Automatic Programming of Agents by Genetic Programming

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Overview

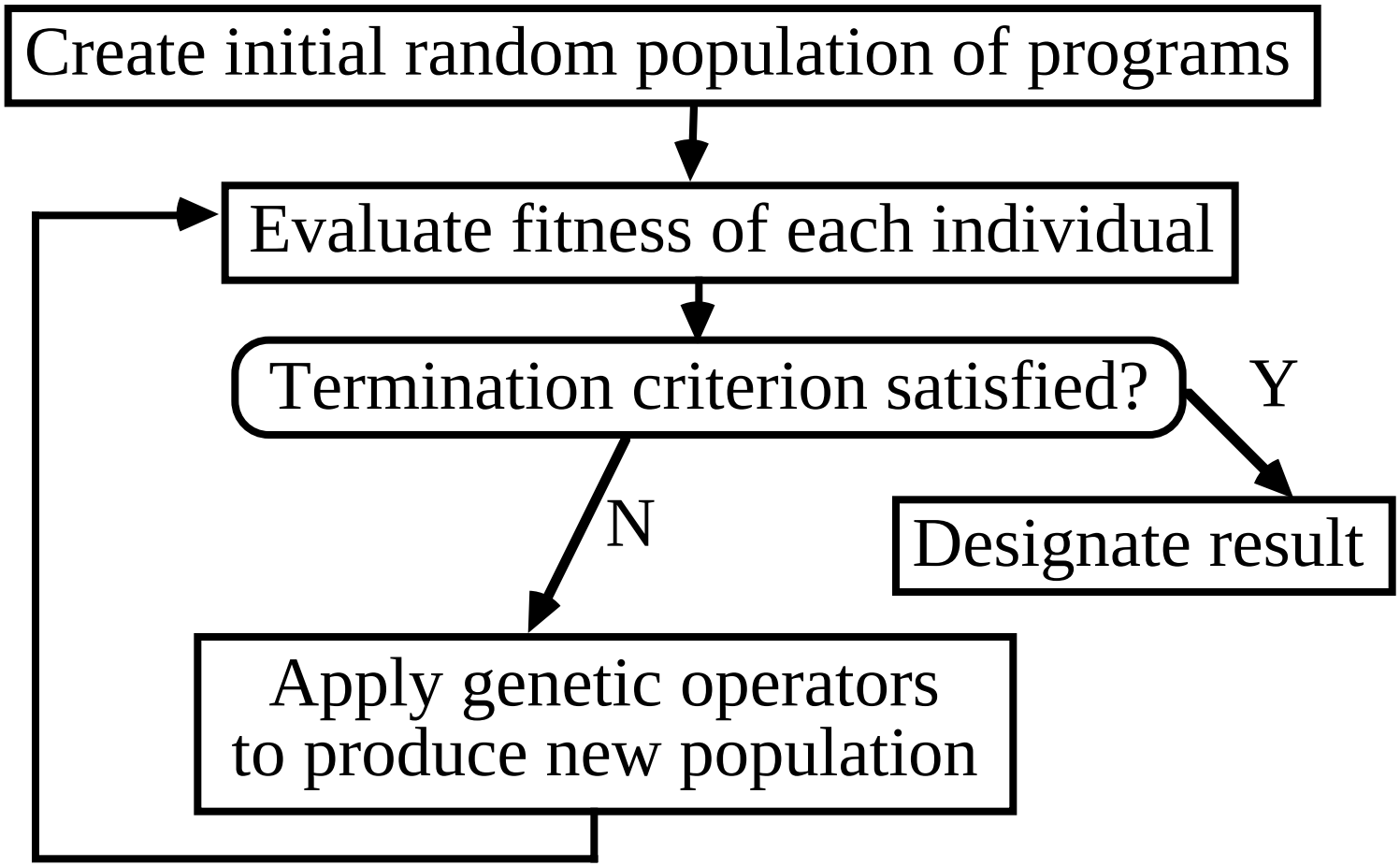
Genetic Programming

Evolved Agents in Dynamic Environments

New Techniques: PushGP, Pushpop

New Worlds: Traffic, Airlift

Genetic Programming (Koza, 1992)



Mutation of Symbolic Expressions

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```
(+ (* X Y)
   (+ 4 (- Z 23)))

(+ (* X Y)
   (+ 4 (- Z 23)))

