

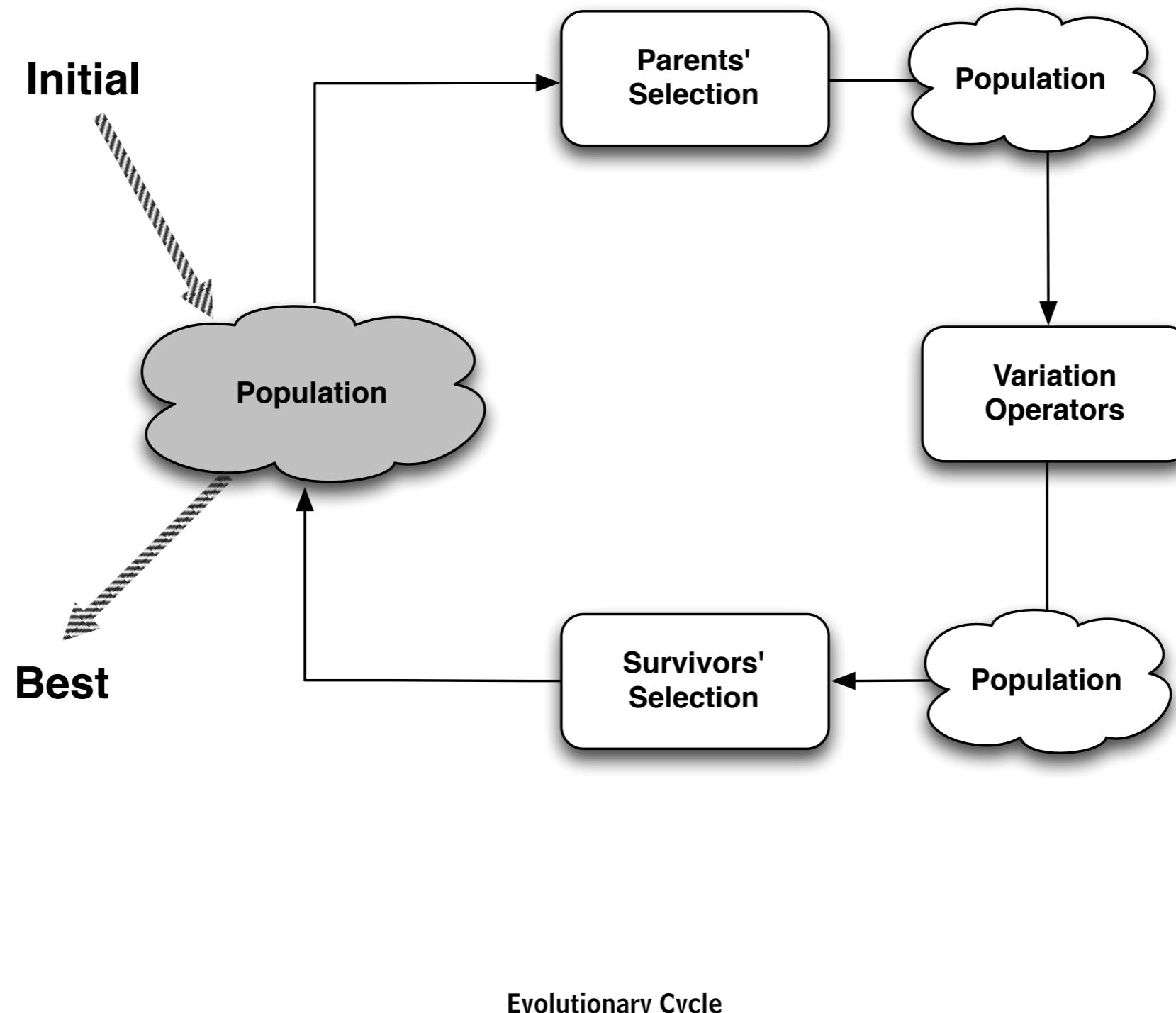
# **Evolving Grammars: A Structured Point of View**

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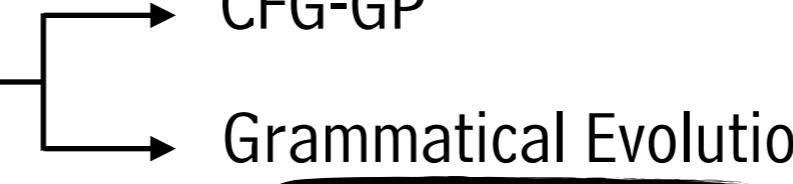
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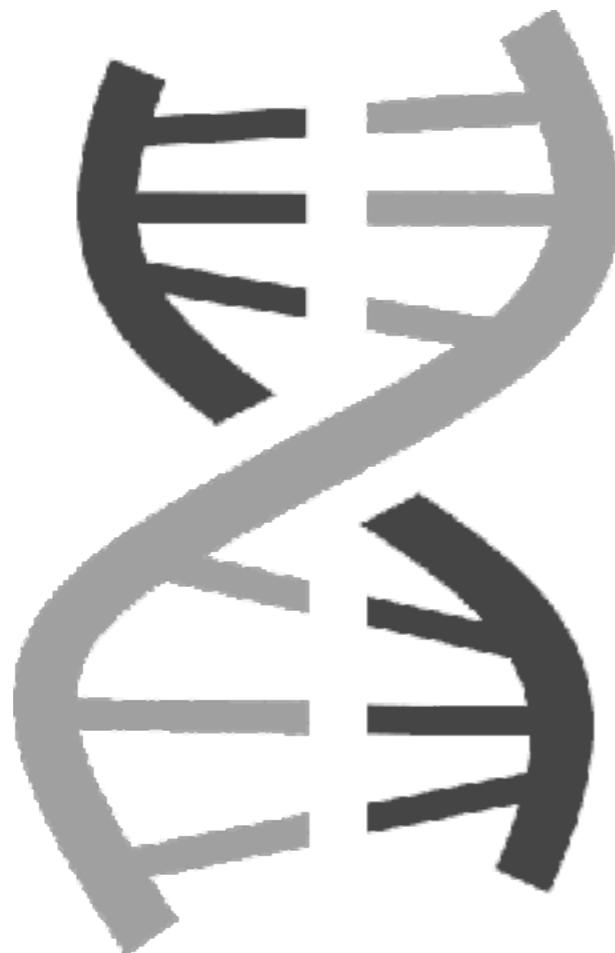
**EVOLUTIONARY ALGORITHMS**

