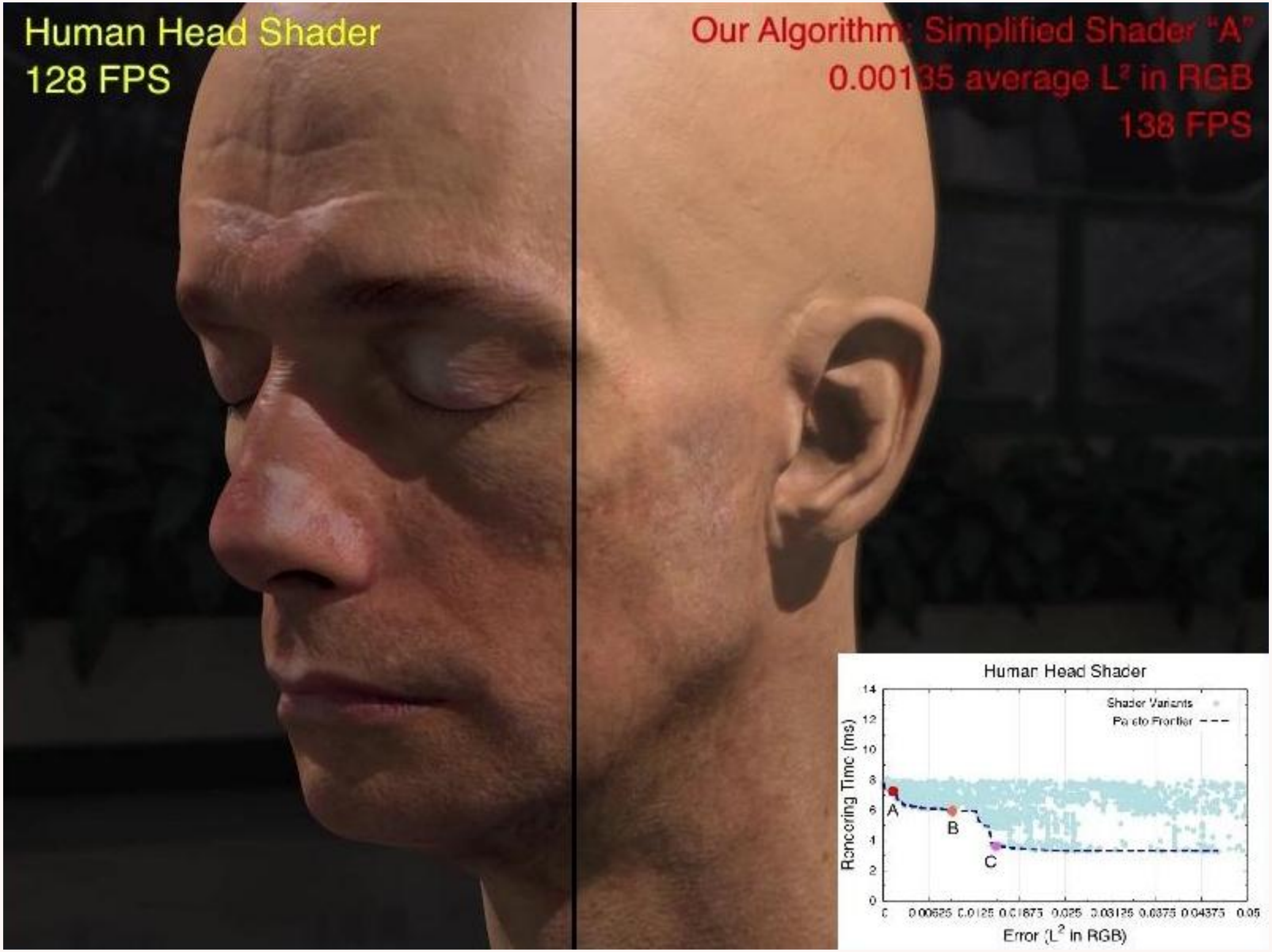
- Finch: evolve Java bytecode
  - no compilation errors, 6 benchmarks
- Improving GPU shaders
- Functionality v speed or battery life




```
int Factorial(int a)
{
  if  (a <= 0)
      return  1;
  else
      return  (a * Factorial(a-1));
}
```

Factorial source code,
87% reduction in instructions, [white,2011]