(+ (- (+ 2 2) Z)
   (+ 4 (- Z 23)))
```

Crossover of Symbolic Expressions

Parent 1:
```
(+ (* X Y)
   (+ 4 (- Z 23)))
```

Parent 2:
```
(- (* 17 (+ 2 X))
   (* (- (* 2 Z) 1)
      (+ 14 (/ Y X))))
```

Child 1:
```
(+ (- (* 2 Z) 1)
   (+ 4 (- Z 23)))
```

Child 2:
```
(- (* 17 (+ 2 X))
   (* (* X Y)
      (+ 14 (/ Y X))))
```

Symbolic Regression

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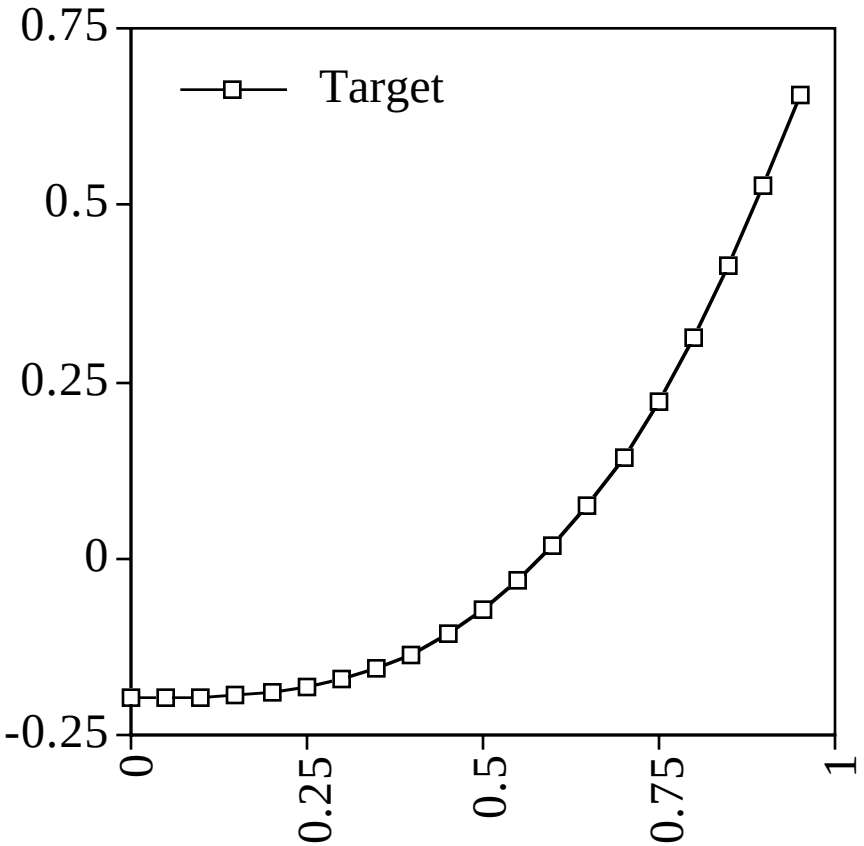
Goal: given a data set of (x,y) pairs, produce a program that takes an x value as input and produces the appropriate y value as output.

Function set: {+, -, *, %}

Terminal set: {X, 0.1}

Fitness function: sum the error for X values 0.0, 0.2, ..., 0.9

Target Function: $y=x^3-0.2$

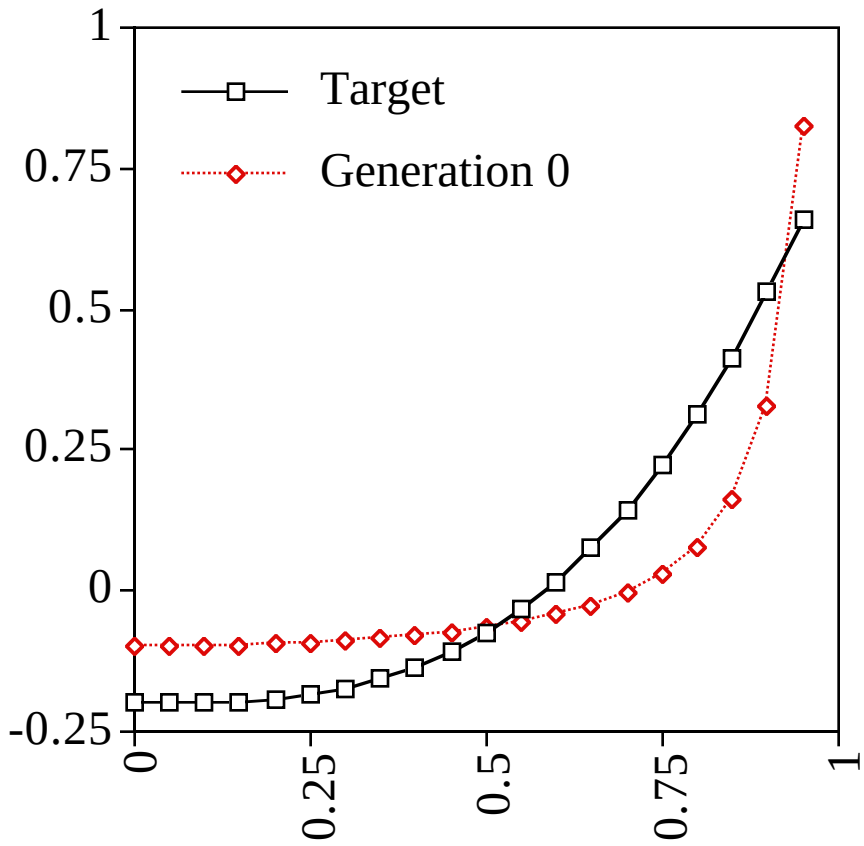


Other GP parameters

Maximum number of Generations: 51
Size of Population: 1000
Maximum depth of new individuals: 6
Maximum depth of new subtrees for mutants: 4
Maximum depth of individuals after crossover: 17
Fitness-proportionate reproduction fraction: 0.1
Crossover at any point fraction: 0.3
Crossover at function points fraction: 0.5
Selection method: FITNESS-PROPORTIONATE
Generation method: RAMPED-HALF-AND-HALF
Randomizer seed: 1.2

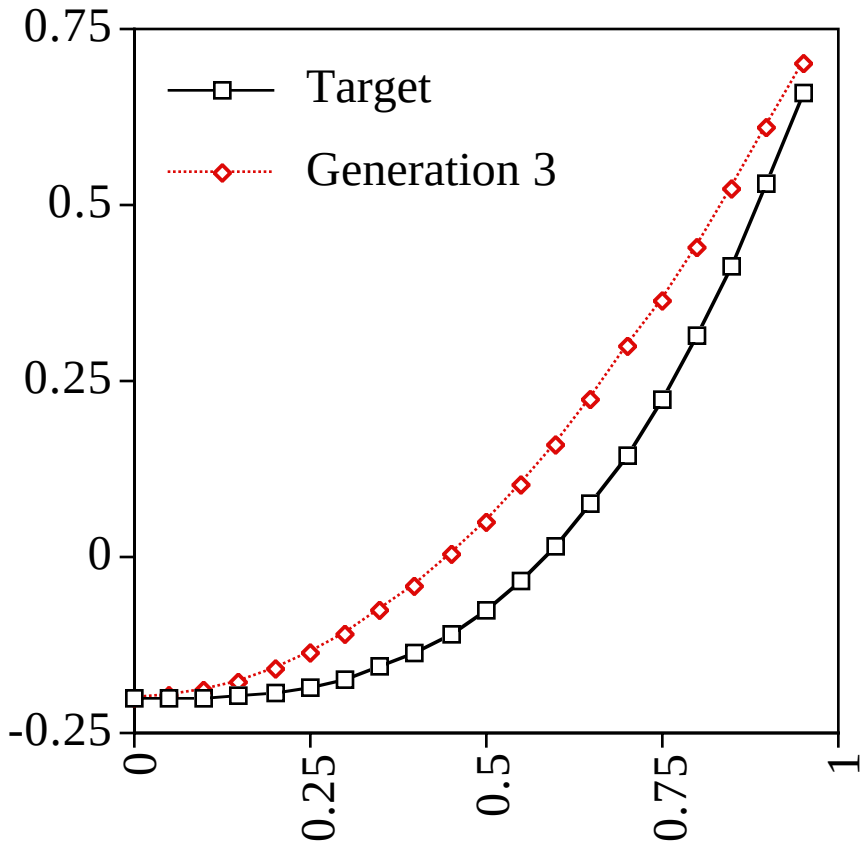
Best Program, Generation 0