- ▶ Genetic Algorithm
- ▶ Evolutionary Strategies
- ▶ Genetic Programming

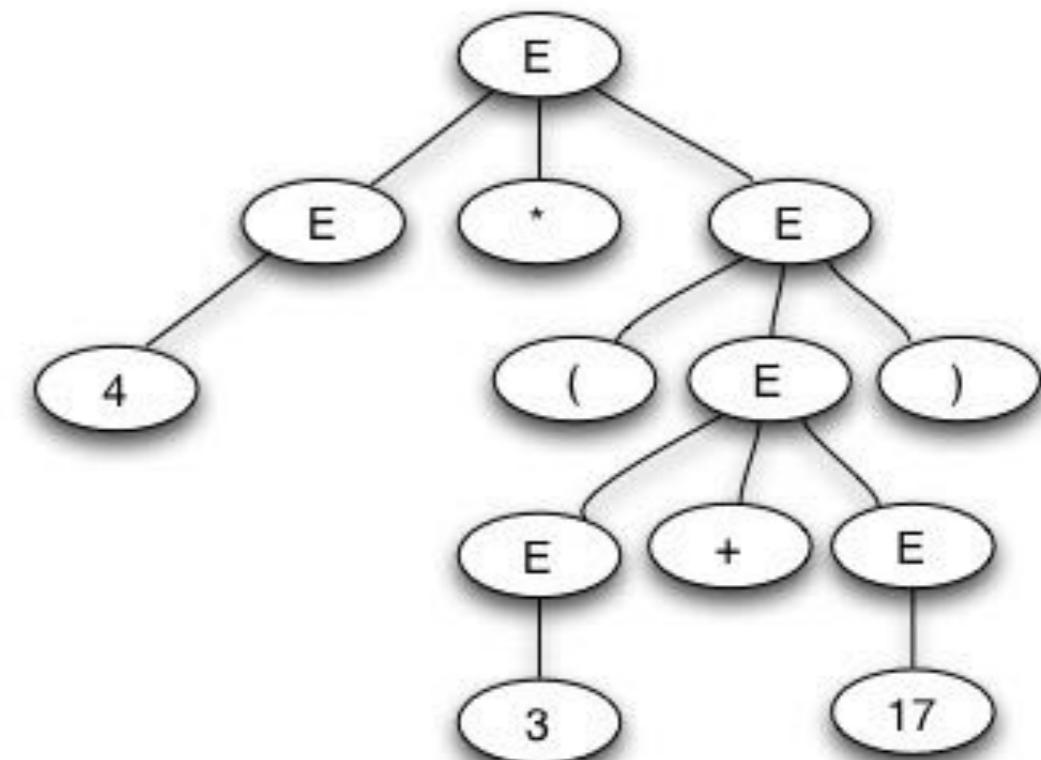
**EVOLUTIONARY ALGORITHMS**

**GENETIC PROGRAMMING**

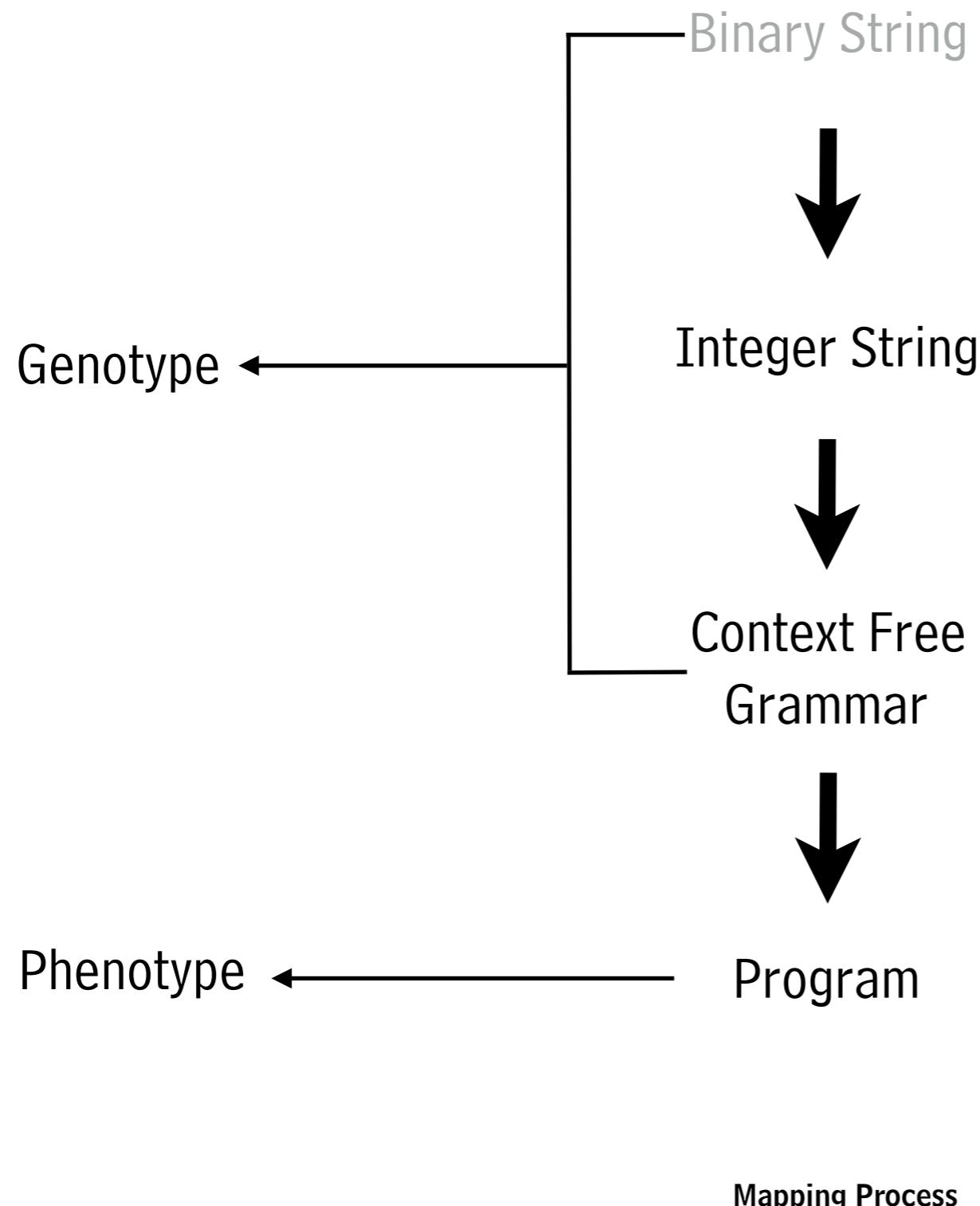
- ▶ Tree-Based
  - ▶ Graph-Based
  - ▶ Linear
  - ▶ Grammar-Based
- 
- CFG-GP
- Grammatical Evolution

**GRAMMATICAL EVOLUTION**

Genotype



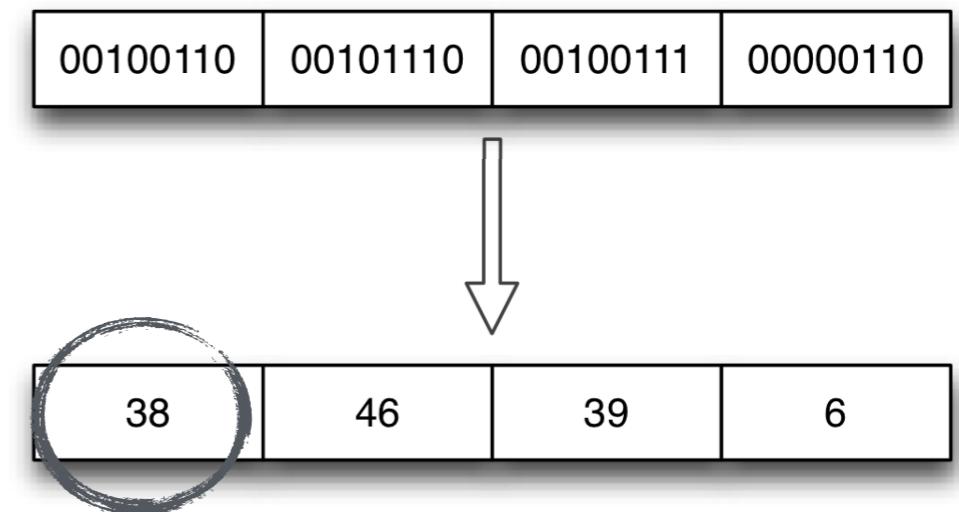
Phenotype

**GRAMMATICAL EVOLUTION**

**GRAMMATICAL EVOLUTION**

<movement> := left(0)

- | back (1)
- | right (2)      ←
- | front (3)



Mapping Rule: Codon Value % Number of Possible Derivations

$$38 \% 4 = 2$$

Mapping Example

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**GRAMMATICAL EVOLUTION**

- ▶ On the Locality of Grammatical Evolution, Rothlauf et al.
- ▶ Examining the “Best of Both Worlds” of Grammatical Evolution, Whigham et al.

# Can We Overcome the Grammatical Evolution Issues?

## STRUCTURED GRAMMATICAL EVOLUTION

- ▶ structured genotypic representation that ensures an **ONE-TO-ONE** mapping between genes and non-terminals another

**STRUCTURED GRAMMATICAL EVOLUTION**

```
<start> ::= <expr><op><expr> | <expr>
<expr> ::= <term><op><term> | (<term><op><term>)
<term> ::= x | 0.5
<op> ::= + | - | * | /
```



<start>	<expr>	<term>	<op>
---------	--------	--------	------

Genotype			
[0]	[0,1]	[0,1,0,1]	[0,2,1]

**STRUCTURED GRAMMATICAL EVOLUTION**

<start>	<expr>	<term>	<op>
---------	--------	--------	------

Genotype

<del>[0]</del>	<del>[0,1]</del>	<del>[0,1,0,1]</del>	<del>[0,2,1]</del>
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$\langle start \rangle ::= \langle expr \rangle \langle op \rangle \langle expr \rangle \mid \langle expr \rangle$   
 $\langle expr \rangle ::= \langle term \rangle \langle op \rangle \langle term \rangle \mid (\langle term \rangle \langle op \rangle \langle term \rangle)$   
 $\langle term \rangle ::= x \mid 0.5$   
 $\langle op \rangle ::= + \mid - \mid * \mid /$

&lt;start&gt;

**STRUCTURED GRAMMATICAL EVOLUTION**

```
< start > ::= < expr >  
< expr > ::= < expr > < op > < expr > | < var >  
    < op > ::= + | - | * | /  
    < var > ::= x
```

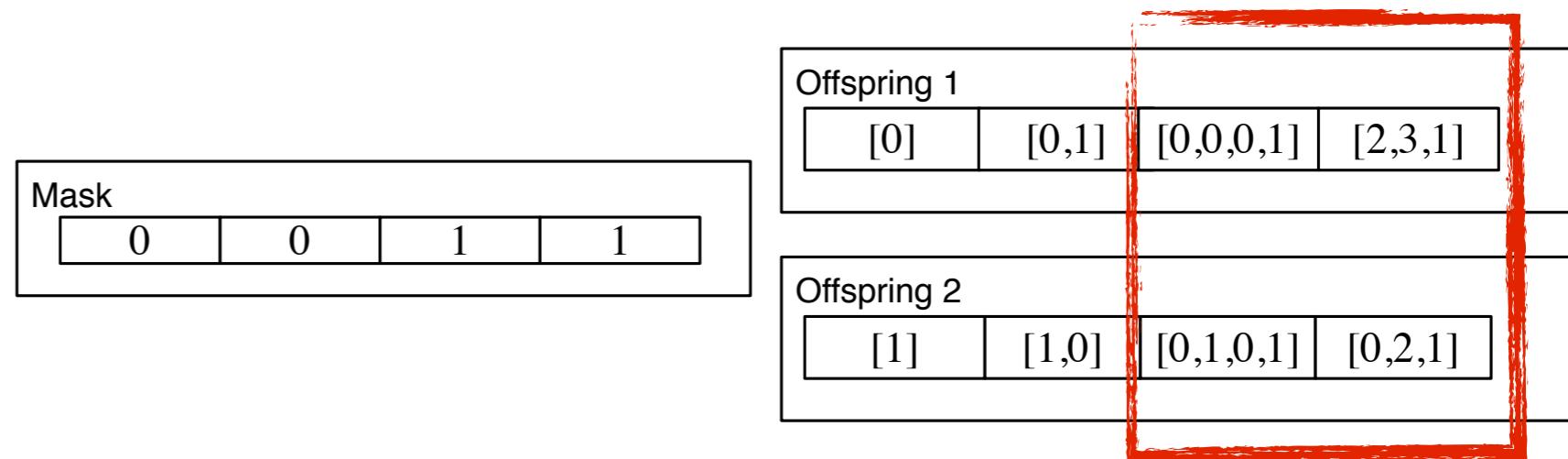
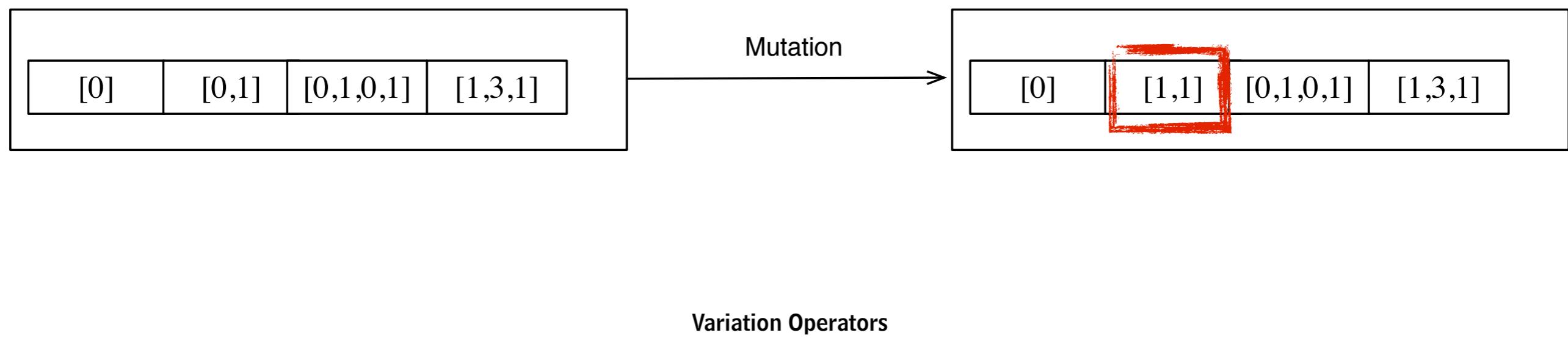
2 Levels of Recursion