Improving GPU code



Sitthi-amorn, SIGGRAPH Asia 2011

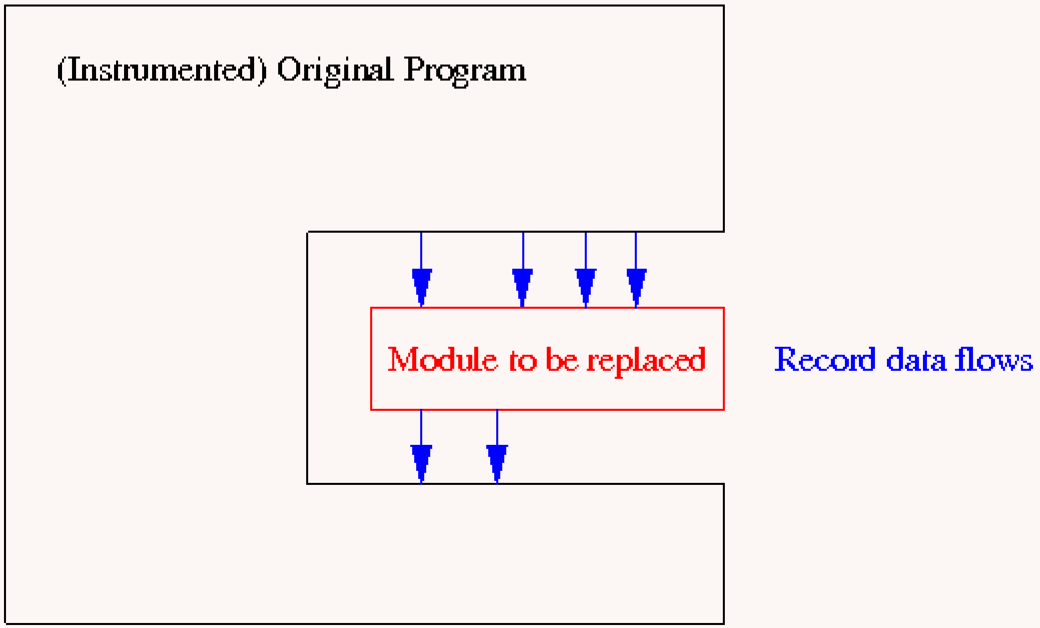
GP Automatic Bug Fixing

- Run code: example to reproduce bug, a few tests to show fixed code still works.
- Search for replacement C statement which fixes bug.
- Real bugs in real C programs.
  - 1st prize Human-Competitive GECCO 2009

GP Automatic Coding

- Target small unit.
- Use existing system as environment holding evolving code.
- Use existing test suite to exercise existing system but record data crossing interface.
- Use inputs & *answer* (Oracle) to train GP.
- How to guide GP initially?
- Clean up/validate new code

GP Automatic Coding



- Actual data into and out of module effectively act as the specification.
- Evolved code tested to ensure it responds like original code to inputs.
- Recorded data flows becomes test Oracle.

Proof of Concept: gzip

- Example: compute intensive part of gzip
- Automatically recode as parallel function written in CUDA
- Use nVidia's examples as starting point.
- BNF grammar keeps GP code legal, compliable, executable and terminates.
- Use training data gathered from original gzip to test evolved code.
- Why gzip? Well known, open source (C code), test suite.

Langdon+Harman WCCI 2010

CUDA Template

- nVidia supply lots of working examples.
- Choose simplest, that does a data scan. (We know gzip scans data).
- Naive template too simple to give speed up, but shows plausibility of approach.
- NB template knows nothing of gzip functionality. GP search is guided by the test suite (fitness function).

scan_naive_kernel.cu

```
//WBL 30 Dec 2009 $Revision: 1.11 $ Remove comments, blank lines. int g_odata, uch g_idata. Add
strstart1 strstart2, const.
 move offset and n, rename n as num_elements
WBL 14 r1.11 Remove crosstalk between threads threadIdx.x, temp -> g_idata[strstart1/strstart2]
__device__ void scan_naive(int *g_odata, const uch *g_idata, const int strstart1, const int strstart2)
{
    //extern  __shared__  uch temp[];
    int thid = 0; //threadIdx.x;
    int pout = 0;
    int pin = 1;
    int offset = 0;
    int num_elements = 258;
    <3var> /*temp[pout*num_elements+thid]*/ = (thid > 0) ? g_idata[thid-1] : 0;
    for (offset = 1; offset < num_elements; offset *= 2)
    {
        pout = 1 - pout;
        pin  = 1 - pout;
        //__syncthreads();
        //temp[pout*num_elements+thid] = temp[pin*num_elements+thid];
        <3var> =  g_idata[strstart+pin*num_elements+thid];
        if (thid >= offset)
        <3var> += g_idata[strstart+pin*num_elements+thid - offset];
    }
    //__syncthreads();
    g_odata[threadIdx.x] = <3var>
}
```

