Push

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Instructors (1)

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Outline

- The Push programming language
- Types and control without syntax
- Evolving Push programs
- Examples of Push program evolution
- Evolving Push program evolution

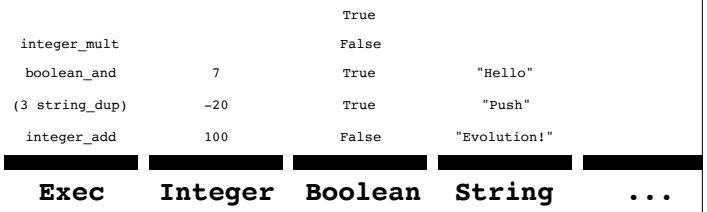
Push

- Programming language for programs that evolve
- Data flows via per-type stacks, not syntax
- Trivial syntax, rich data and control structures
- PushGP: GP system that evolves Push programs
- Clojure, Python, C++, Common Lisp, Elixir, Java, Javascript, Racket, Ruby, Scala, Scheme, Swift; **build your own in any language quickly**
- http://pushlanguage.org

Expressive

- Multiple types
- Arbitrary control
- Multiple tasks (use lexicase selection)
- Self reproduction/variation (optional)

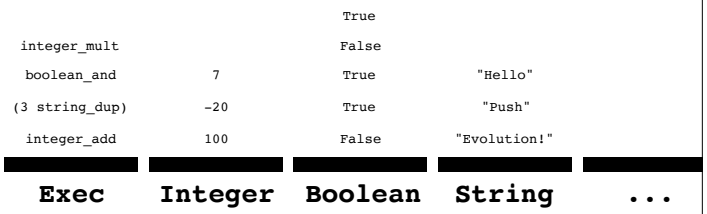
The Push VM

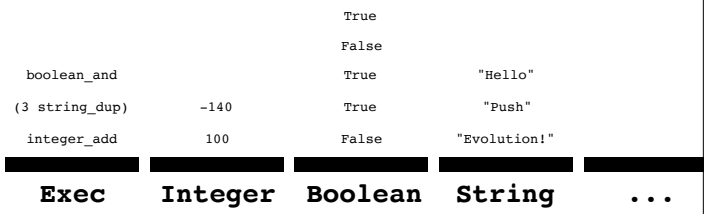


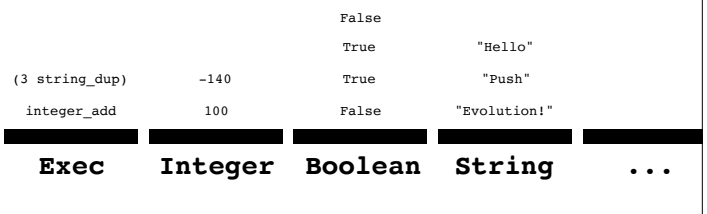
Push Execution

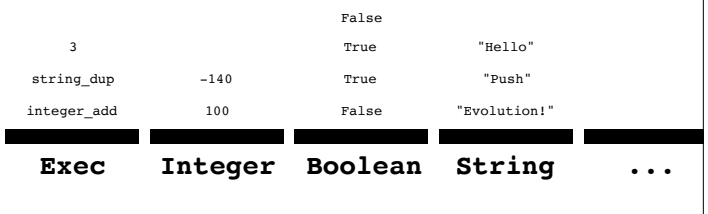
- Push the program onto the **exec** stack.
- While **exec** isn't empty and we haven't hit the step limit, pop **exec** and do the top:
  - If it's an instruction, execute it. (Insufficient arguments? Do nothing.)
  - If it's a literal, push it onto the appropriate stack.
  - If it's a list, push its elements back onto the **exec** stack one at a time.