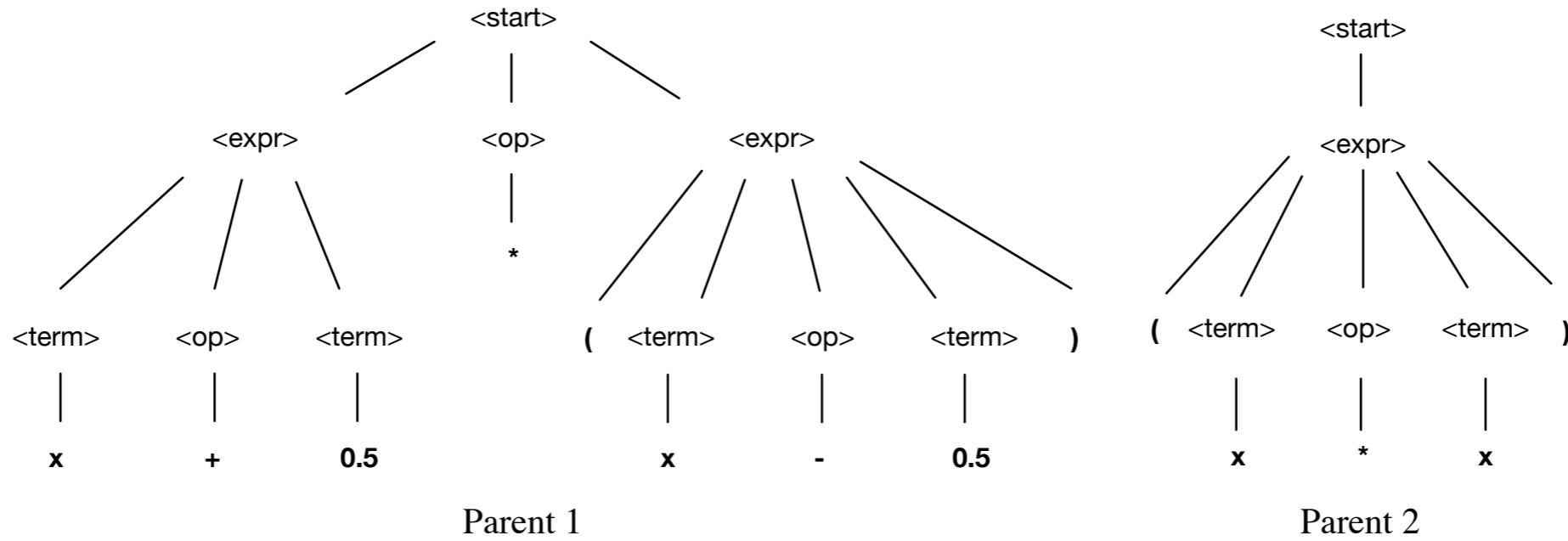
```
< start > ::= < expr >  
< expr > ::= < expr_lvl_0 > < op > < expr_lvl_0 >  
            | < var >  
→ < expr_lvl_0 > ::= < expr_lvl_1 > < op > < expr_lvl_1 >  
            | < var >  
→ < expr_lvl_1 > ::= < var > < op > < var > | < var >  
    < op > ::= + | - | * | /  
    < var > ::= x
```

Recursion

**STRUCTURED GRAMMATICAL EVOLUTION****CROSSOVER**

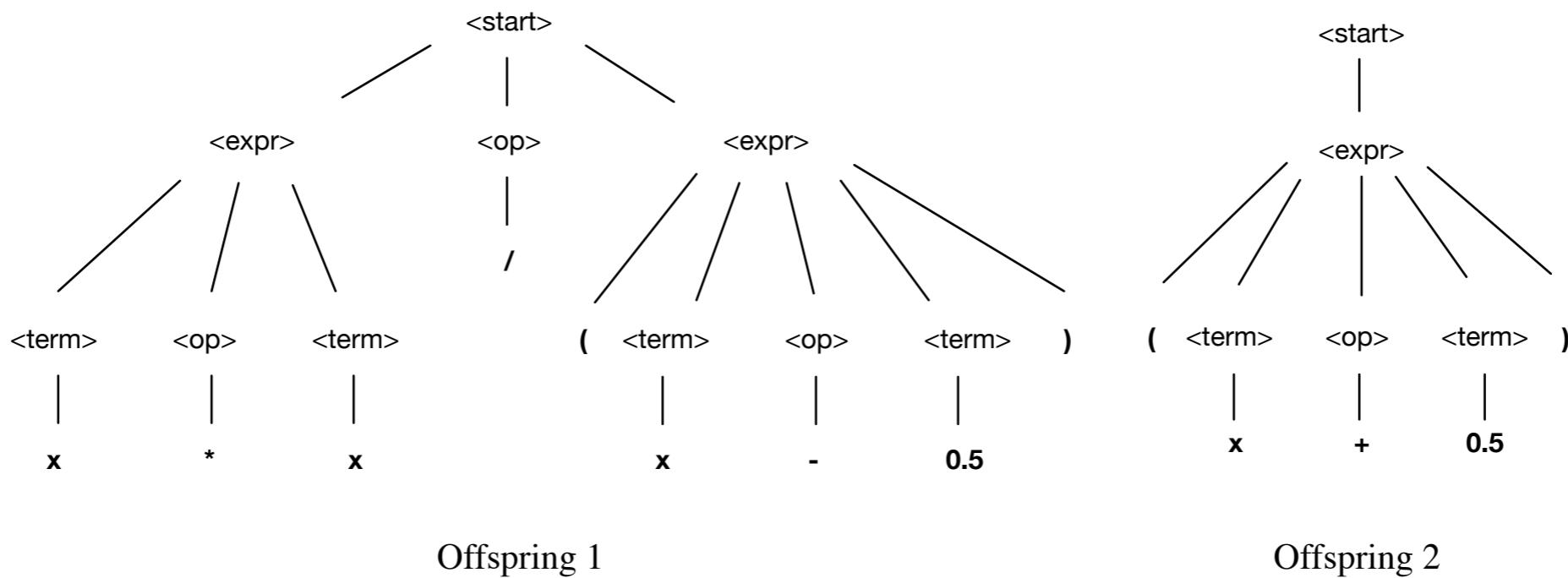
Parent 1	[0]	[0,1]	[0,1,0,1]	[0,2,1]
Parent 2	[1]	[1,0]	[0,0,0,1]	[2,3,1]