BNF grammar

scan_naive_kernel.cu converted into grammar (169 rules) which generalises code.

```
<line10-18>      ::=   "" | <line10-18a>
<line10-18a>     ::=   <line10e> <line11> <forbody> <line18>
<line11>         ::=   "{\n" "if(!ok()) break;\n"
<line18>         ::=   "}\n"
<line10e>        ::=   <line10> | <line10e1>
<line10e1>       ::=   "for (offset =" <line10.1> ";" <line10e.2> ";offset" <line10.4> ")\n"
<line10.1>       ::=   <line10.1.1> | <intexpr>
<line10.1.1>     ::=   "1" | <intconst>

<line10e.2>      ::=   <line10e.2.1> | <forcompexpr>
<line10e.2.1>    ::=   "offset" <line10.2> <line10.3>
<line10.2>       ::=   "<" | <compare>
<line10.3>       ::=   <line10.3.1> | <intexpr>
<line10.3.1>     ::=   "num_elements" | <intconst>

<line10.4>       ::=   "*= 2" | <intmod>

<intmod>         ::=   "++" | <intmod2>
<intmod2>        ::=   "*=" <intconst>
```

Fragment of
4 page grammar

gzip

- gzip scans input file looking for strings that occur more than once. Repeated sequences of bytes are replaced by short codes.
- n^2 reduced by hashing etc. but gzip still does 42 million searches (sequentially).
- Demo: convert CPU hungry code to parallel GPU graphics card code.

gzip longest_match()

```c
/* ===========================================================================
 * Set match_start to the longest match starting at the given string and
 * return its length. Matches shorter or equal to prev_length are discarded,
 * in which case the result is equal to prev_length and match_start is
 * garbage.
 * IN assertions: cur_match is the head of the hash chain for the current
 *   string (strstart) and its distance is <= MAX_DIST, and prev_length >= 1
 */
#ifndef ASMV
/* For MSDOS, OS/2 and 386 Unix, an optimized version is in match.asm or
 * match.s. The code is functionally equivalent, so you can use the C version
 * if desired.
 */
int longest_match(cur_match)
    IPos cur_match;                             /* current match */
{
    unsigned chain_length = max_chain_length;   /* max hash chain length */
    register uch *scan = window + strstart;     /* current string */
    register uch *match;                        /* matched string */
    register int len;                           /* length of current match */
    int best_len = prev_length;                 /* best match length so far */
    IPos limit = strstart > (IPos)MAX_DIST ? strstart - (IPos)MAX_DIST : NIL;
    /* Stop when cur_match becomes <= limit. To simplify the code,
     * we prevent matches with the string of window index 0.
     */

/* The code is optimized for HASH_BITS >= 8 and MAX_MATCH-2 multiple of 16.
 * It is easy to get rid of this optimization if necessary.
 */
#if HASH_BITS < 8 || MAX_MATCH != 258
   error: Code too clever
#endif

#ifdef UNALIGNED_OK
    /* Compare two bytes at a time. Note: this is not always beneficial.
     * Try with and without -DUNALIGNED_OK to check.
     */
    register uch *strend = window + strstart + MAX_MATCH - 1;
    register ush scan_start = *(ush*)scan;
    register ush scan_end   = *(ush*)(scan+best_len-1);
#else
    register uch *strend = window + strstart + MAX_MATCH;
    register uch scan_end1  = scan[best_len-1];
    register uch scan_end   = scan[best_len];
#endif

    /* Do not waste too much time if we already have a good match: */
    if (prev_length >= good_match) {
        chain_length >>= 2;
    }
    Assert(strstart <= window_size-MIN_LOOKAHEAD, "insufficient lookahead");

    do {
        Assert(cur_match < strstart, "no future");
        match = window + cur_match;

        /* Skip to next match if the match length cannot increase
         * or if the match length is less than 2:
         */
#if (defined(UNALIGNED_OK) && MAX_MATCH == 258)
        /* This code assumes sizeof(unsigned short) == 2. Do not use
         * UNALIGNED_OK if your compiler uses a different size.
         */
        if (*(ush*)(match+best_len-1) != scan_end ||
            *(ush*)match != scan_start) continue;

        /* It is not necessary to compare scan[2] and match[2] since they are
         * always equal when the other bytes match, given that the hash keys
         * are equal and that HASH_BITS >= 8. Compare 2 bytes at a time at
         * strstart+3, +5, ... up to strstart+257. We check for insufficient
         * lookahead only every 4th comparison; the 128th check will be made
         * at strstart+257. If MAX_MATCH-2 is not a multiple of 8, it is
         * necessary to put more guard bytes at the end of the window, or
         * to check more often for insufficient lookahead.
         */
        scan++, match++;
        do {
        } while (*(ush*)(scan+=2) == *(ush*)(match+=2) &&
                 *(ush*)(scan+=2) == *(ush*)(match+=2) &&
                 *(ush*)(scan+=2) == *(ush*)(match+=2) &&
                 *(ush*)(scan+=2) == *(ush*)(match+=2) &&
                 scan < strend);
        /* The funny "do {}" generates better code on most compilers */

        /* Here, scan <= window+strstart+257 */
        Assert(scan <= window+(unsigned)(window_size-1), "wild scan");
        if (*scan == *match) scan++;

        len = (MAX_MATCH - 1) - (int)(strend-scan);
        scan = strend - (MAX_MATCH-1);

#else /* UNALIGNED_OK */

        if (match[best_len]   != scan_end  ||
            match[best_len-1] != scan_end1 ||
            *match            != *scan     ||
            *++match          != scan[1])      continue;

        /* The check at best_len-1 can be removed because it will be made
         * again later. (This heuristic is not always a win.)
         * It is not necessary to compare scan[2] and match[2] since they
         * are always equal when the other bytes match, given that
         * the hash keys are equal and that HASH_BITS >= 8.
         */
        scan += 2, match++;

        /* We check for insufficient lookahead only every 8th comparison;
         * the 256th check will be made at strstart+258.
         */
        do {
        } while (*++scan == *++match && *++scan == *++match &&
                 *++scan == *++match && *++scan == *++match &&
                 *++scan == *++match && *++scan == *++match &&
                 *++scan == *++match && *++scan == *++match &&
                 scan < strend);

        len = MAX_MATCH - (int)(strend - scan);
        scan = strend - MAX_MATCH;

#endif /* UNALIGNED_OK */

        if (len > best_len) {
            match_start = cur_match;
            best_len = len;
            if (len >= nice_match) break;
#ifdef UNALIGNED_OK
            scan_end = *(ush*)(scan+best_len-1);
#else
            scan_end1  = scan[best_len-1];
            scan_end   = scan[best_len];
#endif
        }
    } while ((cur_match = prev[cur_match & WMASK]) > limit
             && --chain_length != 0);

    return best_len;
```