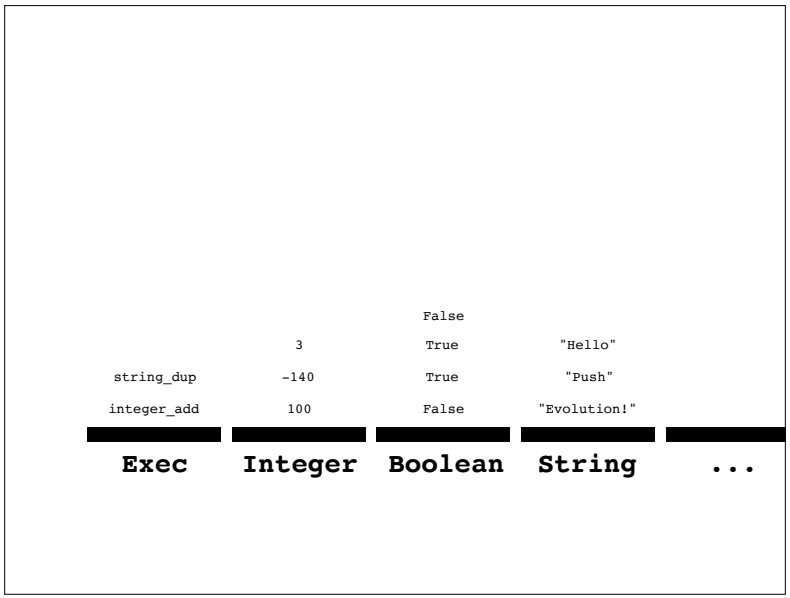
Example Execution

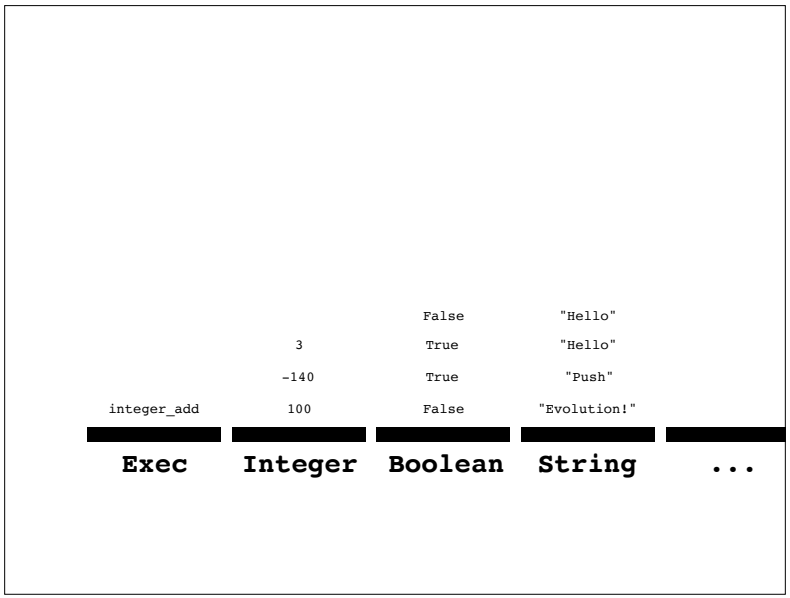


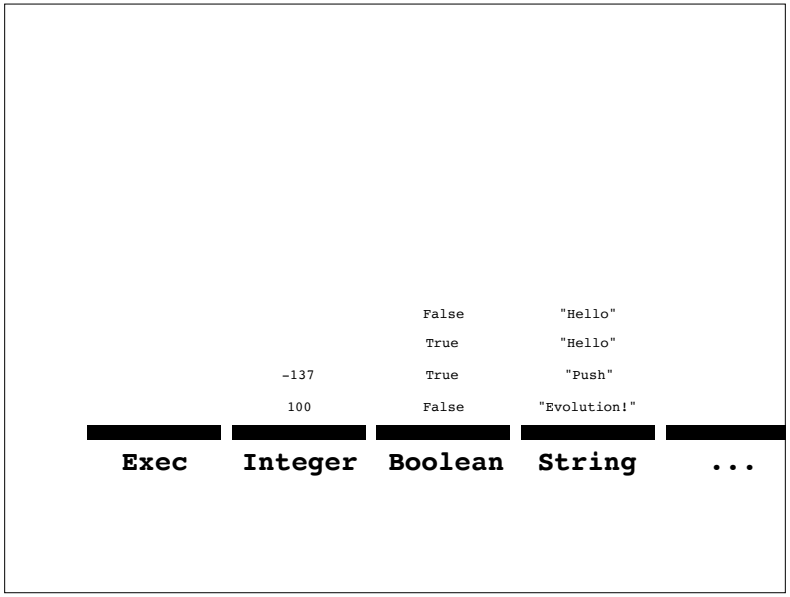




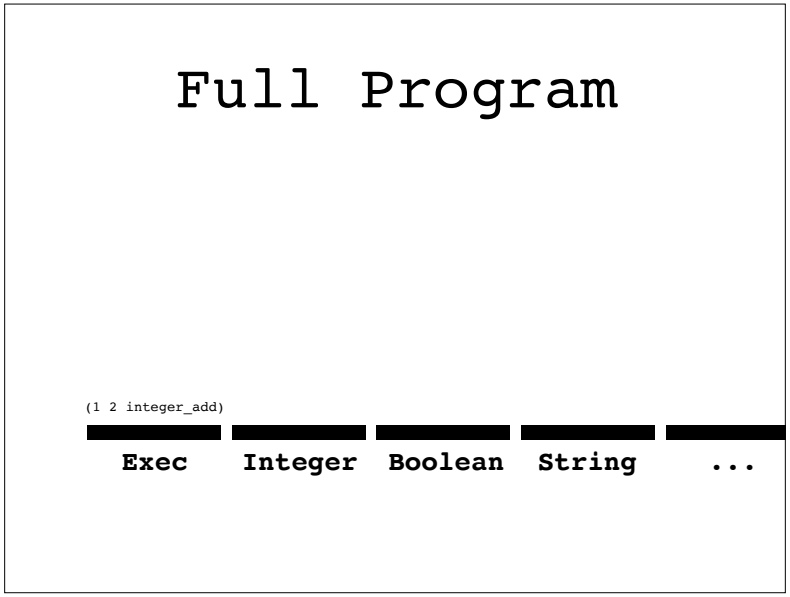


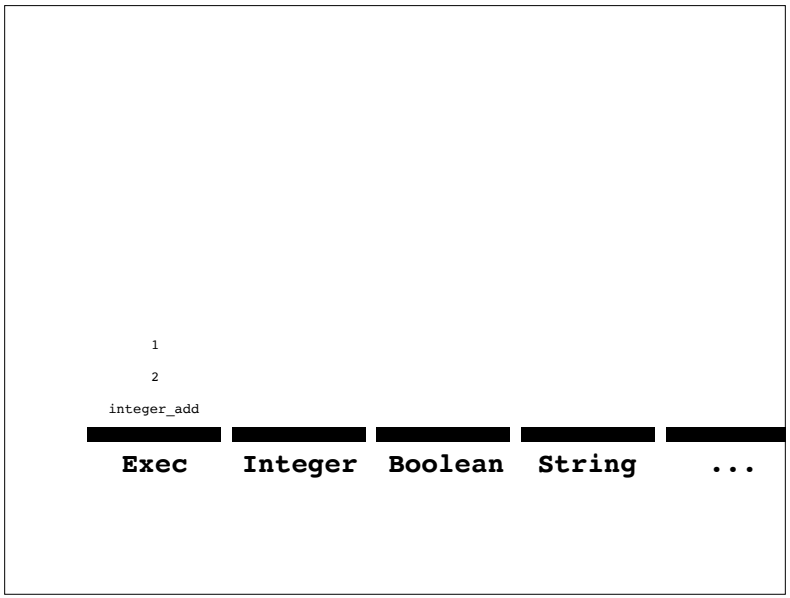


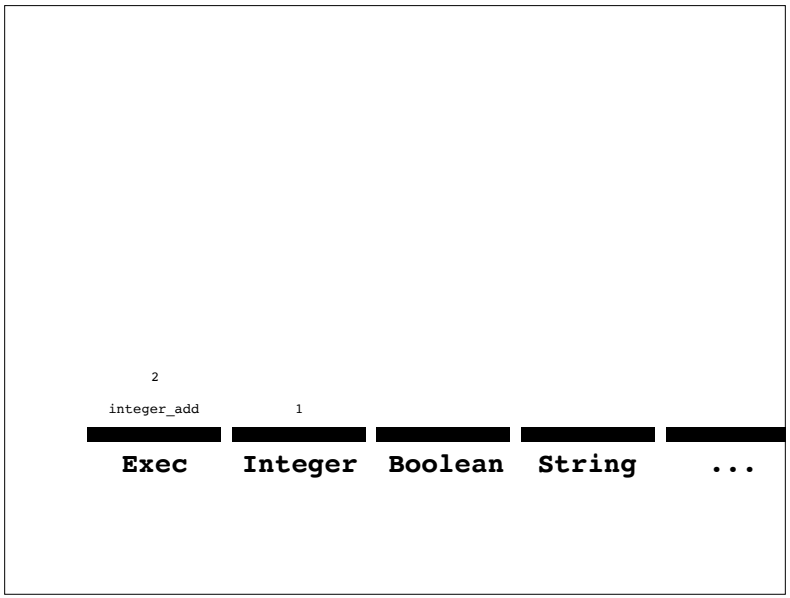


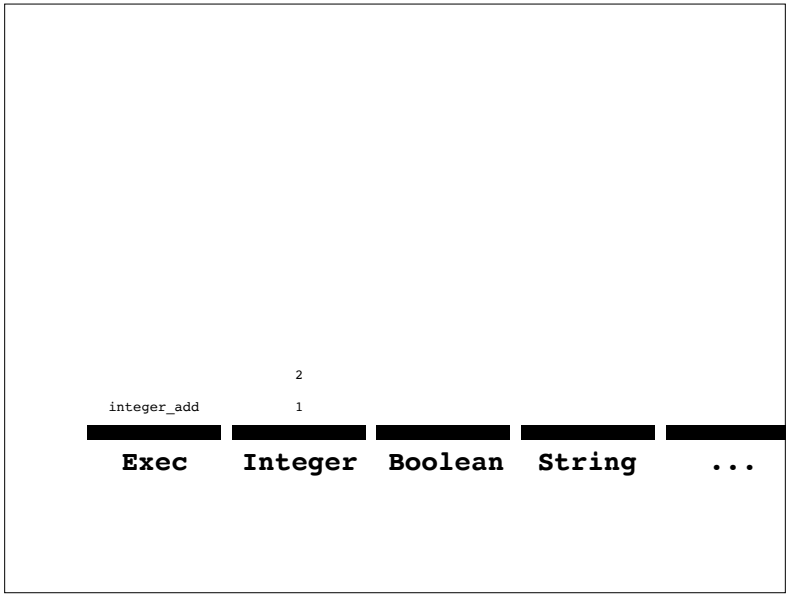


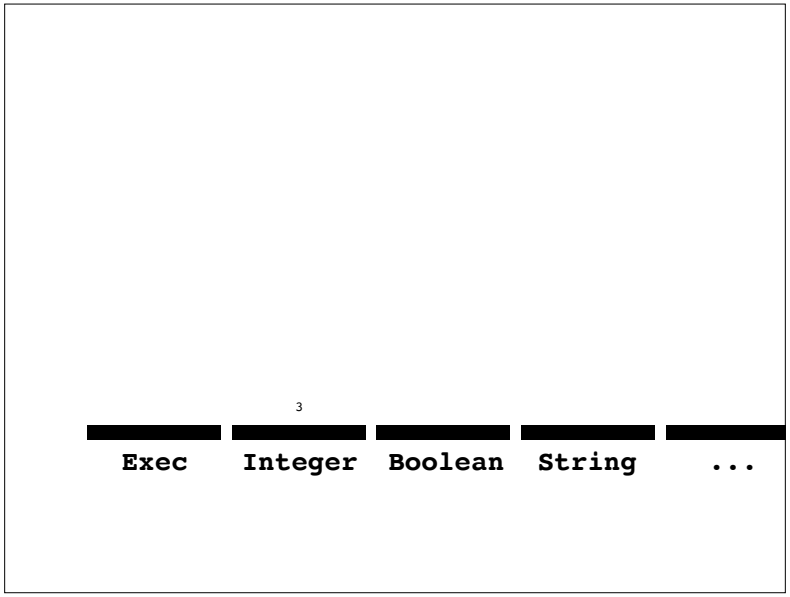
Full Program




1
2
integer_add
Exec
Integer
Boolean
String
...


2
integer_add
1
Exec
Integer
Boolean
String
...


2
integer_add
1
Exec
Integer
Boolean
String
...


3
Exec
Integer
Boolean
String
...

```
(1 2 integer_add)
```

leaves 3 on the integer stack

```
(True False boolean_or boolean_not)
```

leaves False on the boolean stack

```
(3 5 integer_lte)
```

leaves True on the boolean stack

```
(3 5 integer_lte exec_if (1 "yes") (2 "no"))
```

leaves "yes" on string, 1 on integer

For Most Types

- <type>_dup
- <type>_empty
- <type>_eq
- <type>_flush
- <type>_pop
- <type>_rot
- <type>_shove
- <type>_stackdepth
- <type>_swap
- <type>_yank
- <type>_yankdup

Selected Integer Instructions

integer_add integer_dec integer_div
integer_gt integer_fromstring integer_min
integer_mult integer_rand

Selected Boolean Instructions

boolean_and boolean_xor boolean_frominteger

Selected String Instructions

string_concat string_contains string_length
string_removechar string_replacechar

Exec (selected)