**MUTATION**

**STRUCTURED GRAMMATICAL EVOLUTION**

Parent 1

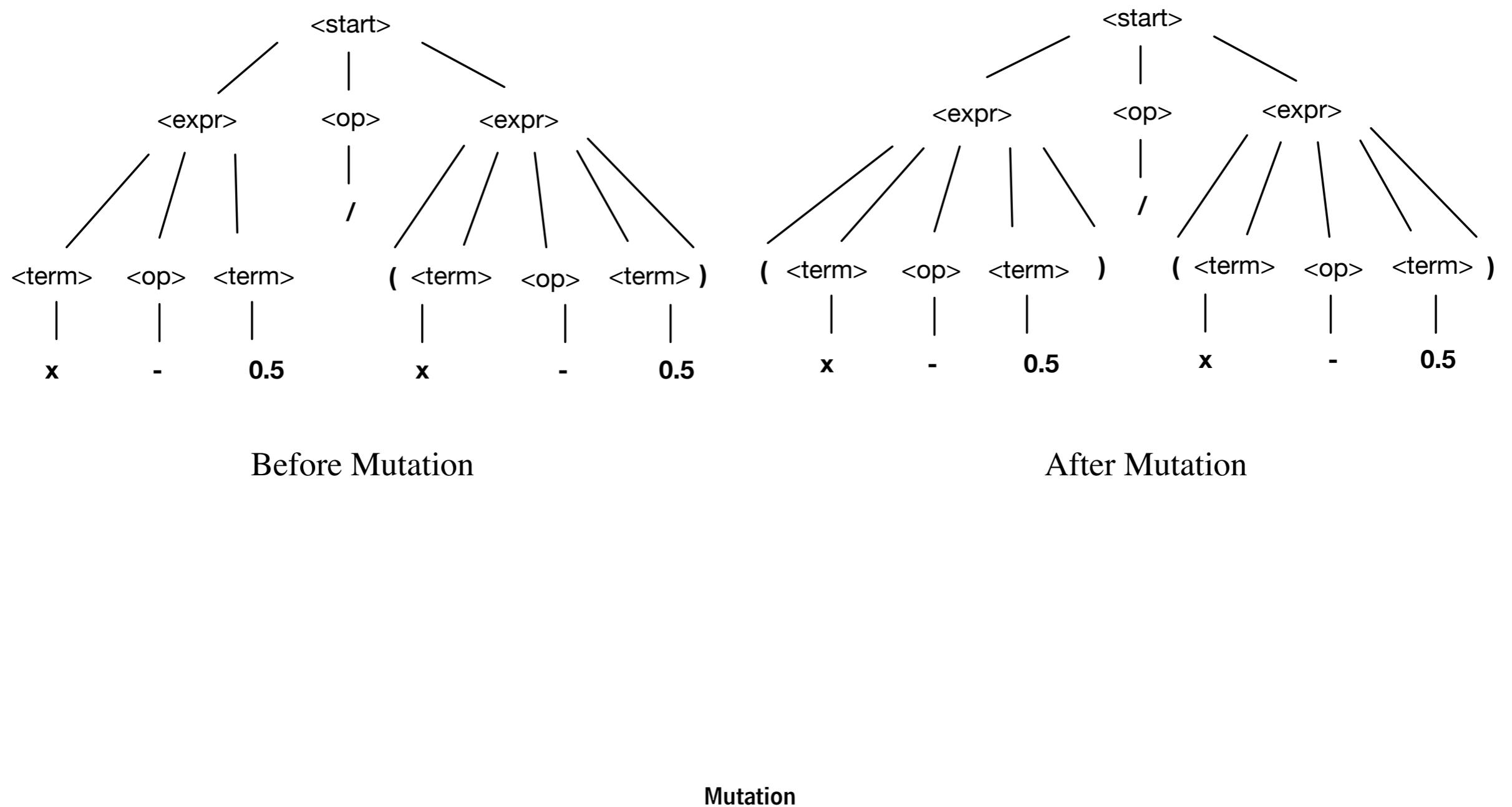
Parent 2



Offspring 1

Offspring 2

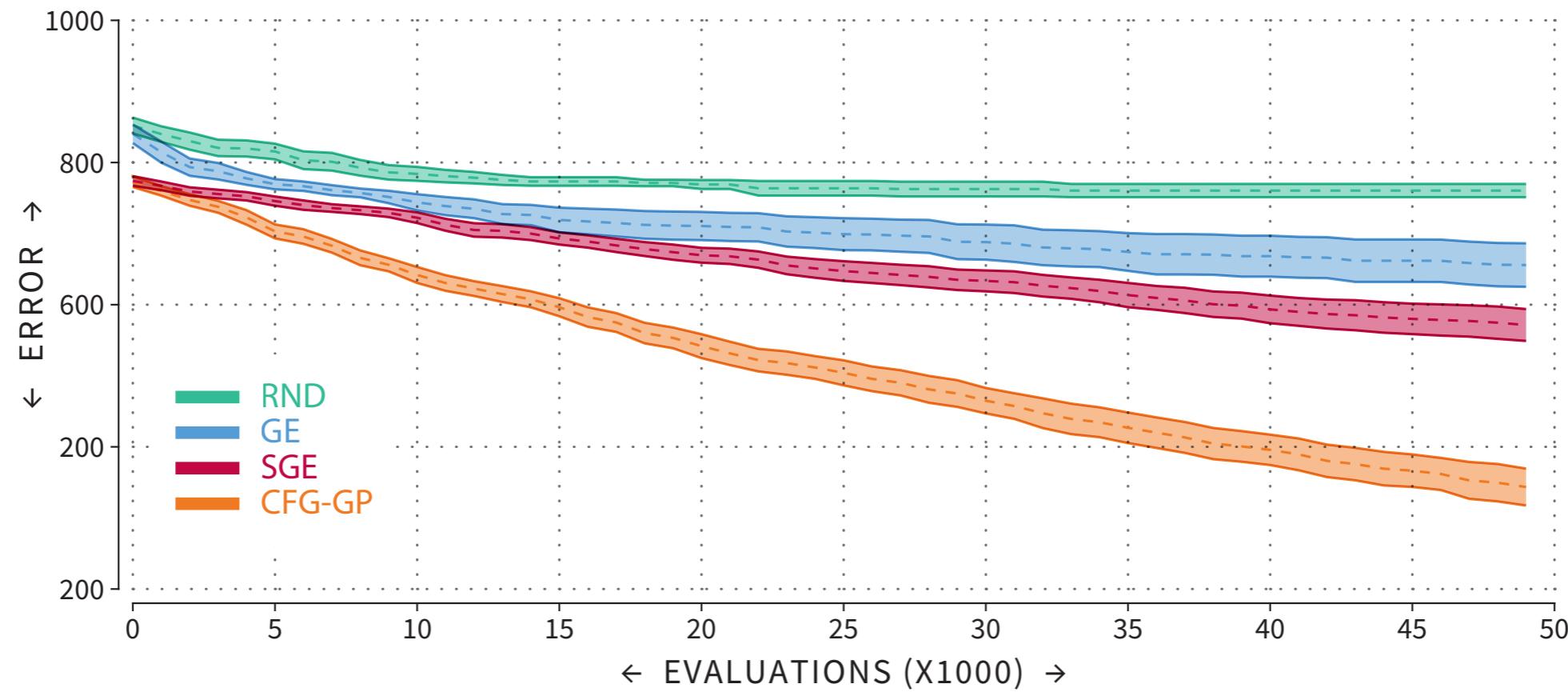
Crossover

**STRUCTURED GRAMMATICAL EVOLUTION**

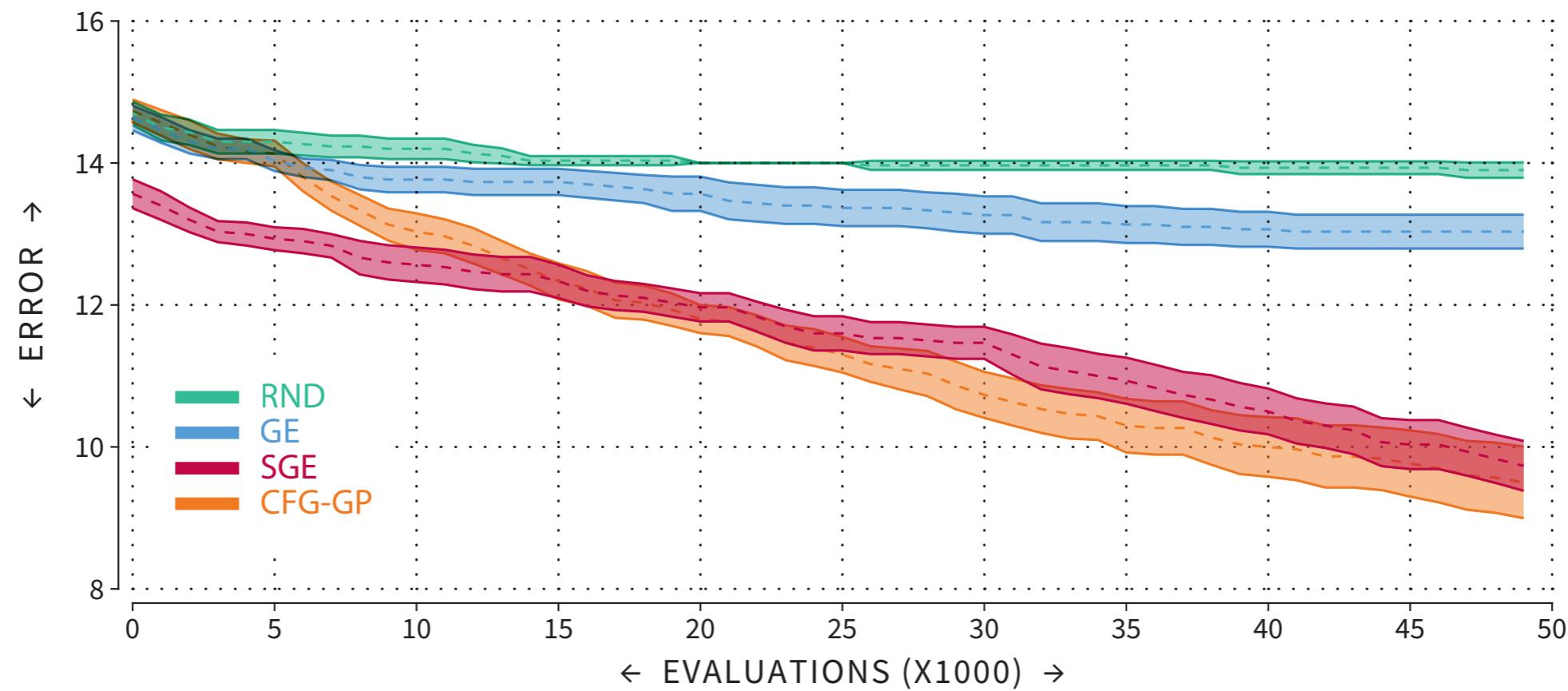
# Experimental Analysis

## PROBLEMS

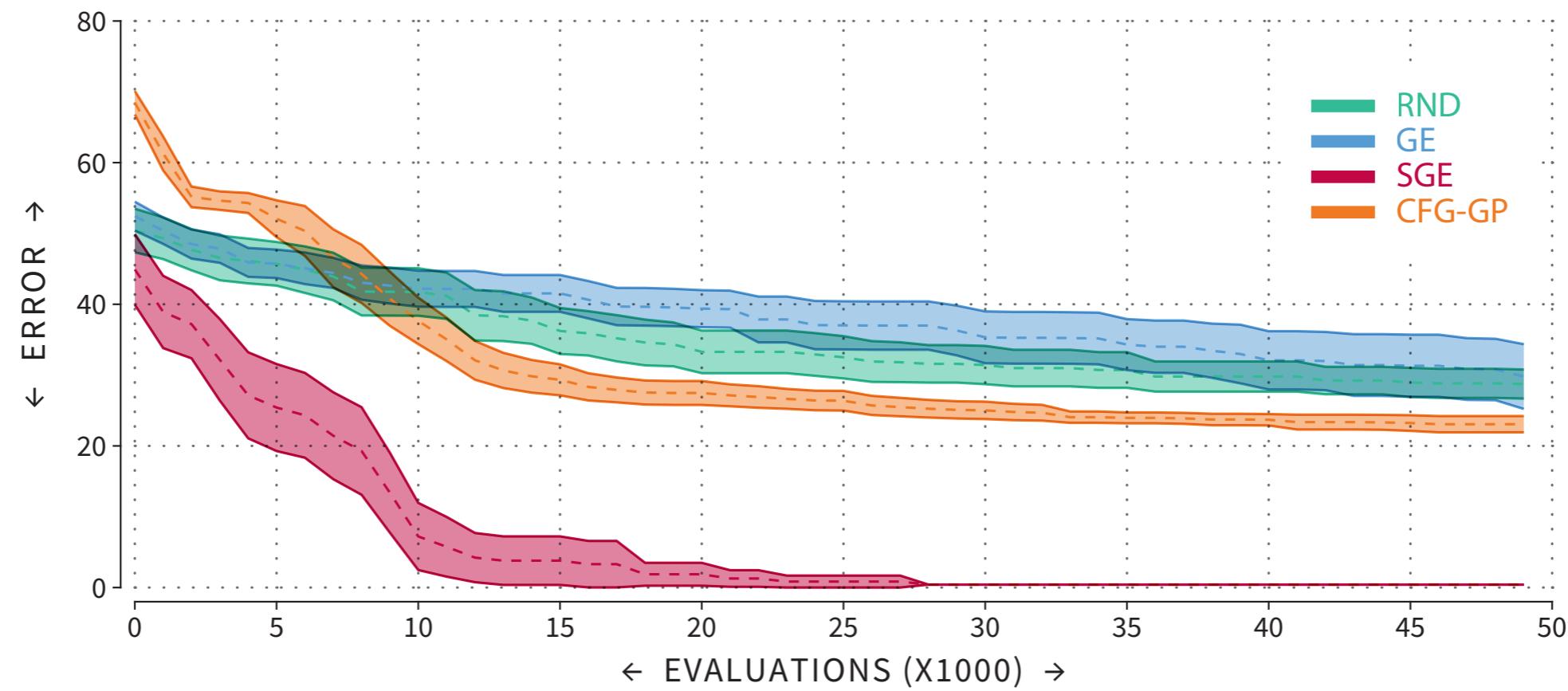
- ▶ 11-Bit Boolean Multiplexer
- ▶ 5-Bit Parity
- ▶ Santa Fe Ant Trail
- ▶ Quartic Polynomial
- ▶ Boston Housing Problem