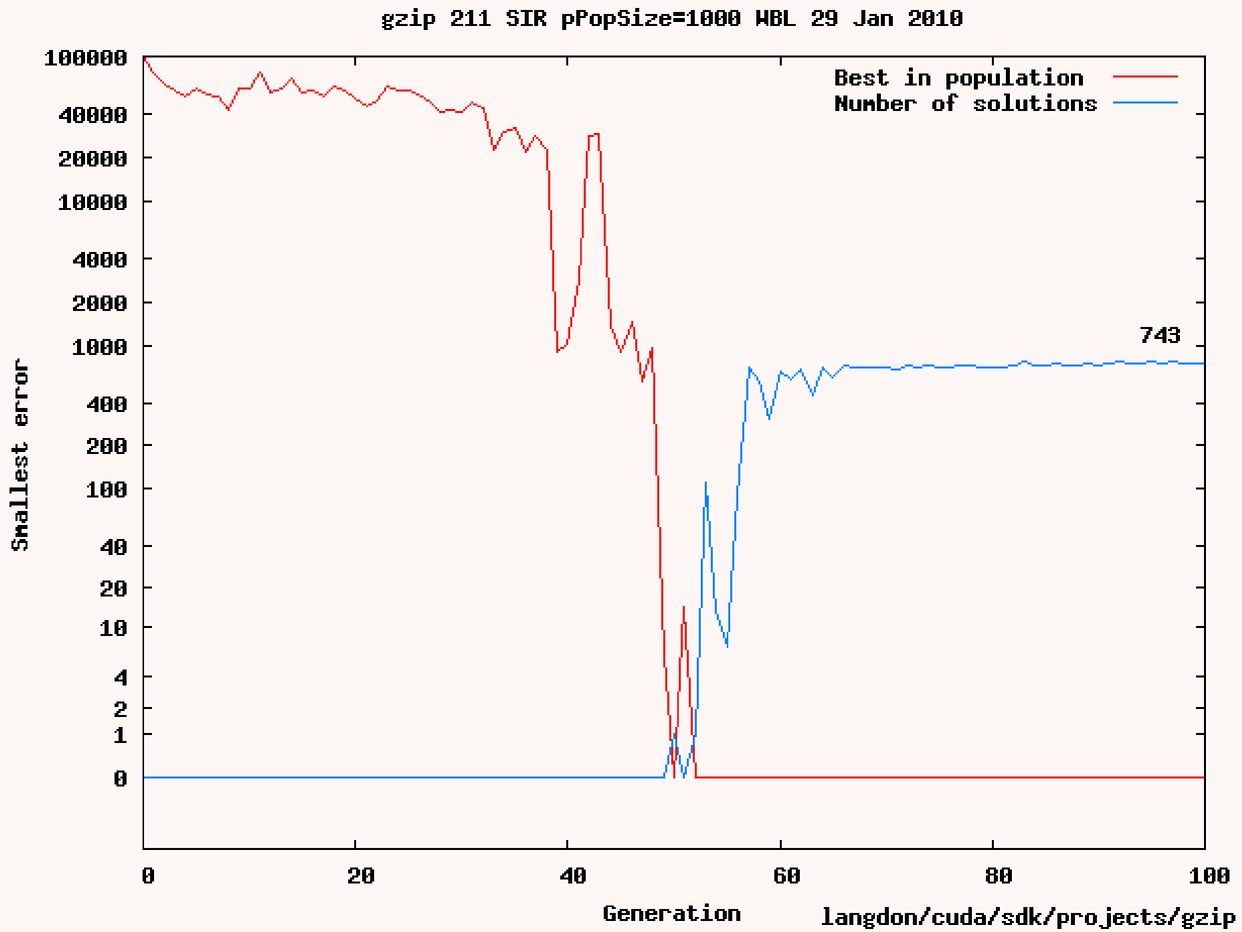
Fitness

- Instrument gzip.
- Run gzip on test suite. Log all inputs to longest_match(). 1,599,028 records.
- Select 29,315 for training GP.
- Each generation uses 100 of these.