Conditionals:
exec_if exec_when

General loops:
exec_do*while

"For" loops:
exec_do*range exec_do*times

Looping over structures:
exec_do*vector_integer exec_string_iterate

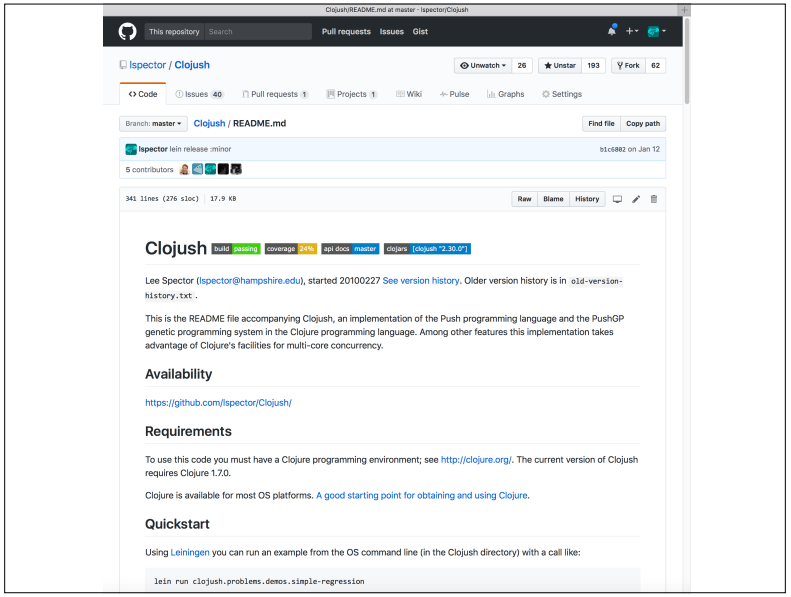
Combinators:
exec_k exec_y exec_s

More

code_atom code_car print_newline integer_sub integer_inc boolean_stackdepth return_exec_pop vector_integer_eq autoconstructive_integer_rand boolean_pop genome_close_inc string_fromchar vector_string_shove zip_yankdup genome_new vector_float_yankdup exec_yankdup vector_integer_shove integer_yankdup string_flush boolean_swap zip_empty exec_shove vector_boolean_yank code_eq exec_y boolean_yank integer_eq genome_silence string_butlast code_contains string_conjchar code_do*count vector_float_last genome_pop string_substring integer_mult code_length vector_integer_dup boolean_or code_position boolean_empty zip_fromcode print_vector_string vector_boolean_swap return_frominteger vector_float_pushall char_iswhitespace code_cdr exec_do*vector_integer integer_rand vector_string_replacefirst string_first vector_boolean_first exec_do*while exec_string_iterate string_indexofchar vector_float_replace integer_fromstring code_list code_swap char_frominteger genome_gene_randomize vector_integer_emptyvector vector_string_eq vector_float_butlast exec_empty zip_end7 exec_fromzipnode string_shove vector_boolean_pushall zip_insert_left_fromcode exec_rot vector_string_concat vector_float_indexof code_pop vector_string_subvec vector_integer_swap code_subst char_pop return_string_pop zip_yank exec_dup vector_integer_butlast vector_float_rest vector_string_flush boolean_fromfloat code_fromziprights float_sin boolean_flush char_isdigit float_lte exec_fromziproot vector_integer_empty print_code vector_string_stackdepth string_reverse exec_k vector_integer_yank float_frominteger char_rot print_char vector_integer_stackdepth vector_boolean_concat boolean_xor integer_gte genome_yankdup vector_float_shove vector_integer_take code_quote string_replacefirst return_fromstring exec_fromziplefts vector_integer_yankdup boolean_shove float_lt vector_string_dup vector_string_occurrencesof vector_integer_replace zip_branch7 vector_float_reverse float_mod vector_float_subvec string_last print_boolean boolean_rot vector_string_rest integer_div vector_float_remove integer_fromfloat integer_lte code_fromzipchildren environment_end vector_integer_rot integer_mod string_concat vector_string_butlast genome_swap code_null exec_do*count vector_float_emptyvector vector_string_yankdup integer_rot float_yankdup vector_string_rot zip_replace_fromexec vector_string_take integer_add vector_integer_occurrencesof integer_shove genome_dup return_code_pop char_swap integer_max return_fromexec code_wrap return_float_pop code_flush genome_yank zip_shove vector_integer_flush vector_integer_subvec vector_boolean_indexof vector_float_pop vector_string_remove vector_integer_contains zip_remove code_append vector_float_eq vector_integer_conj string_eq zip_leftmost code_yankdup code_rot integer_stackdepth float_max vector_boolean_set zip_append_child_fromexec zip_next vector_float_conj zip_fromexec string_take zip_left zip_replace_fromcode char_stackdepth return_fromchar genome_eq vector_integer_replacefirst float_stackdepth code_fromziproot float_fromchar float_gt boolean_dup float_fromboolean code_fromzipnode genome_rot vector_float_replacefirst vector_boolean_conj vector_boolean_dup vector_integer_indexof vector_string_swap exec_eq string_emptystring string_swap integer_yank exec_while float_empty print_vector_boolean integer_min exec_swap genome_rotate integer_fromchar vector_string_yank string_stackdepth code_do*range string_replacechar char_allfromstring vector_integer_rest vector_boolean_length char_yank vector_float_empty code_fromfloat genome_parent2 return_fromcode string_pop float_eq vector_boolean_empty zip_insert_child_fromexec vector_string_last string_nth code_do* return_zip_pop vector_string_pop zip_rot vector_integer_nth exec_do*range exec_if char_shove zip_down zip_insert_left_fromexec code_frominteger vector_boolean_remove vector_integer_remove boolean_invert_first_then_and genome_flush print_string integer_fromboolean char_yankdup code_do vector_string_first boolean_frominteger string_setchar vector_integer_last char_isletter genome_gene_dup vector_integer_concat print_integer code_map boolean_eq float_gte return_fromfloat genome_gene_copy string_occurrencesof string_replacefirstchar print_float boolean_rand integer_flush float_shove string_replace char_dup float_pop char_eq vector_float_nth vector_string_conj integer_gt return_integer_pop float_sub vector_integer_length vector_float_set vector_string_indexof vector_boolean_rest code_dup vector_boolean_shove zip_eq float_min boolean_not float_mult float_fromstring genome_unsilence code_if vector_integer_pop vector_boolean_last exec_do*times zip_pop zip_rightmost float_dec vector_float_contains genome_gene_copy_range environment_new exec_do*vector_string code_nthcdr string_empty char_empty exec_pop vector_integer_set autoconstructive_boolean_rand vector_float_rot string_yankdup exec_do*vector_float string_removechar code_extract vector_string_replace vector_float_first genome_parent1 return_tagspace char_flush vector_float_occurrencesof vector_string_emptyvector float_add code_stackdepth exec_s zip_insert_right_fromexec float_dup vector_string_nth zip_stackdepth vector_integer_reverse print_vector_integer char_fromfloat code_do*times code_noop zip_swap code_yank integer_lt vector_boolean_eq genome_stackdepth code_fromziplefts noop_open_paren string_containschar string_yank char_rand zip_flush vector_boolean_rot float_swap exec_fromziprights vector_string_pushall vector_string_set vector_boolean_flush exec_noop code_size vector_boolean_stackdepth vector_integer_pushall vector_boolean_reverse integer_swap string_split vector_boolean_contains string_fromboolean return_boolean_pop vector_float_dup vector_boolean_replace integer_dup vector_boolean_nth vector_string_length string_rest zip_insert_child_fromcode float_tan string_rot string_rand exec_yank string_parse_to_chars integer_pop integer_empty vector_float_flush vector_float_yank noop_delete_prev_paren_pair print_exec zip_append_child_fromcode genome_gene_delete code_empty float_inc zip_right vector_float_length float_rand integer_dec string_contains return_fromboolean vector_float_concat vector_float_stackdepth exec_do*vector_boolean vector_integer_first genome_shove code_rand print_vector_float float_rot return_char_pop vector_string_contains vector_boolean_occurrencesof genome_empty zip_prev genome_toggle_silent vector_string_reverse zip_dup code_cons code_member exec_stackdepth float_flush boolean_and vector_boolean_butlast string_length float_cos string_frominteger exec_flush vector_string_empty exec_when vector_float_swap genome_close_dec code_insert vector_boolean_pop float_div zip_insert_right_fromcode code_fromboolean vector_boolean_take code_shove environment_begin vector_float_take boolean_invert_second_then_and code_container code_nth vector_boolean_subvec float_yank zip_up vector_boolean_emptyvector vector_boolean_replacefirst string_fromfloat vector_boolean_yankdup string_dup boolean_yankdup exec_fromzipchildren