```
(- (% (* 0.1
         (* X X))
      (- (% 0.1 0.1)
         (* X X)))
   0.1)
```



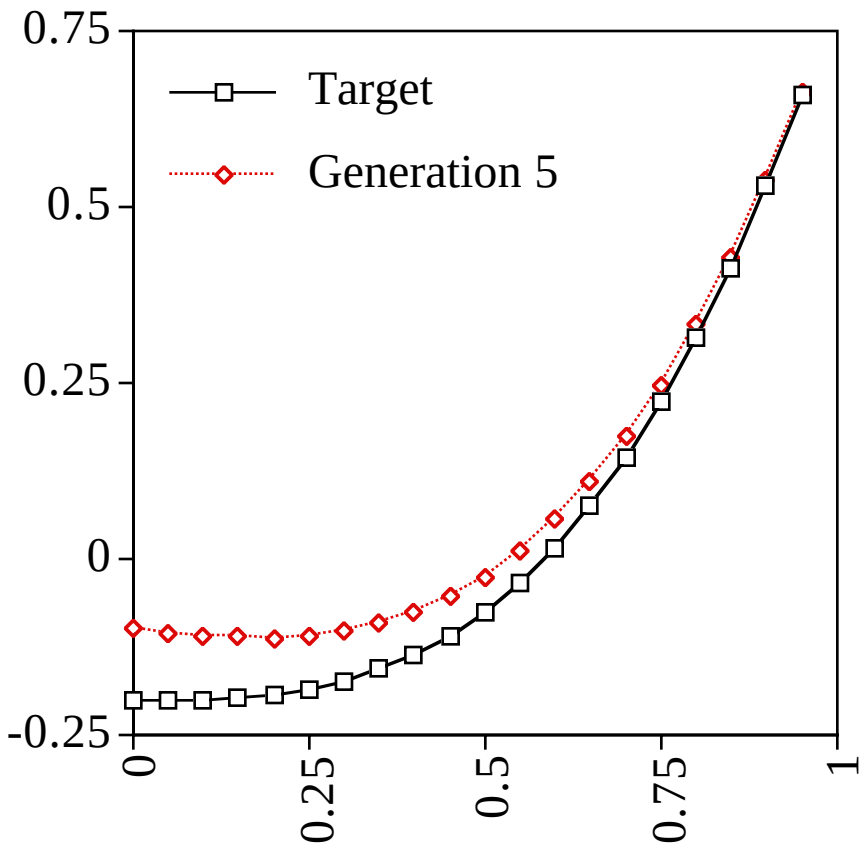
Best Program, Generation 3

```
(- (* X X)
   (+ 0.1 0.1))
```



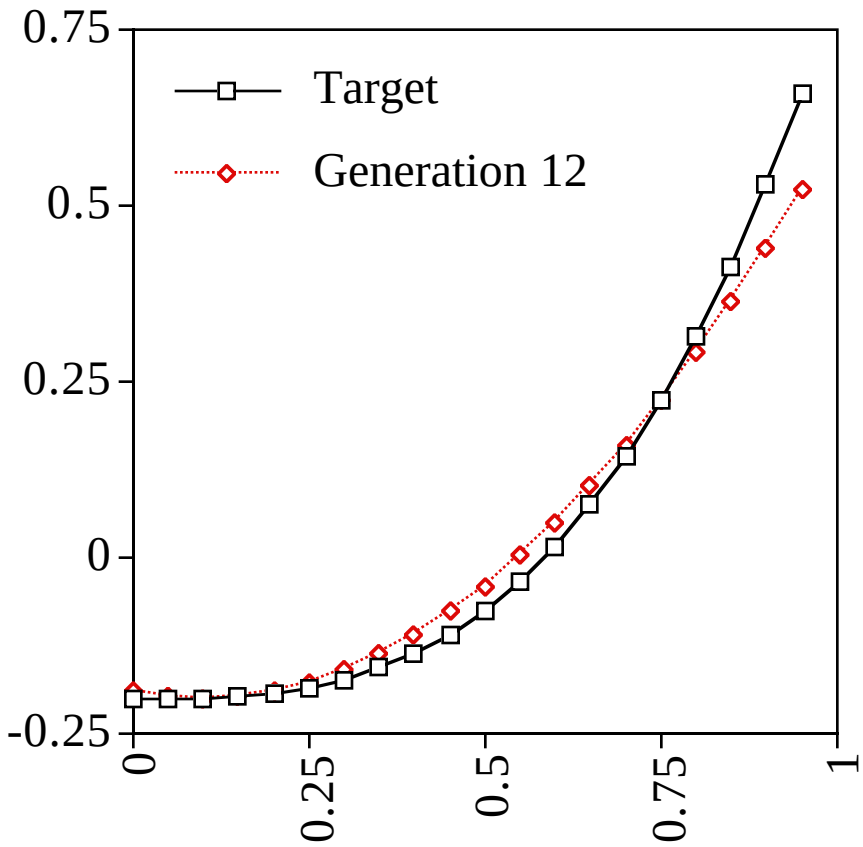
Best Program, Generation 5