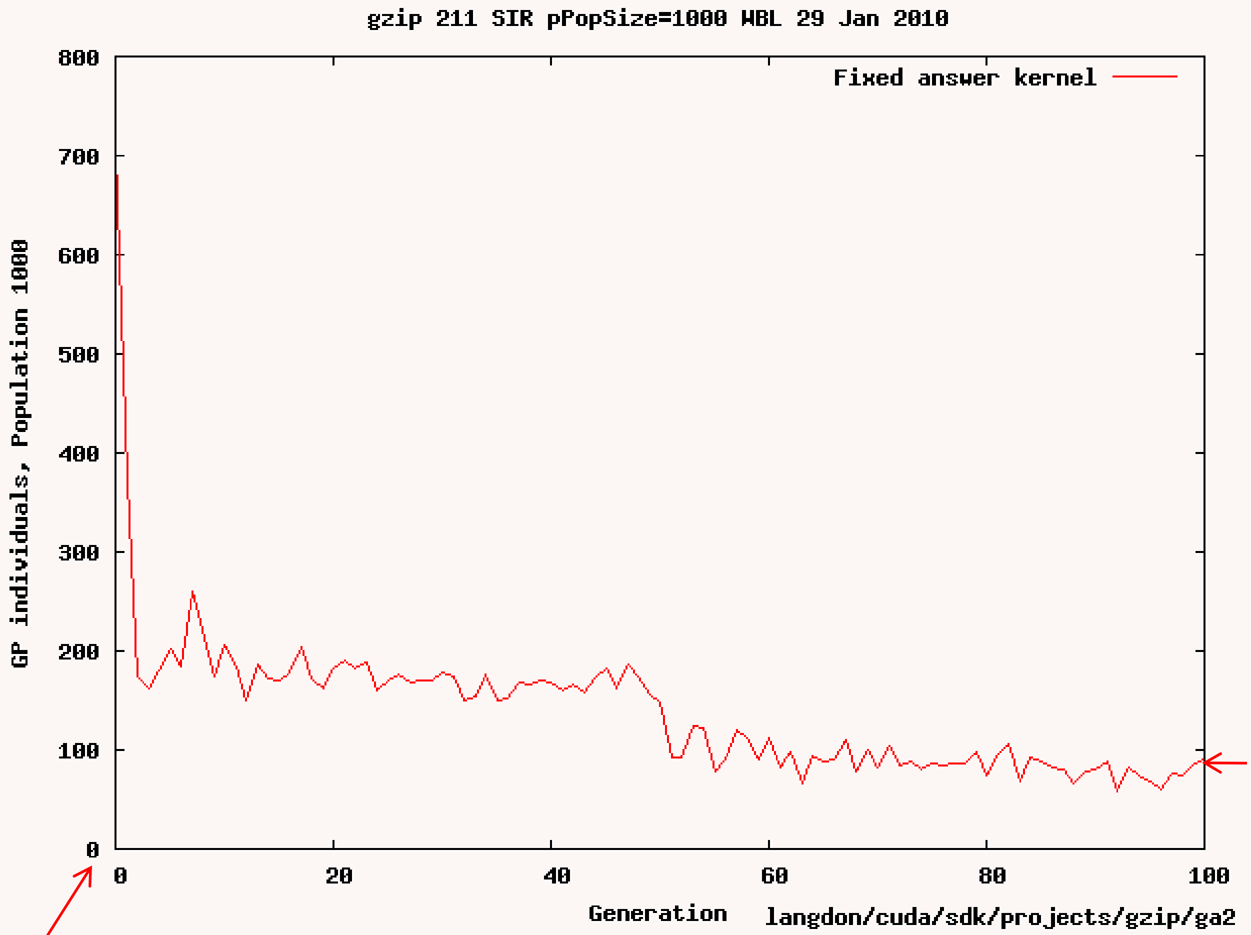
Fitness 2

- The tests are run on the original gzip code and its answers saved.
- Each evolved CUDA function (1000) is run and answers compared with gzip's answer. Up to 1588000 threads.
- performance = $\Sigma|\text{error}|$ + penalty
- Many functions always return 0, these get high penalty.