More

- Input instructions
- Print instructions
- Associative storage via tags
- Environment/return stacks
- Limits, termination modes




```
;; https://github.com/lspector/Clojush/

=> (run-push '(1 2 integer_add) (make-push-state))

:exec ((1 2 integer_add))
:integer ()

:exec (1 2 integer_add)
:integer ()

:exec (2 integer_add)
:integer (1)

:exec (integer_add)
:integer (2 1)

:exec ()
:integer (3)
```

```
=> (run-push '(2 3 integer_mult
               4.1 5.2 float_add
               true false boolean_or)
              (make-push-state))

:exec ()
:integer (6)
:float (9.3)
:boolean (true)
```

In other words
- Put 2 × 3 on the integer stack
- Put 4.1 + 5.2 on the float stack
- Put *true* ∨ *false* on the boolean stack

```
=> (run-push '(2 boolean_and 4.1 true integer_div
               false 3 5.2 boolean_or integer_mult
               float_add)
              (make-push-state))

:exec ()
:integer (6)
:float (9.3)
:boolean (true)
```

Same as before, but
- Several operations (e.g., `boolean_and`) become NOOPs
- Interleaved operations
  - Extremely common
  - Complicates understanding evolved programs

```
=> (run-push
     '(4.0 exec_dup (3.13 float_mult) 10.0 float_div)
     (make-push-state))

:exec ((4.0 exec_dup (3.13 float_mult) 10.0 float_div))
:float ()

:exec (4.0 exec_dup (3.13 float_mult) 10.0 float_div)
:float ()

:exec (exec_dup (3.13 float_mult) 10.0 float_div)
:float (4.0)

:exec((3.13 float_mult) (3.13 float_mult) 10.0 float_div)
:float (4.0)

...

:exec ()
:float (3.91876)
```

Computes 4.0 **× 3.13 × 3.13** / 10.0

```
=> (run-push '(1 8 exec_do*range integer_mult)
             (make-push-state))

:integer (40320)
```

Computes 8! in a fairly “human” way

```
=> (run-push '(code_quote
                (code_quote (integer_pop 1)
                            code_quote (code_dup integer_dup
                                        1 integer_sub code_do
                                        integer_mult)
                            integer_dup 2 integer_lt code_if)
                code_dup
                8
                code_do)
              (make-push-state))

:code ((code_quote (integer_pop 1) code_quote (code_dup
       integer_dup 1 integer_sub code_do integer_mult)
       integer_dup 2 integer_lt code_if))
:integer (40320)
```

A less “obvious” recursive calculation of 8! achieved by code duplication

```
=> (run-push '(0 true exec_while
                    (1 integer_add true))
             (make-push-state))

:exec (1 integer_add true exec_while (1 integer_add
       true))
:integer (199)
:termination :abnormal
```

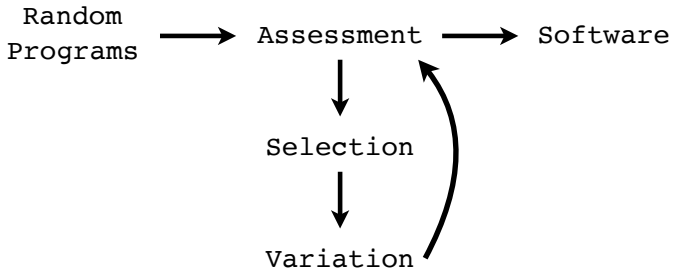
- An infinite loop
  - Terminated by eval limit
  - Probably happens a lot in evolution
- Result taken from appropriate stack(s) upon termination

```
=> (run-push '(in1 in1 float_mult 3.141592 float_mult)
             (push-item 2.5 :input (make-push-state)))

:float (19.63495)
:input (2.5)
```

Computes the area of a circle with the given radius: 3.141592 × in1 × in1

Genetic Programming



Linear Genomes

- Support uniform variation
- Structure where we want it, via translation
- PLUSH: epigenetic markers (Clojush)
- Plushy: close instructions (plushi, propel)

Uniform Variation

- All genetic material that a child inherits should be ≈ likely to be mutated
- Parts of both parents should be ≈ likely to appear in children (at least if they are ≈ in size), and to appear in a range of combinations
- Should be applicable to genomes of varying size and structure

Structure

- Parentheses matter mostly for defining code blocks for **exec** instructions
- Openings of blocks can be determined by placement of relevant **exec** instructions
- Closings of blocks can be encoded in genomes in several ways

Plush

Instruction	integer_eq	exec_dup	char_swap	integer_add	exec_if	
Close?	2	0	0	0	1	
Silence?	1	0	0	1	0	

- Linear sequences of instructions and literals
- Instructions specify opens; epigenetic markers specify closes
- Permits uniform linear genetic operators
- Facilitates useful placement of code blocks
- Allows for epigenetic hill-climbing

Plushy

- Instructions specify opens
- "close" pseudo-instructions specify closes
- Used in plushi, propel

Genetic Operators

- Uniform mutation
- Alternation
- Uniform crossover
- Uniform mutation by addition and deletion (UMAD)
- Autoconstruction (genome instructions)

PushGP in Clojush

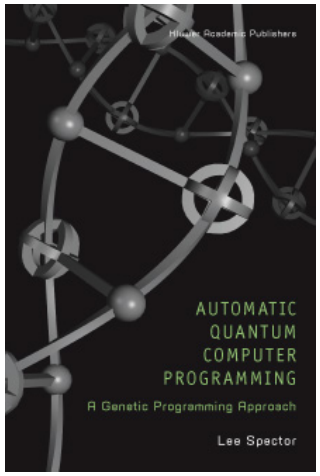
Set up run for target $x^3 - 2x^2 - x$

```
(pushgp
  {:error-function
   (fn [{:keys [program] :as individual}]
     (assoc individual :errors
       (vec
         (for [input (mapv float (range 10))]
           (let [output (->> (make-push-state)
                             (push-item input :input)
                             (run-push program)
                             (top-item :float))]
             (if (number? output)
               (Math/abs (float (- output
                                   (- (* input input input)
                                      (* 2 input input)
                                      input))))
               1000000))))))
   :atom-generators
     '(in1 float_div float_mult float_add float_sub)})
```

DEMO

Problems Solved by PushGP in the GECCO-2005 Paper on Push3

- Reversing a list
- Factorial (many algorithms)
- Fibonacci (many algorithms)
- Parity (any size input)
- Exponentiation
- Sorting



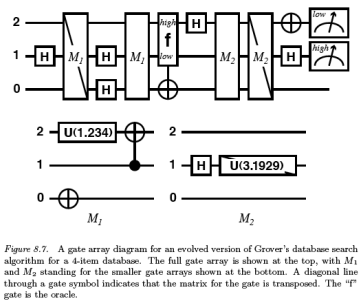


Figure 8.7. A gate array diagram for an evolved version of Grover's database search algorithm for a 4-item database. The full gate array is shown at the top, with M_1 and M_2 standing for the smaller gate arrays shown at the bottom. A diagonal line through a gate symbol indicates that the matrix for the gate is transposed. The "f" gate is the oracle.