```
(- (* (* (% X 0.1)
         (* 0.1 X))
      (- X
         (% 0.1 X)))
   0.1)
```



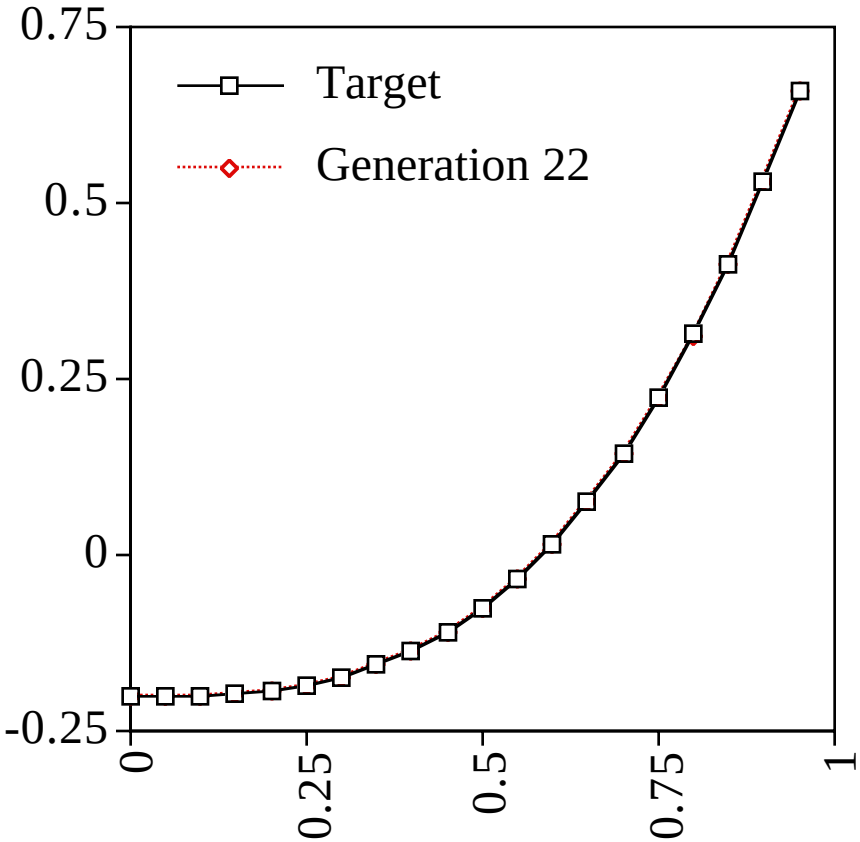
Best Program, Generation 12

```
(+ (- (- 0.1
         (- 0.1
            (- (* X X)
               (+ 0.1
                  (- 0.1
                     (* 0.1
                        0.1))))))
      (* X
         (* (% 0.1
               (% (* (* (- 0.1 0.1)
                        (+ X
                           (- 0.1 0.1)))
                     X)
                  (+ X (+ (- X 0.1)
                          (* X X)))))
            (+ 0.1 (+ 0.1 X)))))
   (* X X))
```

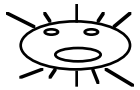


Best Program, Generation 22