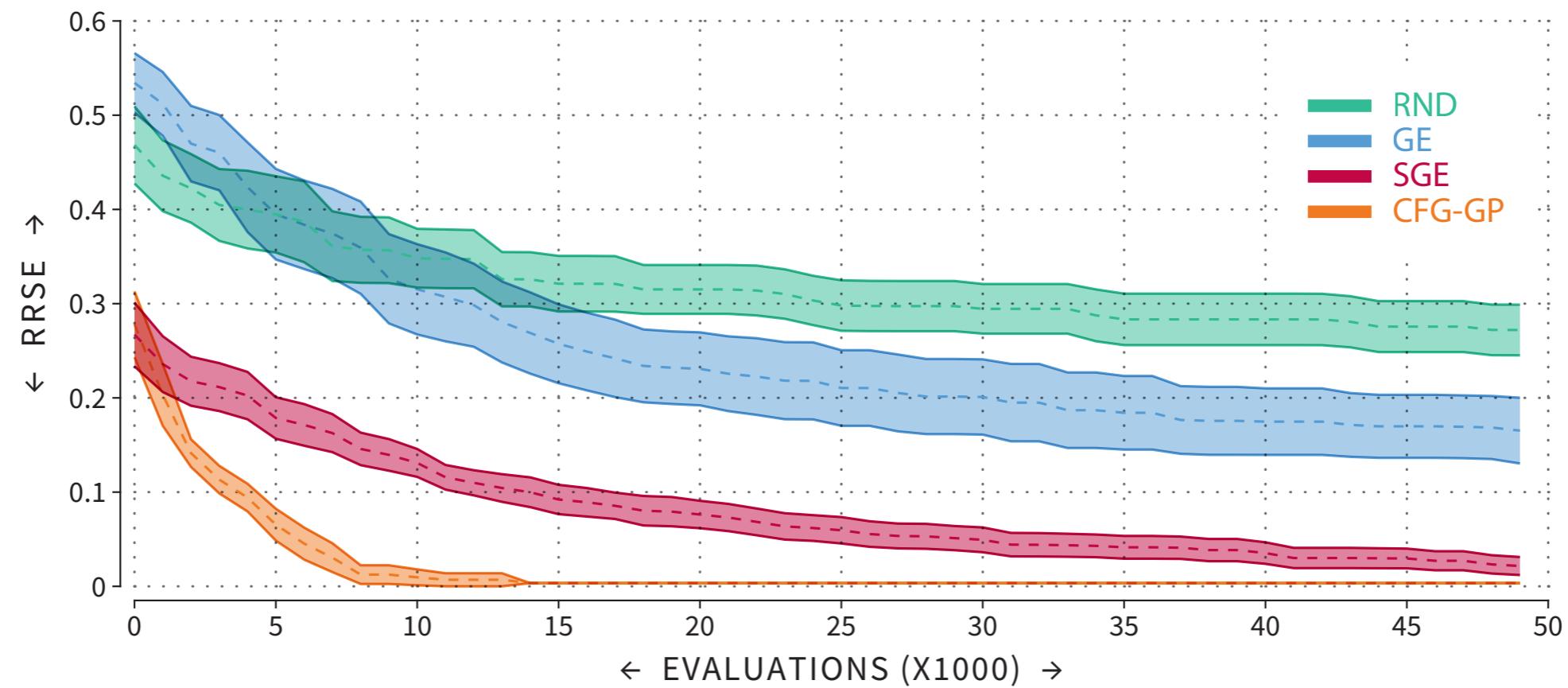
**EXPERIMENTAL RESULTS**

11-Bit Multiplexer

**EXPERIMENTAL RESULTS**

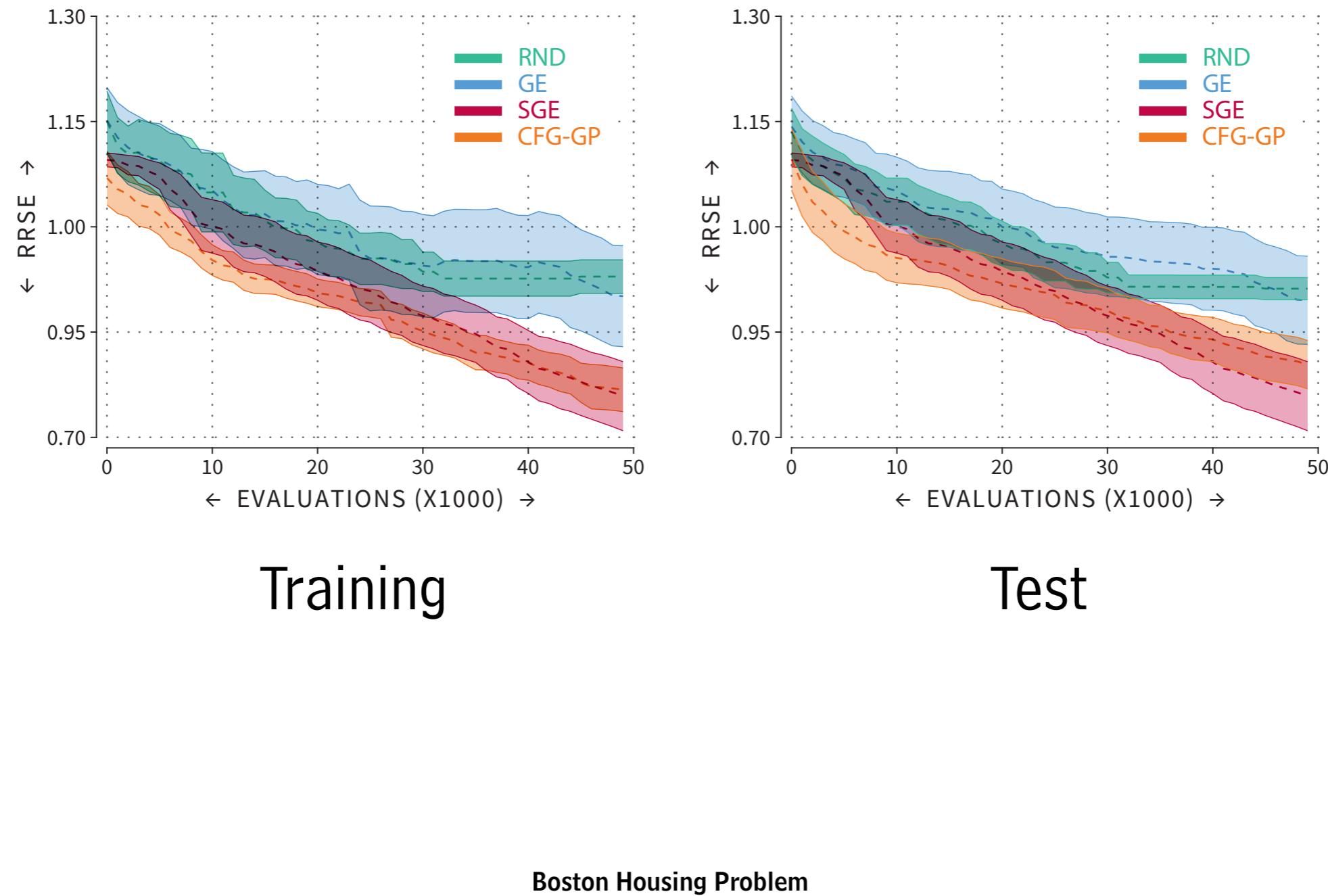
5-Bit Parity

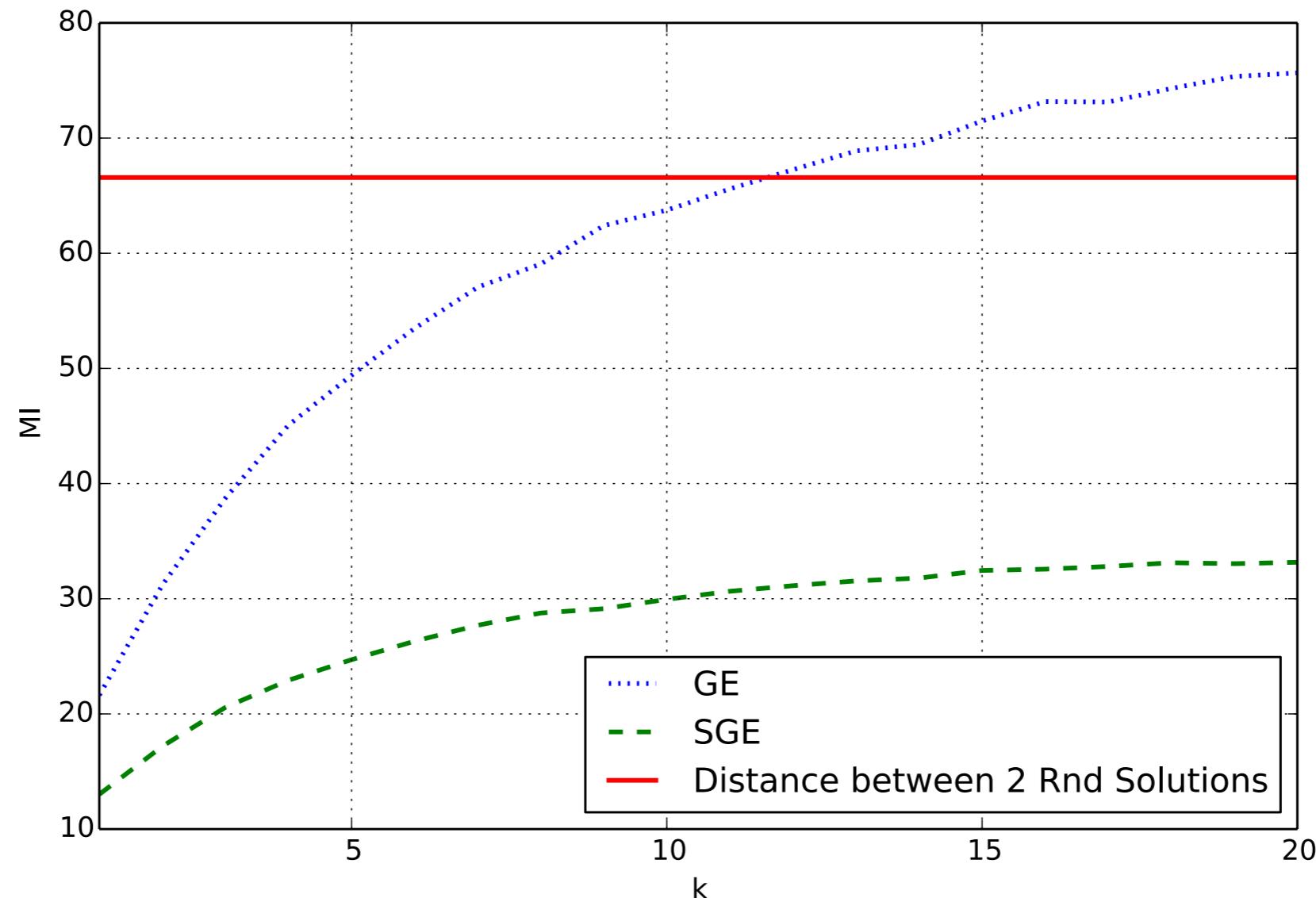
**EXPERIMENTAL RESULTS****Santa Fe Ant Trail**

**EXPERIMENTAL RESULTS**

Quartic

## EXPERIMENTAL RESULTS



**SGE VS GE LOCALITY**

Distance between solutions after K mutations

**SGE is good, but...**

## SGE CRITICISMS

- ▶ The input grammar has to be pre-processed
  - ▶ To remove recursion
  - ▶ Compute the maximum number of expansions

# **Dynamic Structured Grammatical Evolution (DSGE)**

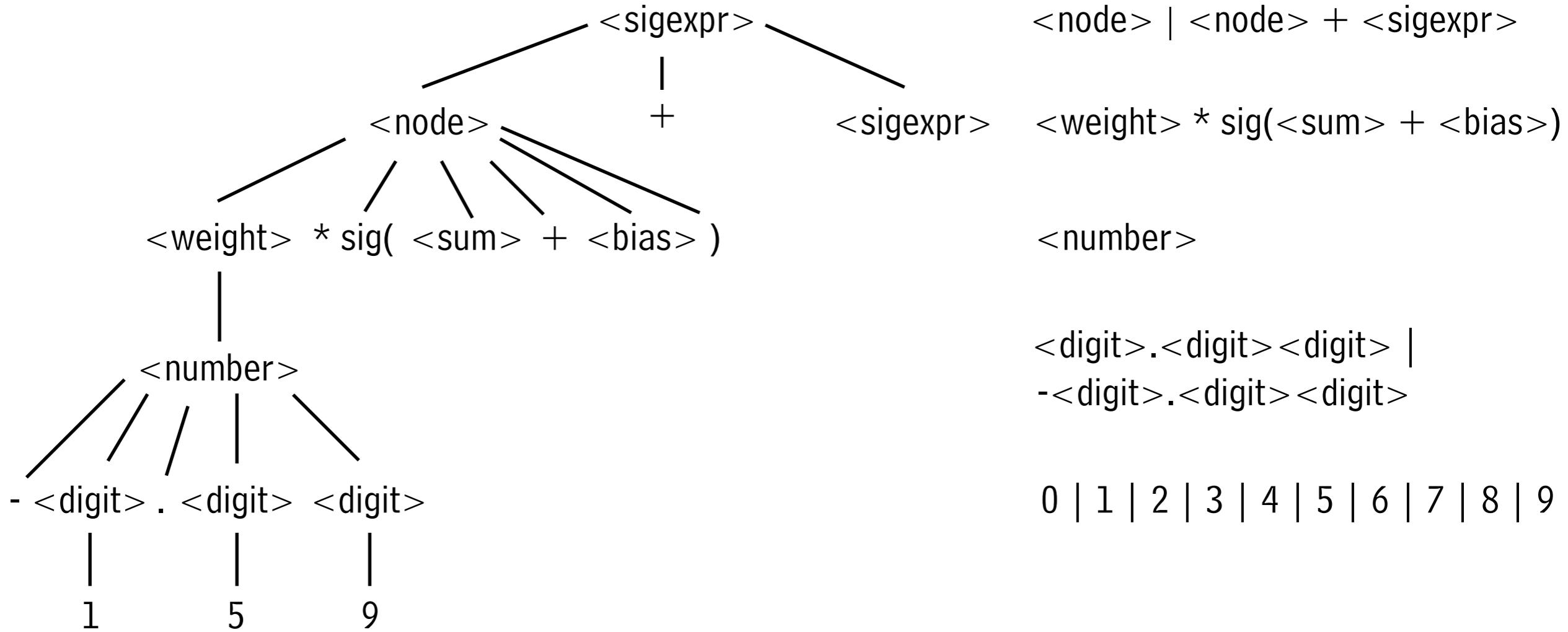
## REPRESENTATION

- ▶ For each non-terminal symbol there is a list of variable size with the integers that encode the expansion possibilities;