Humies 2004
GOLD MEDAL

Genetic Programming for Finite Algebras

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Humies 2008
GOLD MEDAL

29 Software Synthesis Benchmarks

- Number IO, Small or Large, For Loop Index, Compare String Lengths, Double Letters, Collatz Numbers, Replace Space with Newline, String Differences, Even Squares, Wallis Pi, String Lengths Backwards, Last Index of Zero, Vector Average, Count Odds, Mirror Image, Super Anagrams, Sum of Squares, Vectors Summed, X-Word Lines, Pig Latin, Negative to Zero, Scrabble Score, Word Stats, Checksum, Digits, Grade, Median, Smallest, Syllables
- PushGP has solved all of these except for the ones in blue
- Presented in a GECCO-2015 GP track paper

Auto-Simplification

- Loop:
  - Make it randomly simpler
  - Keep simpler if as good or better; otherwise revert
- GECCO-2014 poster: efficiently and reliably reduces the size of the evolved programs
- GECCO-2014 student paper: used as genetic operator
- GECCO-2017 GP best paper nominee: improves generalization

```
SUCCESS at generation 20
Successful program: (boolean_and boolean_shove exec_do*count (exec_swap (integer_empty char_yank boolean_or
integer_fromboolean \space \newline) (exec_dup (char_yank char_iswhitespace string_butlast in1) string_empty boolean_frominteger tagged_275
string_substring) exec_do*times (integer_empty string_dup) string_replacechar print_string string_rot print_char integer_fromboolean
string_length integer_eq string_last boolean_swap integer_yankdup) string_swap string_containschar "Wx{ " exec_stackdepth char_empty
integer_swap integer_rot string_last boolean_swap integer_yankdup string_swap string_containschar "Wx{ " exec_stackdepth char_empty integer_swap
integer_rot integer_fromstring string_pop string_shove char_eq char_empty integer_swap integer_rot integer_fromstring string_pop string_shove
char_rot integer_stackdepth integer_min char_yankdup char_eq char_empty tagged_349 exec_yank string_rot exec_dup (boolean_eq string_removechar
exec_s (exec_dup (boolean_eq exec_rot (exec_s (string_eq string_fromboolean exec_noop char_eq) () (string_butlast) integer_pop) (char_eq
char_empty) (integer_swap integer_rot string_emptystring boolean_stackdepth integer_inc in1 boolean_shove boolean_swap char_isletter integer_gt
integer_yankdup) exec_when (string_emptystring string_nth exec_do*range (\space integer_yankdup string_dup exec_shove (integer_swap
string_removechar exec_yank string_dup exec_empty) char_eq exec_do*times (tagged_349 boolean_pop exec_when (string_removechar integer_mult
integer_inc in1 boolean_shove boolean_swap char_isletter integer_gt string_butlast) integer_mult string_last string_parse_to_chars
boolean_frominteger boolean_yank exec_when (string_nth exec_do*range (\space integer_yankdup string_dup exec_shove (integer_swap
string_removechar exec_yank integer_yank exec_while (boolean_or)) char_isdigit boolean_swap char_isletter) integer_gt integer_yankdup
integer_mult string_last string_parse_to_chars boolean_frominteger char_isletter exec_when (string_nth exec_do*range (\space integer_yankdup
string_dup exec_shove (integer_swap string_removechar exec_yank integer_yank integer_mult integer_inc in1 boolean_shove boolean_swap
char_isletter integer_gt string_butlast) boolean_invert_second_then_and exec_empty string_rot)) boolean_rot char_iswhitespace integer_yank
string_conjchar boolean_dup) integer_add char_dup string_length integer_fromchar string_split char_isdigit boolean_swap boolean_eq char_isdigit
exec_shove (boolean_invert_second_then_and string_empty string_conjchar string_shove) string_fromchar boolean_not string_stackdepth exec_y ()
integer_empty exec_do*range (in1 string_replace)))))) () ()))
Errors: [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
Total error: 0.0
Size: 231
```

```
Auto-simplifying with starting size: 231
...
step: 5000
program: (\space \newline in1 string_replacechar print_string "Wx{ "
string_last in1 string_removechar string_length)
errors: [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
Total error: 0.0
Size: 11
```

Checksum

Multiple types, looping, and code blocks

Simplified solution:

```
("Check sum is " print_string
  in1 64 exec_string_iterate (integer_fromchar integer_add)
  64 integer_mod
  \space integer_fromchar integer_add char_frominteger
  print_char)
```


Checksum

Multiple types, looping, and code blocks

Simplified solution:


```
("Check sum is " print_string
  in1 64 exec_string_iterate (integer_fromchar integer_add)
  64 integer_mod
  \space integer_fromchar integer_add char_frominteger
  print_char)
```

First: Print out the header

Checksum

Multiple types, looping, and code blocks

Simplified solution:

```
("Check sum is " print_string
  in1 64 exec_string_iterate (integer_fromchar integer_add)
  64 integer_mod
  \space integer_fromchar integer_add char_frominteger
  print_char)
```

Second: Convert each character to an integer, sum, and add to 64.

Checksum

Multiple types, looping, and code blocks

Simplified solution:

```
("Check sum is " print_string
  in1 64 exec_string_iterate (integer_fromchar integer_add)
  64 integer_mod
  \space integer_fromchar integer_add char_frominteger
  print_char)
```

Third: Mod result by 64

Checksum

Multiple types, looping, and code blocks

Simplified solution:

```
("Check sum is " print_string
  in1 64 exec_string_iterate (integer_fromchar integer_add)
  64 integer_mod
  \space integer_fromchar integer_add char_frominteger
  print_char)
```

Third: Add modulus result to 32 and convert to char

Checksum

Multiple types, looping, and code blocks

Simplified solution:

```
("Check sum is " print_string
  in1 64 exec_string_iterate (integer_fromchar integer_add)
  64 integer_mod
  \space integer_fromchar integer_add char_frominteger
  print_char)
```

Fourth: Print resulting char

3 different evolved solutions to Syllables

Syllables: essentially "Count the vowels"

- 3 very different evolved solutions
  - One uses explicit looping
  - One "unrolls" the loop
  - One is crazy and mysterious
- All starting from same initial population