```
(- (- (* X (* X X))
      0.1)
   0.1)
```



Wumpus World

Breeze	O Pit	Breeze		Breeze	O Pit
O Pit	Breeze			Breeze	O Pit
Breeze		Breeze			Breeze
	Breeze	O Pit	Breeze Stench		$ Gold
		Breeze Stench	 Wumpus	Stench	Breeze
 Agent			Stench	Breeze	O Pit

Wumpus World Problem

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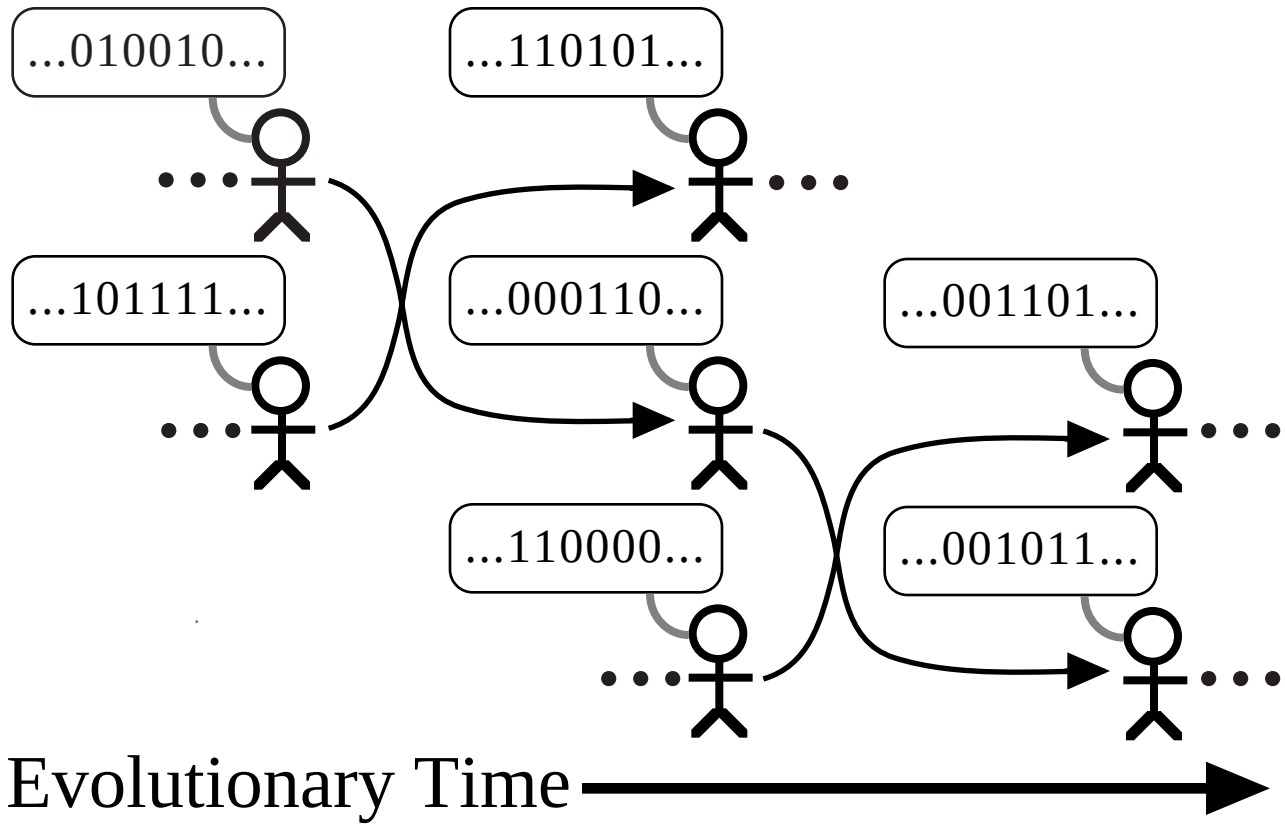
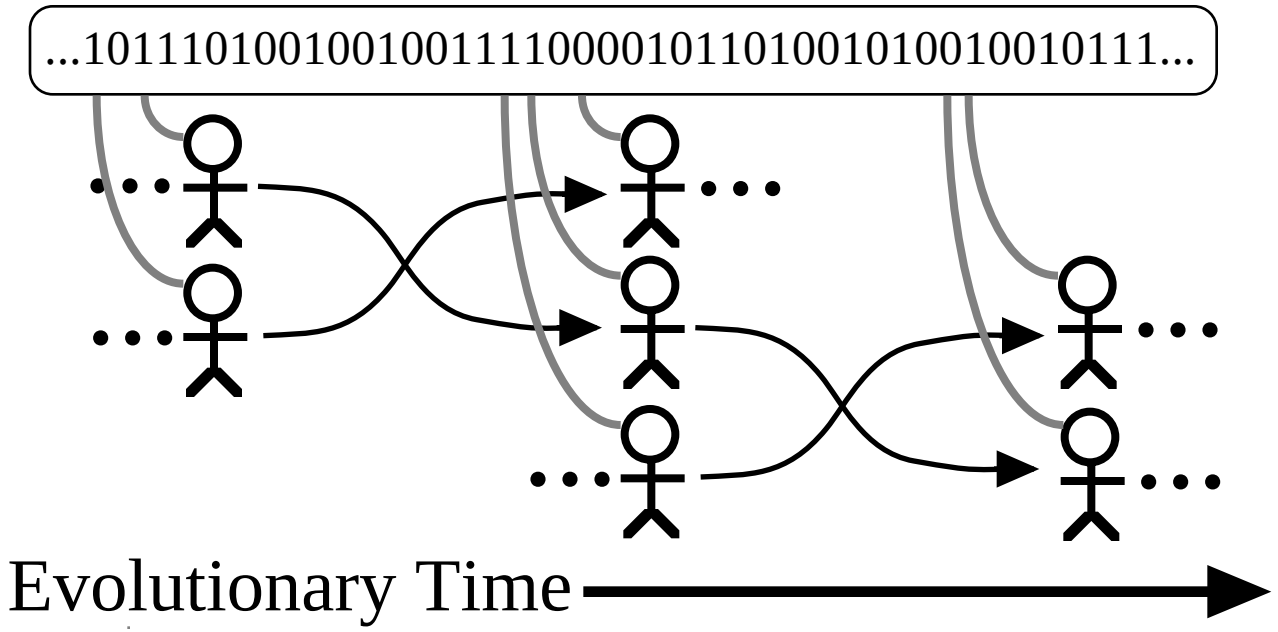
Goal: to guide an agent through a complex and dangerous virtual world (Russell and Norvig, 1995).

Function set: and, or, not, sequence, if-zero, if-less-or-equal, +, -, *, sensors, constants, [read, write]

Evolving Agents with Memory



Evolving Agents with Culture



Memory/Culture in Wumpus World

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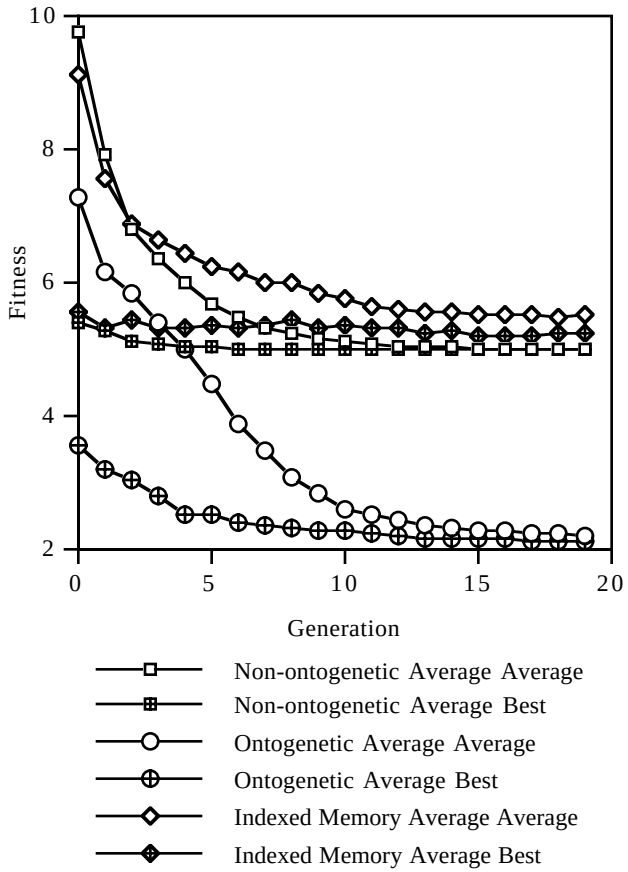
Total runs: 1709 (population size 1000, 21 generations/run)

Condition	Computational Effort
No memory	1,710,000
Memory	2,100,000
Culture	1,386,000

Evolving Learning Agents

Ontogenetic Programming:
Ontogeny via self-modification.



Evolving Teamwork and Coordination

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Lions and Gazelles in Serengeti World (Luke & Spector, 1996)

Team composition:
homogeneous, heterogeneous, segregated

Sensing:
absolute, deictic

	Restricted Breeding		Free Breeding		Clones	
Sensing	Average	Best	Average	Best	Average	Best
Deictic	1.65	0.13	2.03	0.23	1.52	0.20
Name–Based	1.33	0.03	1.79	0.07	1.93	0.22