- ▶ Maximum recursion is defined as the maximum sub-tree depth for each non-terminal symbol.

**INITIALISATION**

<code>&lt;sigexpr&gt;</code>	<code>&lt;node&gt;</code>	<code>&lt;sum&gt;</code>	<code>&lt;features&gt;</code>	<code>&lt;weight&gt;</code>	<code>&lt;bias&gt;</code>	<code>&lt;number&gt;</code>	<code>&lt;digit&gt;</code>
------------------------------	---------------------------	--------------------------	-------------------------------	-----------------------------	---------------------------	-----------------------------	----------------------------

1	0			0		1	1, 5, 9
---	---	--	--	---	--	---	---------



initialisation

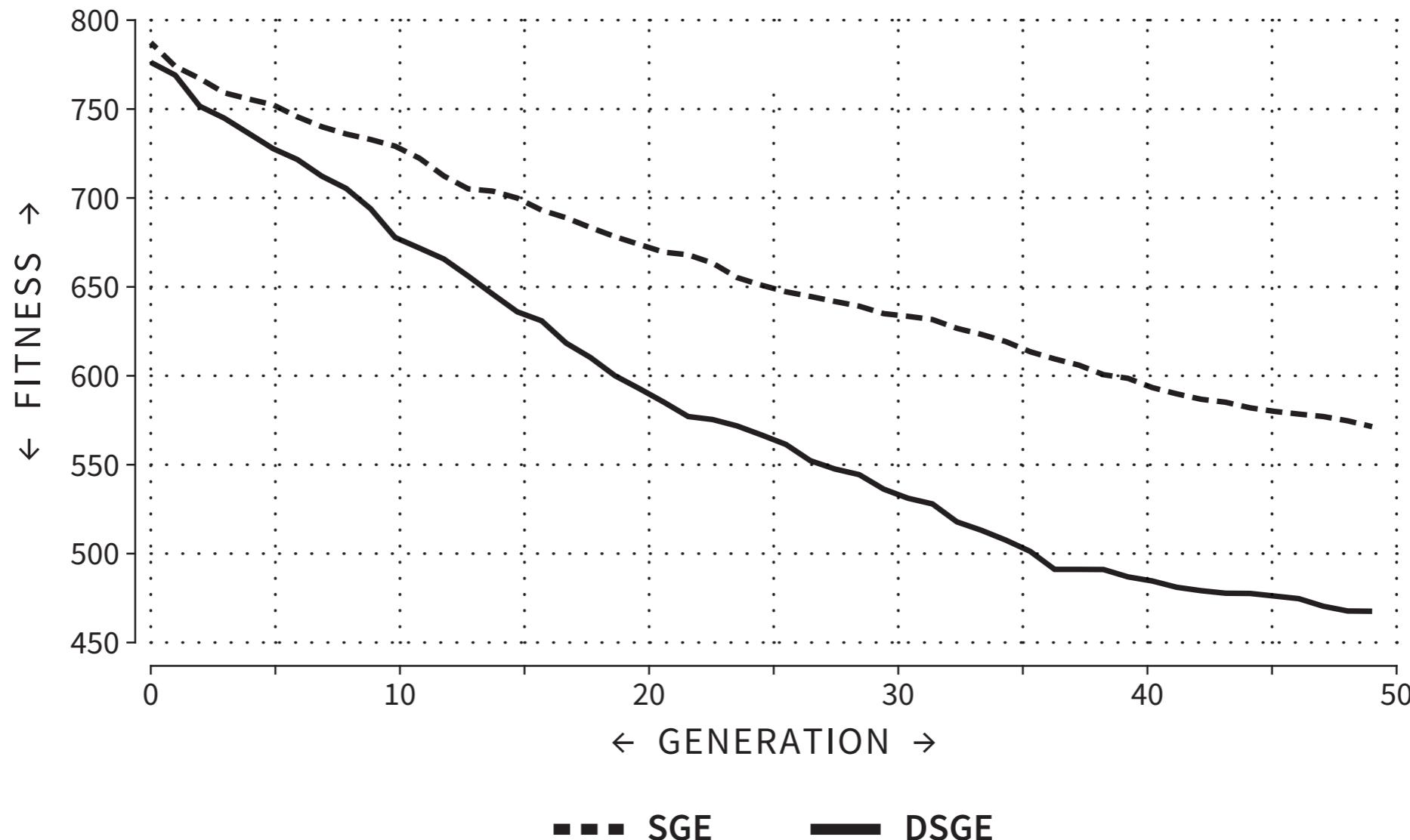
## DECODING PROCEDURE

- ▶ Similar to the initialisation procedure;
- ▶ Instead of selecting random expansion possibilities, the ones encoded in the genotype are used;