3 Syllables solutions

Explicit looping

```
(string_empty integer_empty \y
  "The number of syllables is "
  integer_empty \e integer_empty \a \o \i \u
  print_string
  exec_dup
    (exec_do*while
      (integer_add in1 string_occurrencesofchar))
  integer_add print_integer)
```

Push 4 false's onto boolean stack

3 Syllables solutions

Explicit looping

```
(string_empty integer_empty \y
  "The number of syllables is "
  integer_empty \e integer_empty \a \o \i \u
  print_string
  exec_dup
    (exec_do*while
      (integer_add in1 string_occurrencesofchar))
  integer_add print_integer)
```

Push 6 vowels onto character stack

3 Syllables solutions

Explicit looping

```
(string_empty integer_empty \y
  "The number of syllables is "
  integer_empty \e integer_empty \a \o \i \u
  print_string
  exec_dup
    (exec_do*while
      (integer_add in1 string_occurrencesofchar))
  integer_add print_integer)
```

Print intro string

3 Syllables solutions

Explicit looping

```
(string_empty integer_empty \y
  "The number of syllables is "
  integer_empty \e integer_empty \a \o \i \u
  print_string
  exec_dup
    (exec_do*while
      (integer_add in1 string_occurrencesofchar))
  integer_add print_integer)
```

Make two copies of the loop

3 Syllables solutions

Explicit looping

```
(string_empty integer_empty \y
  "The number of syllables is "
  integer_empty \e integer_empty \a \o \i \u
  print_string
  (exec_do*while
     (integer_add in1 string_occurrencesofchar))
  (exec_do*while
     (integer_add in1 string_occurrencesofchar))
  integer_add print_integer)
```

Process 5 vowels (4 true's and one free)

3 Syllables solutions

Explicit looping

```
(string_empty integer_empty \y
  "The number of syllables is "
  integer_empty \e integer_empty \a \o \i \u
  print_string
  (exec_do*while
     (integer_add in1 string_occurrencesofchar))
  (exec_do*while
     (integer_add in1 string_occurrencesofchar))
  integer_add print_integer)
```

Process last vowel (1 free loop in do*while)

3 Syllables solutions

Explicit looping

```
(string_empty integer_empty \y
  "The number of syllables is "
  integer_empty \e integer_empty \a \o \i \u
  print_string
  (exec_do*while
     (integer_add in1 string_occurrencesofchar))
  (exec_do*while
     (integer_add in1 string_occurrencesofchar))
  integer_add print_integer)
```

Final addition and print

3 Syllables solutions

"Unrolling" the loop

```
("The number of syllables is " print_string \e \y \u
 exec_s (\o in1 \i)
   (in1 \a string_occurrencesofchar
            string_occurrencesofchar)
   (exec_dup
     (in1 integer_add string_occurrencesofchar integer_add))
 print_integer)
```

To simplify, let's first "Apply" exec_s and exec_dup. (Not how it actually works.)

3 Syllables solutions

"Unrolling" the loop

```
("The number of syllables is " print_string \e \y \u
 (\o in1 \i)
 (in1 integer_add string_occurrencesofchar integer_add)
 (in1 integer_add string_occurrencesofchar integer_add)
 (in1 \a string_occurrencesofchar string_occurrencesofchar)
 (in1 integer_add string_occurrencesofchar integer_add)
 (in1 integer_add string_occurrencesofchar integer_add)
print_integer)
```

Now we have 6 string_occurrencesofchar calls, one for each vowel

3 Syllables solutions

"Unrolling" the loop

```
("The number of syllables is " print_string \e \y \u
 (\o in1 \i)
 (in1 integer_add string_occurrencesofchar integer_add)
 (in1 integer_add string_occurrencesofchar integer_add)
 (in1 \a string_occurrencesofchar string_occurrencesofchar)
 (in1 integer_add string_occurrencesofchar integer_add)
 (in1 integer_add string_occurrencesofchar integer_add)
print_integer)
```

And (more than) enough integer_add's to sum up the results; 1st three do nothing

3 Syllables solutions

Haven't really worked this one out yet, but it works and generalizes!

```
(\o boolean_empty char_iswhitespace \e exec_empty
char_stackdepth exec_empty \u boolean_stackdepth
boolean_flush "The number of syllables is " \i \o
char_dup_items \o char_dup \a print_string boolean_empty
char_isdigit \i \y \o in1 char_dup exec_rot (exec_dup
(char_dup \i boolean_stackdepth \o char_yankdup char_dup
char_stackdepth boolean_yank \y exec_dup (exec_do*count
(integer_mult \a string_replacefirstchar)) \e \a
string_frominteger boolean_flush char_rot string_concat))
string_reverse (exec_yankdup string_nth)
string_occurrencesofchar print_integer)
```

Replace Space With Newline

Multiple types, looping, multiple tasks

Simplified solution:

```
(\space char_dup exec_dup in1
   \newline string_replacechar print_string
   string_removechar string_length)
```

Replace Space With Newline

Multiple types, looping, multiple tasks

Simplified solution:

```
(\space char_dup exec_dup in1
   \newline string_replacechar print_string
   string_removechar string_length)
```

First: Duplicate space character and input string for use in both tasks

Replace Space With Newline

Multiple types, looping, multiple tasks

Simplified solution:

```
(\space char_dup exec_dup in1
   \newline string_replacechar print_string
   string_removechar string_length)
```

Second: Replace spaces with newlines and print

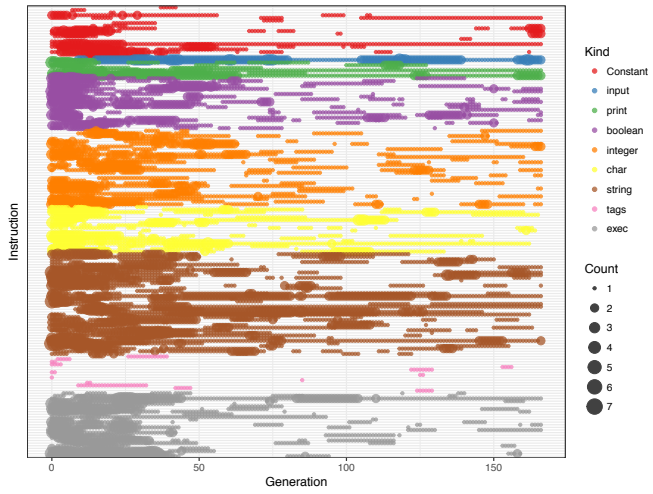
Replace Space With Newline

Multiple types, looping, multiple tasks

Simplified solution:

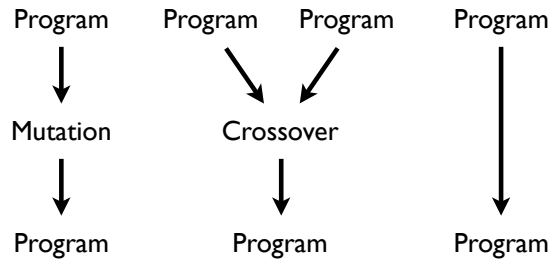
```
(\space char_dup exec_dup in1
   \newline string_replacechar print_string
   string_removechar string_length)
```

Third: Remove all spaces from second copy of input, and push length of result on integer stack for return



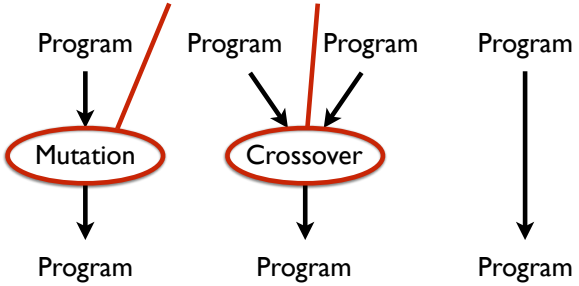
Instructions in successful lineage, Syllables/UMAD

Variation in GP

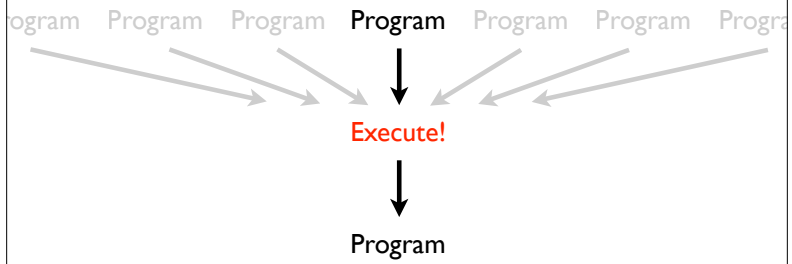


Variation in GP

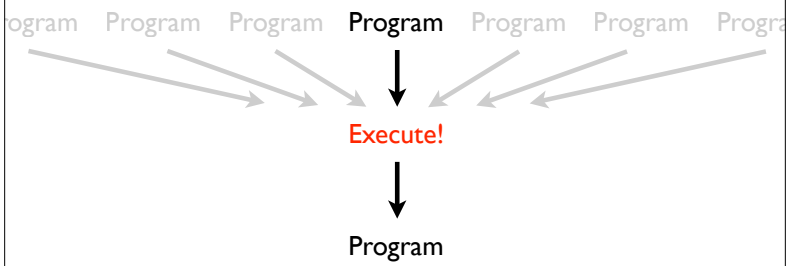
Written and configured by humans



Autoconstruction



Autoconstruction



A bit more complicated when genomes distinguished from programs

Autoconstruction

- Evolve evolution while evolving solutions
- How? Individuals produce and vary their own children, with methods that are subject to variation
- Requires understanding the evolution of variation
- Hope: May produce EC systems more powerful than we can write by hand

Autoconstruction

- A 15 year old project (building on older and broader-based ideas)
- Like genetic programming, but harder and less successful! But with greater potential?
- Recent versions sometimes solve significant problems, intriguing patterns of evolving evolution

For Evolution^2

- Diversity: Individuals vary
- Diversification: Individuals produce descendants that vary, in various ways
- Recursive Variance: Individuals produce descendants that vary in the ways that they vary their offspring

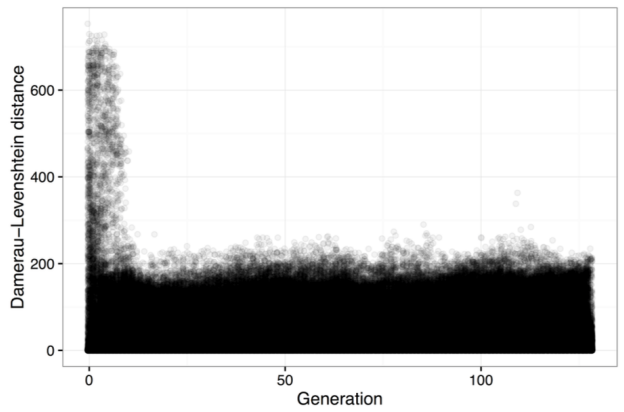


Figure 1: DL-distances between parent and child during a single non-autoconstructive run of GP on the Replace Space With Newline problem

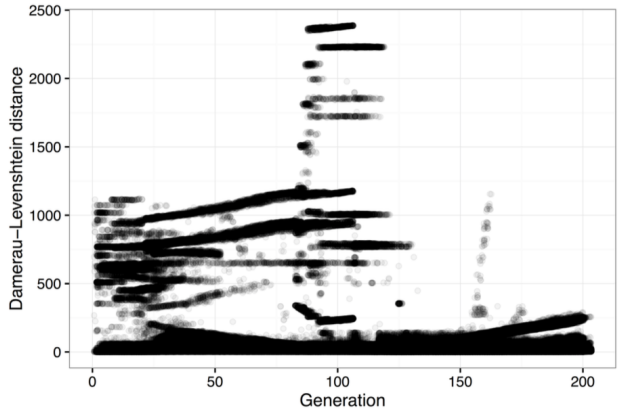


Figure 3: DL-distances between parent and child during a single autoconstructive run of GP on the Replace Space With Newline problem

Evolution Evolving

- Autoconstructive evolution can sometimes succeed as much and as fast as non-autoconstructive evolution
- Autoconstruction found solutions for the string differences software synthesis problem before ordinary GP

Conclusions

- Push supports evolution of expressive programs that use arbitrary types and control structures, possibly to perform multiple tasks
- Push interpreters, and GP systems that evolve Push programs, are easy to write
- Push supports research on expressiveness in genetic programming, for example to support the evolution of modularity

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Software

Implementations of several versions of Push and PushGP, in several host languages, are listed at http://faculty.hampshire.edu/lspector/push.html.

Among the most current and actively maintained projects are:

Clojure:

- **Clojush**, full-featured Push/PushGP research platform: http://github.com/lspector/Clojush
- **Propel**, minimalist implementation of Push/PushGP: https://github.com/lspector/propel
- **Klapaucius**, Push only (no GP), with expanded types and instructions: https://github.com/Vaguery/klapaucius

Python:

- **PyshGP**, an implementation of Push in Python: https://github.com/erp12/PyshGP
- **Plushi**, an embeddable language agnostic Push interpreter for running Push programs via a JSON interface: https://github.com/erp12/plushi