Performance of Evolved Code



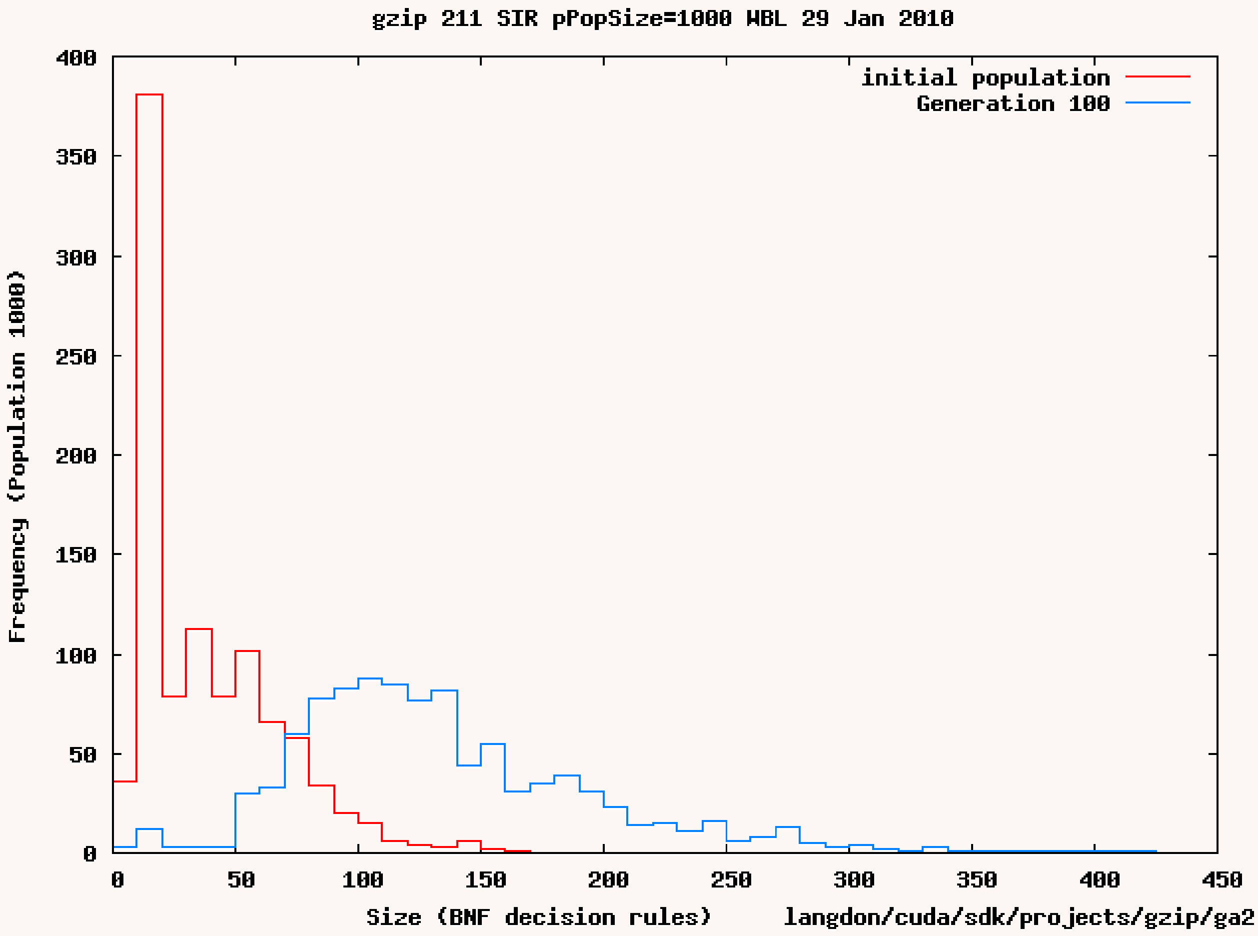
Fall in number of poor programs



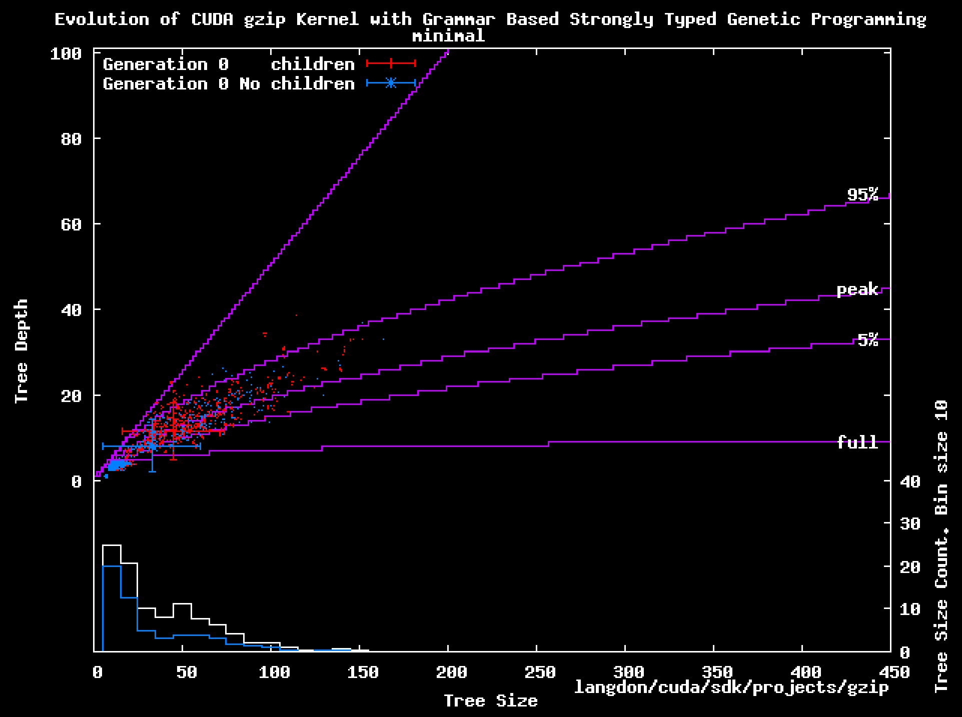
7% constants

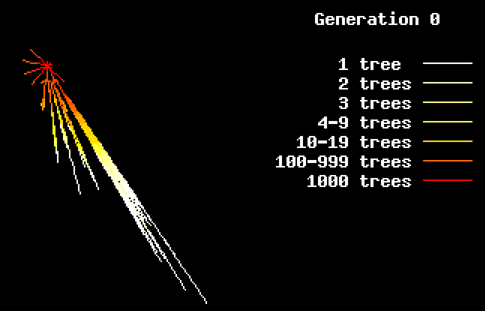
71% useless constants in generation 0

Evolution of program complexity



Evolution of gzip GPU code

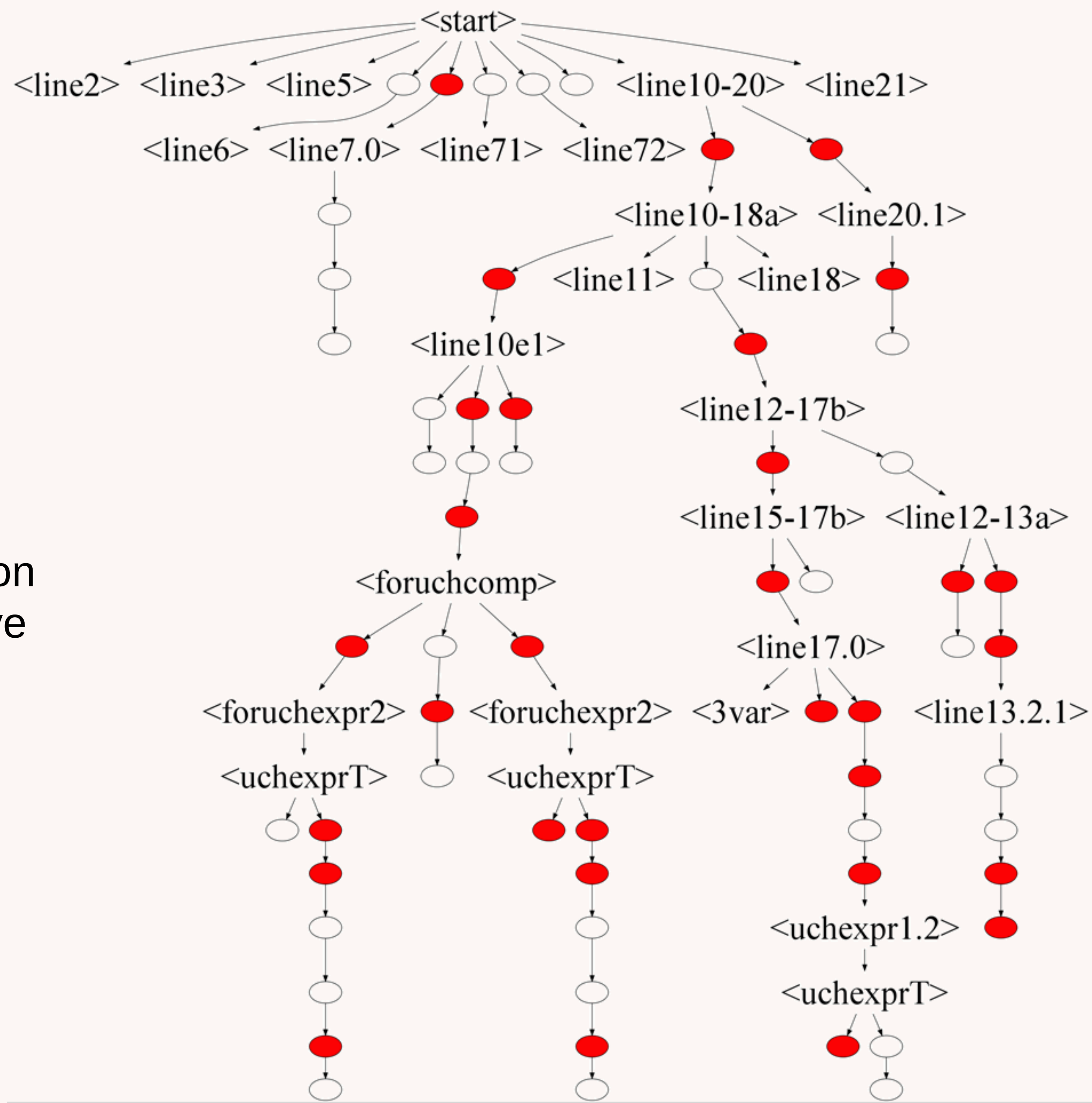




Strongly typed grammar based GP behaving like conventional tree GP

[Movie]

Evolved gzip matches CUDA code



Parse tree of solution evolved in gen 55. Ovals are binary decision rules. Red 2nd alternative used.

Evolved gzip matches CUDA code

```
__device__ int kernel978(const uch *g_idata, const int strstart1, const int strstart2)
{