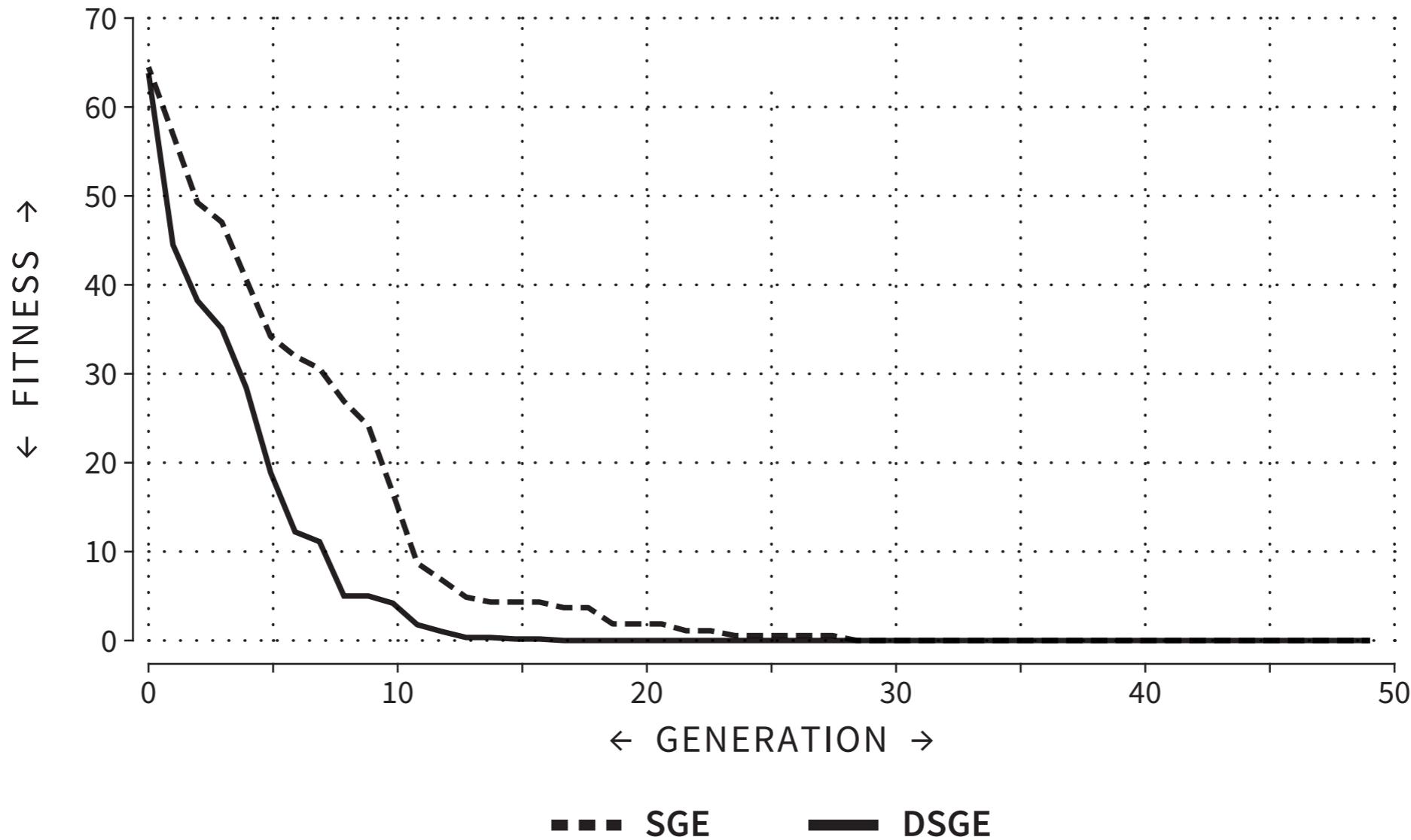
# Experimental Analysis

## PROBLEMS

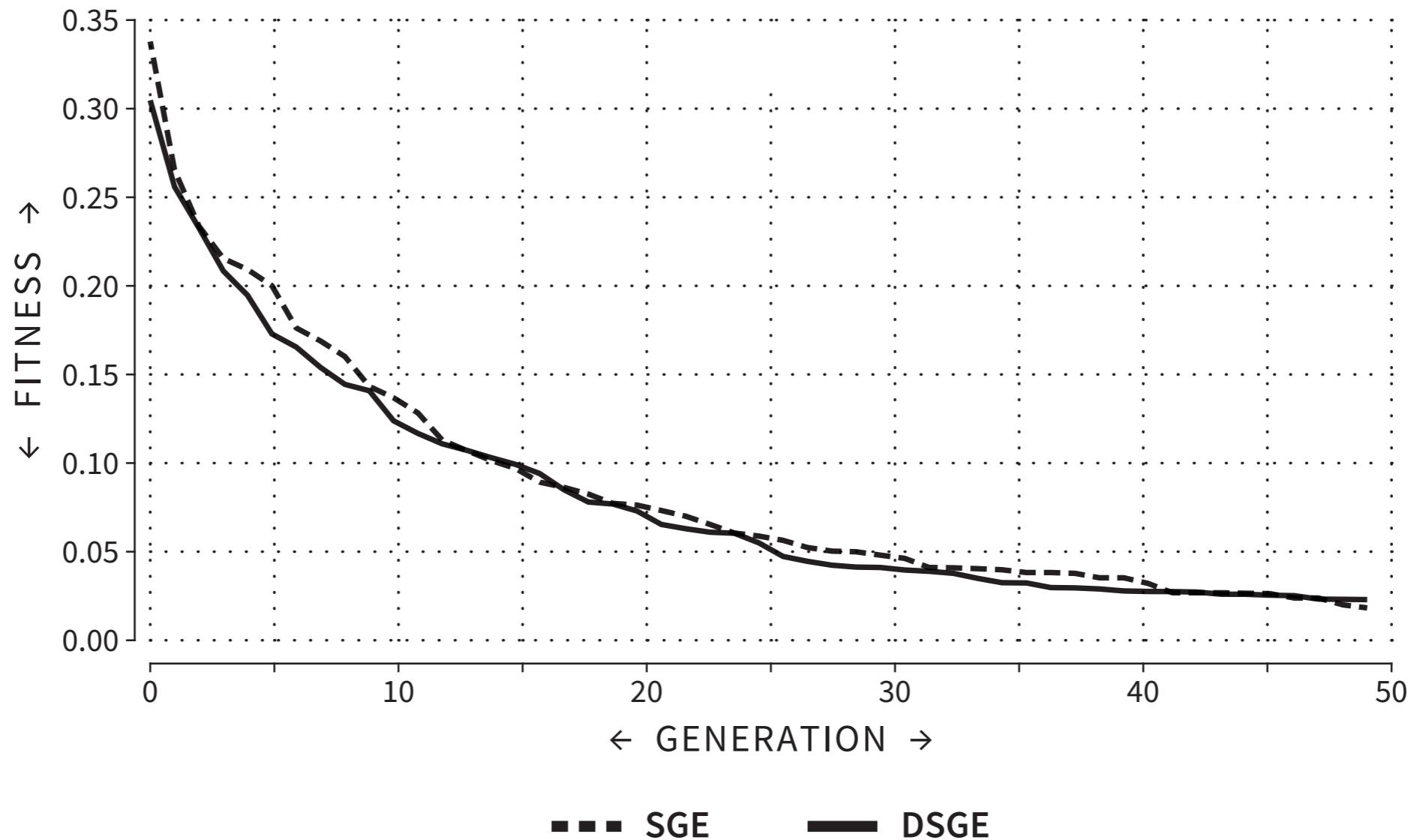
- ▶ 11-Bit Boolean Multiplexer
- ▶ 5-Bit Parity
- ▶ Santa Fe Ant Trail
- ▶ Quartic Polynomial
- ▶ Boston Housing Problem