None	2.20	0.49	2.23	0.50	2.18	0.45

The Push Programming Language for Evolutionary Computation

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Goal: Scale up GP/agents techniques for human-competitive performance in complex, dynamic environments.

Evolve agents that may use:

- multiple data types
- subroutines (any architecture)
- recursion
- evolved control structures
- evolved evolutionary mechanisms

Push supports all of this using simple, mostly standard GP techniques.

Modularity and Scaling

Table 5: Results of PushGP runs on even-parity problems with the instruction set in Table 3.

Arity	Effort	% Random Solutions	% Using `DO` or `DO*`	Effort Relative To Koza Without ADFs	Effort Relative To Koza With ADFs
3	80,000	49%	20%	1.2X	1.5X
4	96,000	23%	62%	0.25X	0.55X
5	352,000	3%	56%	0.54X	0.76X
6	160,000	4%	63%	0.002X	0.12X

Autoconstructive Evolution

Individuals make their own children.

The machinery of reproduction and diversification (and thereby the machinery of evolution) evolves.

Radical self-adaptation.

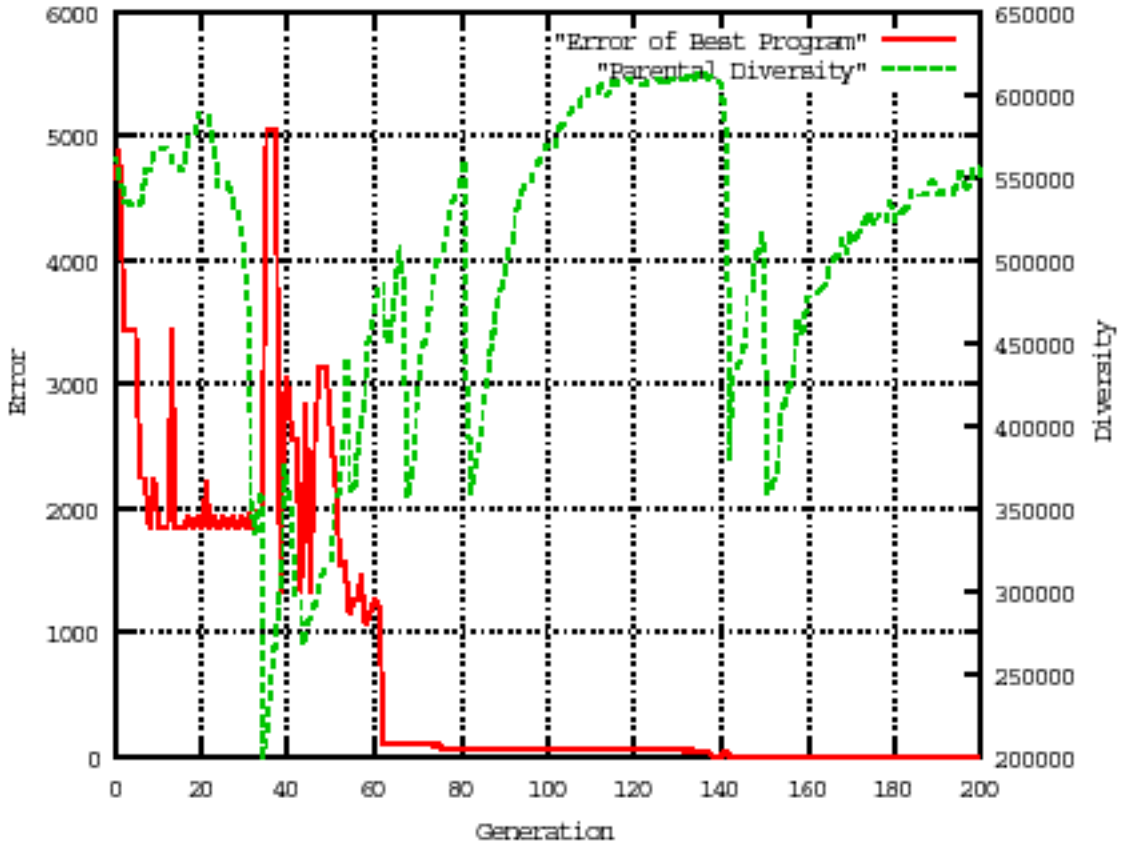
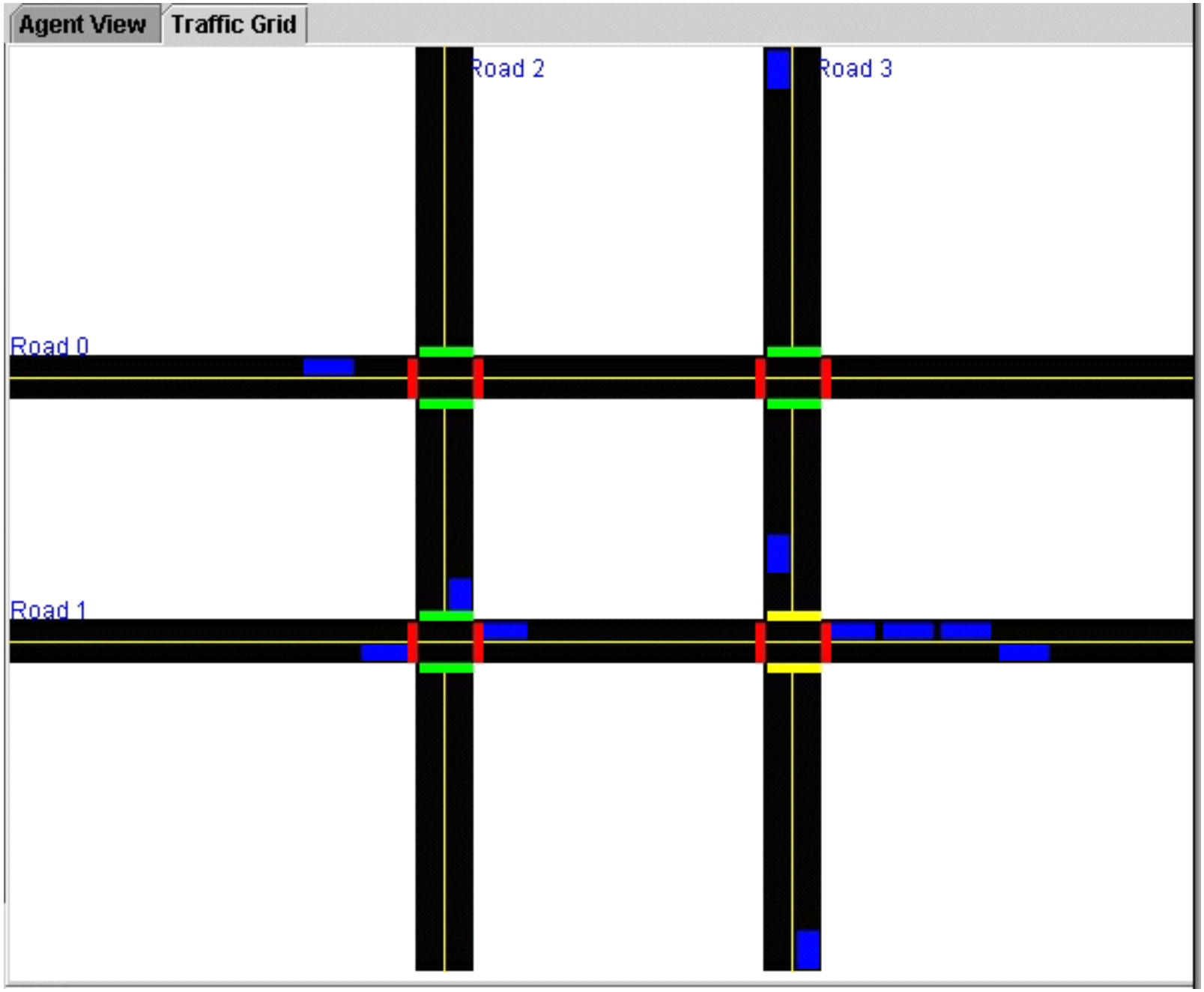


Figure 1: Error of the best program and diversity of successful parents over the course of a Pushpop run on a symbolic regression problem with the target function $y = 5x^2 + x - 2$. Diversity of two individuals was calculated as the sum, over all unique expressions in either of the individuals, of the