int thid = 0;
int pout = 0;
int pin = 0 ;
int offset = 0;
int num_elements = 258;
 for (offset = 1 ; G_idata( strstart1+ pin ) == G_idata( strstart2+ pin ) ;offset ++ )
{
if(!ok()) break;
thid = G_idata( strstart2+ thid ) ;
  pin = offset ;
}
return pin ;
}
```

Blue - fixed by template.
Black - default

Red - evolved
Grey – evolved but no impact.

Conclusions

- Genetic programming can automatically re-engineer source code.
  - Improve hash algorithm
  - Random numbers which take less power, etc.
- Fix bugs (10^6 lines of code, 16 programs)
- speed up 50000 lines of code
- create new code in a new environment (graphics card) for existing program (gzip).

Langdon+Harman WCCI 2010

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END

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

The Genetic Programming Bibliography

The largest, most complete, collection of GP papers.
http://www.cs.bham.ac.uk/~wbl/biblio/

With 8001 references, and 6,250 online publications, the GP Bibliography is a vital resource to the computer science, artificial intelligence, machine learning, and evolutionary computing communities.

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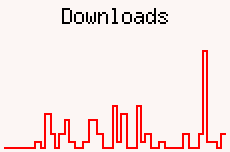
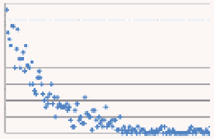


A personalised list of every author's GP publications.



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