**EXPERIMENTAL RESULTS**

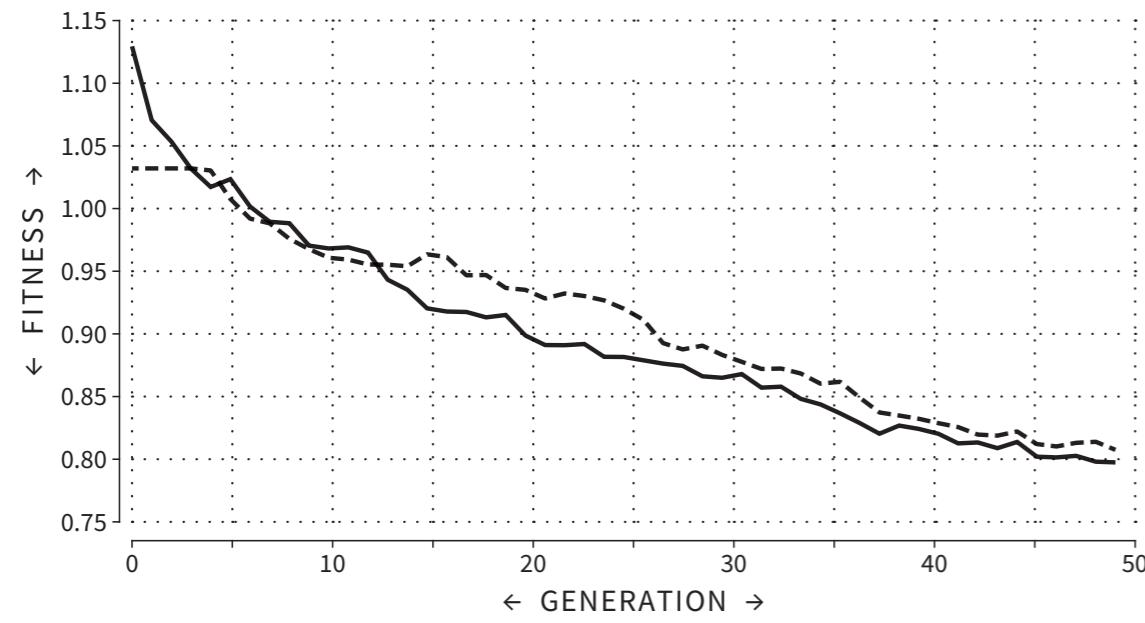
11-Bit Multiplexer

**EXPERIMENTAL RESULTS**

Santa Fe Ant Trail

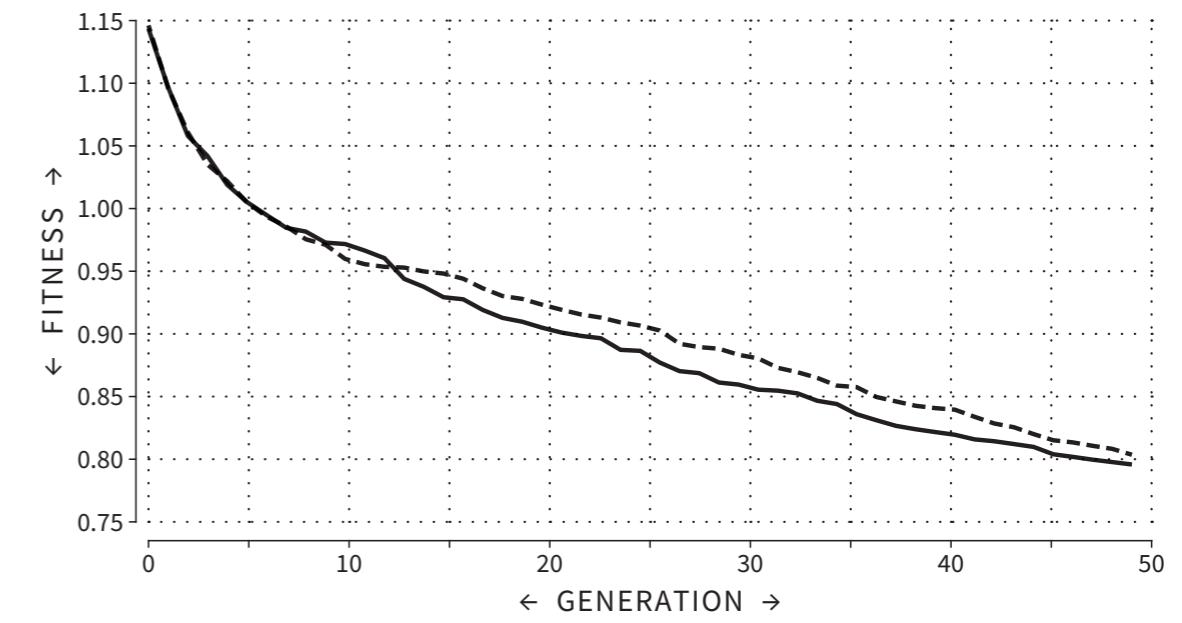
**EXPERIMENTAL RESULTS**

Quartic Problem

**EXPERIMENTAL RESULTS**

--- SGE      — DSGE

Training



Test

Boston Housing Problem

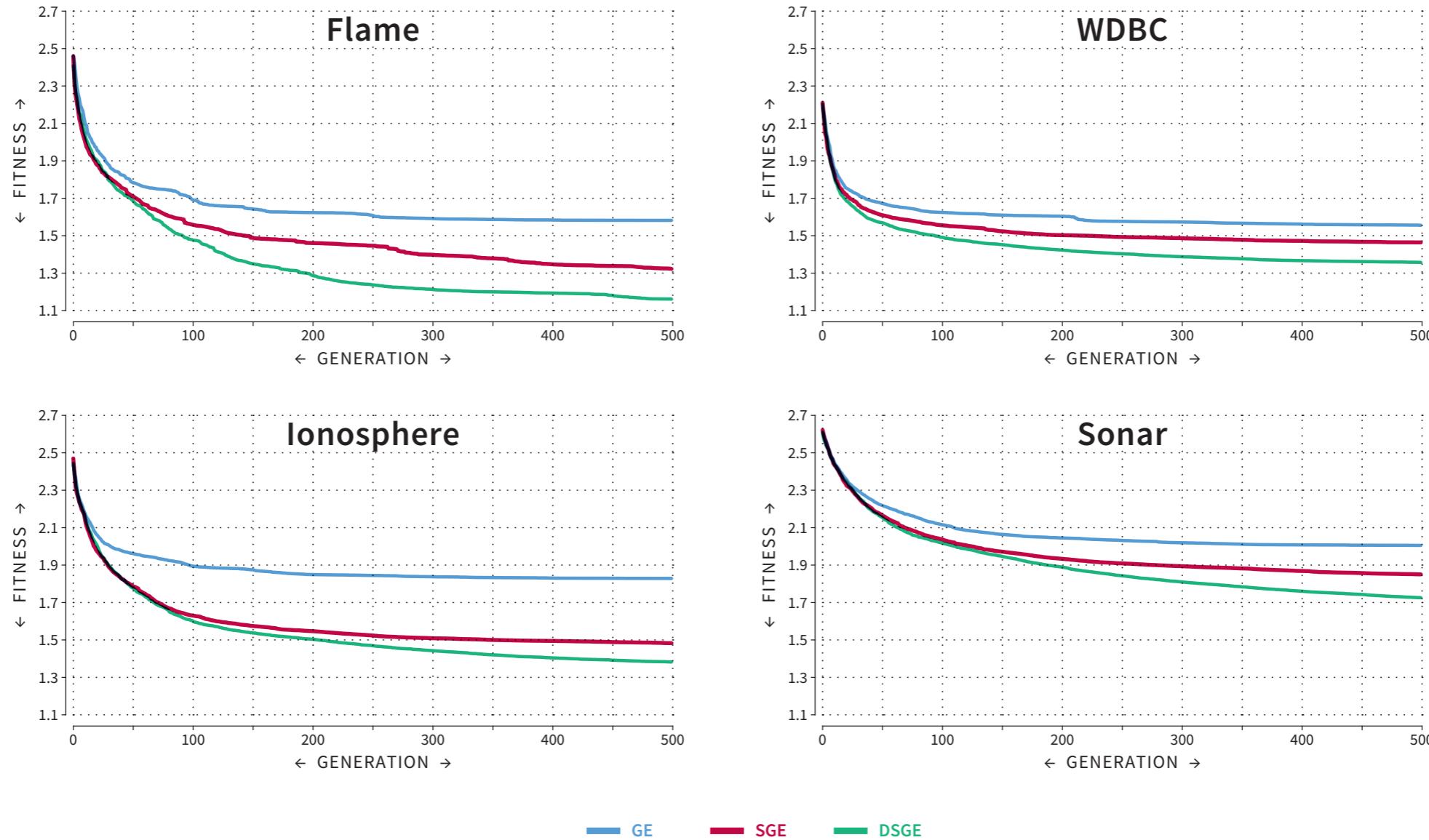
# Evolving Artificial Neural Networks

## DATASETS

- ▶ Flame [2];
- ▶ Wisconsin Breast Cancer Detection (WDBC) [30];
- ▶ Ionosphere [34];
- ▶ Sonar [60].

---

**GRAMMAR**
$$\begin{aligned} <\text{sigexpr}> ::= & \quad <\text{node}> \\ | & \quad <\text{node}> + <\text{sigexpr}> \end{aligned}$$
$$<\text{node}> ::= <\text{weight}> * \text{sig}(<\text{sum}> + <\text{bias}>)$$
$$\begin{aligned} <\text{sum}> ::= & \quad <\text{weight}> * <\text{features}> \\ | & \quad <\text{sum}> + <\text{sum}> \end{aligned}$$
$$\begin{aligned} <\text{features}> ::= & \quad x_1 \\ | & \quad \dots \\ | & \quad x_n \end{aligned}$$
$$<\text{weight}> ::= <\text{number}>$$
$$<\text{bias}> ::= <\text{number}>$$
$$\begin{aligned} <\text{number}> ::= & \quad <\text{digit}>. <\text{digit}><\text{digit}> \\ | & \quad - <\text{digit}>. <\text{digit}><\text{digit}> \end{aligned}$$
$$\begin{aligned} <\text{digit}> ::= & \quad 0 \mid 1 \mid 2 \mid 3 \mid 4 \\ | & \quad 5 \mid 6 \mid 7 \mid 8 \mid 9 \end{aligned}$$

**FITNESS EVOLUTION**

# Conclusions

## CONCLUSIONS

- ▶ New Grammatical Representation
- ▶ Better performance in all the benchmarks used
  - ▶ More Effective
  - ▶ More Efficiente
- ▶ Statistical significant improvements
  - ▶ SGE over GE
  - ▶ DSGE over SGE

# Evolving Grammars: A Structured Point of View

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