difference between the number of occurrences of the expression in the two individuals. The graphed diversity measure is the sum of the diversities of all pairs of individuals in a randomly selected set of 128 successful parents from each generation. When less than 128 parents were successful (in some generations before reproductive competence, which occurred here at generation 32) the graph repeats the value from the previous generation. This run used a population size of 2048, a tournament size of 32, 16 fitness cases (0–15), and a maximum program size of 64 points.

Traffic



Traffic

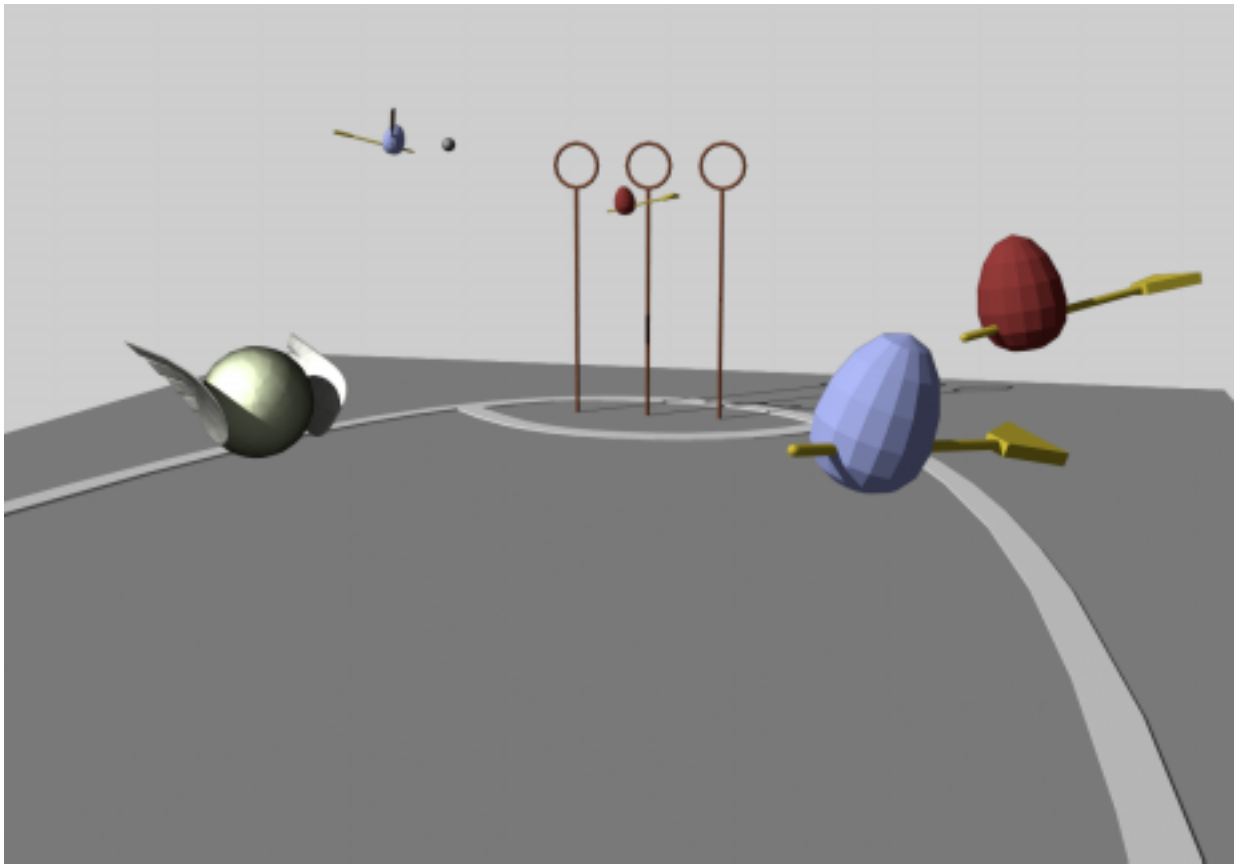
So far:

- Hampshire simulator.
- Simple road networks/conditions.
- Simple metrics (average wait).
- Simple evolved agents.

Soon:

- BBN simulator.
- Complex road networks.
- Alternative metrics.
- Agents using EAMs.

Virtual Quidditch



Virtual Quidditch

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Richly heterogeneous: player roles, balls themselves are active/intelligent.

Richly 3-dimensional: flying game, full use of the third dimension.

Extensible: rules not uniquely determined by the Rowling books; physics based on magic spells so the sky is the limit!

Beyond human experience: unlike soccer, few intuitions about strategy to bias methods.

Like real-time, only faster: model some aspects of real-time but design for rapid fitness tests.

Airlift

(See MIT/BBN report)

Quantum Computing

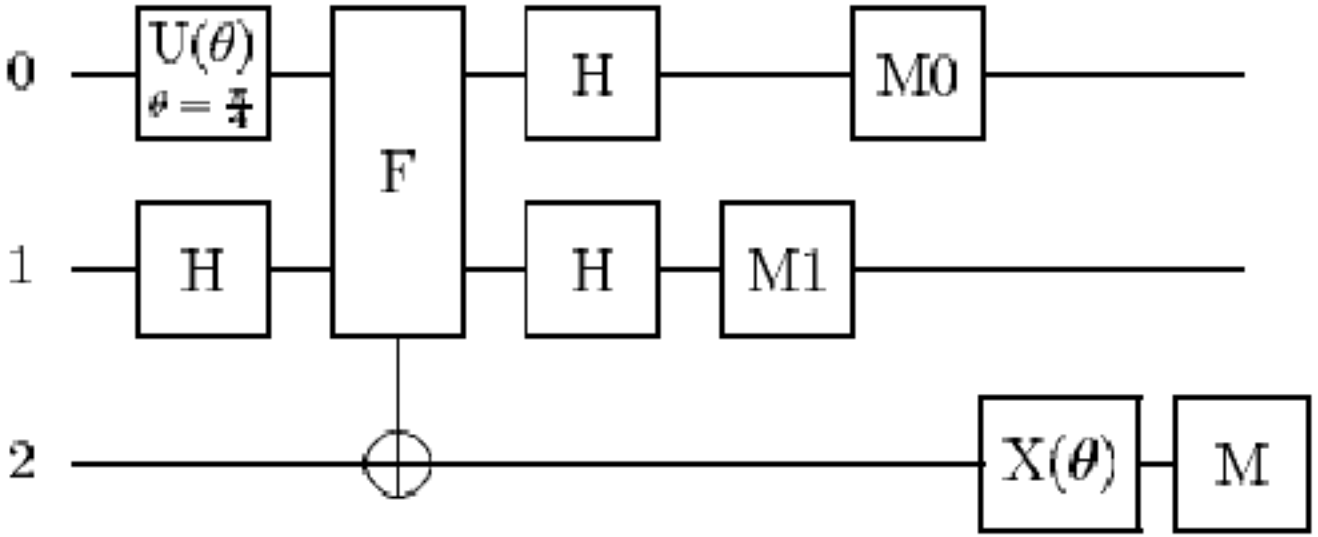

Figure 3. Hand-tuned version of evolved AND/OR; $\theta = 0.749\,09, \ldots$.

Table 1. Error probabilities (to 5 digits) for hand-tuned simplified AND/OR algorithm.

Orbit	p_e	Orbit	p_e
0 0 0 0	0.005 60	0 1 0 1	0.287 31
0 0 0 1	0.287 31	1 1 0 1	0.212 69
0 0 1 1	0.212 69	1 1 1 1	0.005 60

Agenda

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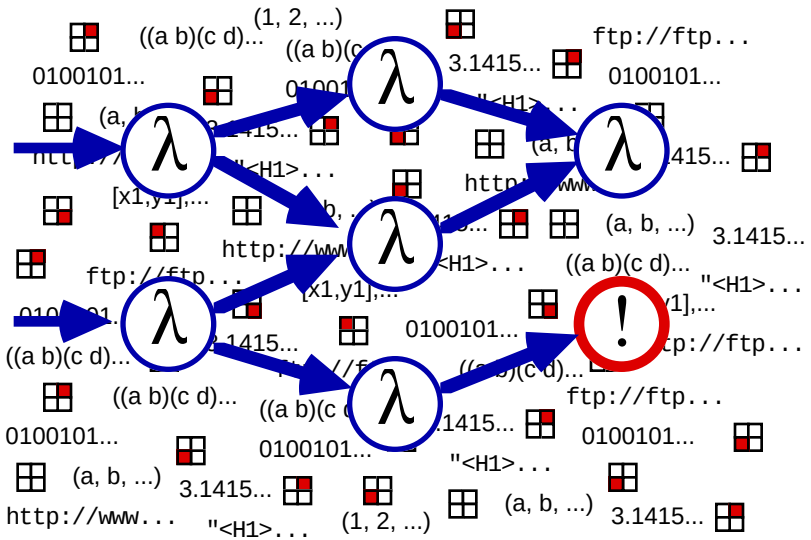
Integrate PushGP/Pushpop with MIT/BBN and/or additional agent simulators.

Evolve agents; compare evolved/hand-crafted agent designs and performance.

Integrate MIT/BBN Elementary Adaptive Modules (EAMs) into PushGP/Pushpop.

Assess utility of components made available to evolution including EAMs.

Multi-Type, Self-Adaptive Genetic Programming for Complex Applications



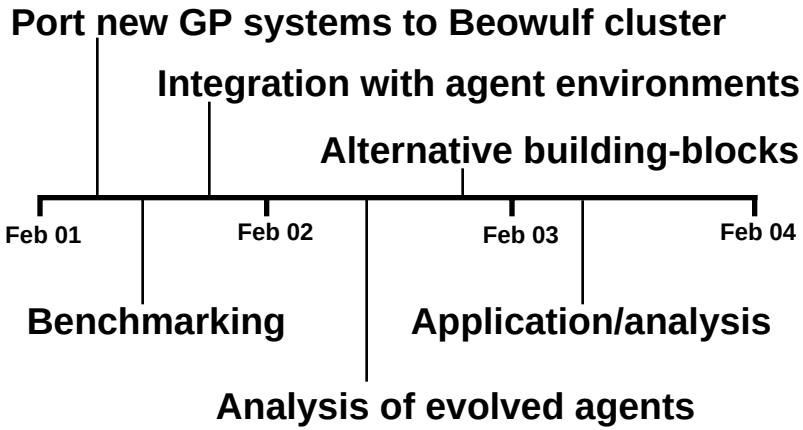
New Ideas

- Richly heterogeneous data can be flexibly integrated in programs produced by stack-based genetic programming.
- Explicit code manipulation allows for automatic emergence of modules and evolved program architecture.
- Self-adaptive construction of evolutionary mechanisms enhances fit to problem environments.

Impact

- Evolved agents for heterogeneous, dynamic environments.
- Broader range of applications for automatic programming technologies.
- Automatic programming with less configuration by users.

Schedule



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