Report of Experiment ExpA. 3-Symmetry: Sequential versus Multicore for GP, GE, and GE by DE.

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Abstract

This experiment compares sequential and multicore learning with `xegaRun` for the 3-symmetry problem with nand functions by three different evolutionary algorithms: grammar-based genetic programming, grammatical evolution, and grammatical evolution by differential evolution. Grammatical evolution by differential evolution is a novel combination of grammatical evolution and differential evolution.

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Definitions

In a **controlled computational experiment** the influence of one or more control parameters on the outcome is studied with regard to a systematic setting of a set of selected control parameters. All other parameters must be known and held constant.
The experiment should be repeatable.

Description of Experiment

The purpose of this computational experiment is to compare sequential (`executionModel="Sequential"`) and multicore (`executionModel="MultiCore"`) processing for each algorithm, and to establish a performance ranking of the three algorithms grammar-based genetic programming (`algorithm="sgp"`), grammatical evolution (`algorithm="sge"`), and grammatical evolution by differential evolution (`algorithm="sgede"`).
The **problem environment** is the 3-symmetry problem: Finding a boolean expression (with the nand function) which is TRUE for symmetric 3-bit strings.
The **solver** used is `xegaRun` from the R-package `xega`.
The experiment consists of 6 treatments, namely the sequential and multicore version of each of the 3 algorithms.

Common Parameters of Experiment ExpA

	Parameter Value
Experiment	ExpA
Problem.Environment	3-Symmetry Problem
Optimize	Minimize!
Trials	200
Max.Depth.of.DTs	7
Grammar	Nand.txt
Replay	0
Evaluation.Method	Deterministic
Verbose	1
Semantics	byValue
Report.Eval.Errors	TRUE
Termination.Condition	AbsoluteError
Termination.Eps	-0.1
Worst.Fitness	-8
Init.Gene	InitGene

Table: Common Parameters of Experiment ExpA (Part 1)

Common Parameters of Experiment ExpA

	Parameter Value
Codons	120
Codon.Precision	LCM
Population.Size	400
Max.Generations	1000
Crossover.Rate	0.2
Mutation.Rate	0.4
IV.Crossover.Rate	Const
Crossover.Rate.2	0.4
IV.Mutation.Rate	Const
Mutation.Rate.2	0.8

Table: Common Parameters of Experiment ExpA (Part 2)

Parameters of Treatments of Experiment ExpA

	Treatment	Algorithm	Execution Model	Gene Map
1	MCSGE	sge	MultiCore	Mod
2	MCSGP	sgp	MultiCore	Bin2Dec
3	MCSGV	sgede	MultiCore	Identity
4	SQSGE	sge	Sequential	Mod
5	SQSGP	sgp	Sequential	Bin2Dec
6	SQSGV	sgede	Sequential	Identity

Table: Parameters of Treatments of Experiment ExpA

The Production Table of Experiment ExpA

	LHS	RHS
1	<fe>	<f0>
2	<fe>	<f2>(<fe>,<fe>)
3	<f0>	D1
4	<f0>	D2
5	<f0>	D3
6	<f2>	NAND

Table: The Production Table of Experiment ExpA

The experiment has two control variables:
`exectionModel` with 2 levels: `"Sequential"` and `"MultiCore"`.
`algorithm` with 3 levels: `"sgp"`, `"sge"` and `"sgede"` .
We investigate sequential versus multicore execution and the performance of the three algorithms.

Observation

In this experiment, the 3-symmetry problem is **not always** correctly solved.

Evidence: In all treatments of the grammatical evolution algorithm (MCSGE and SQSGE), in a few trials, non-optimal solutions were observed with a limit of 1000 generations. See next table.

Fitness (Number of errors).

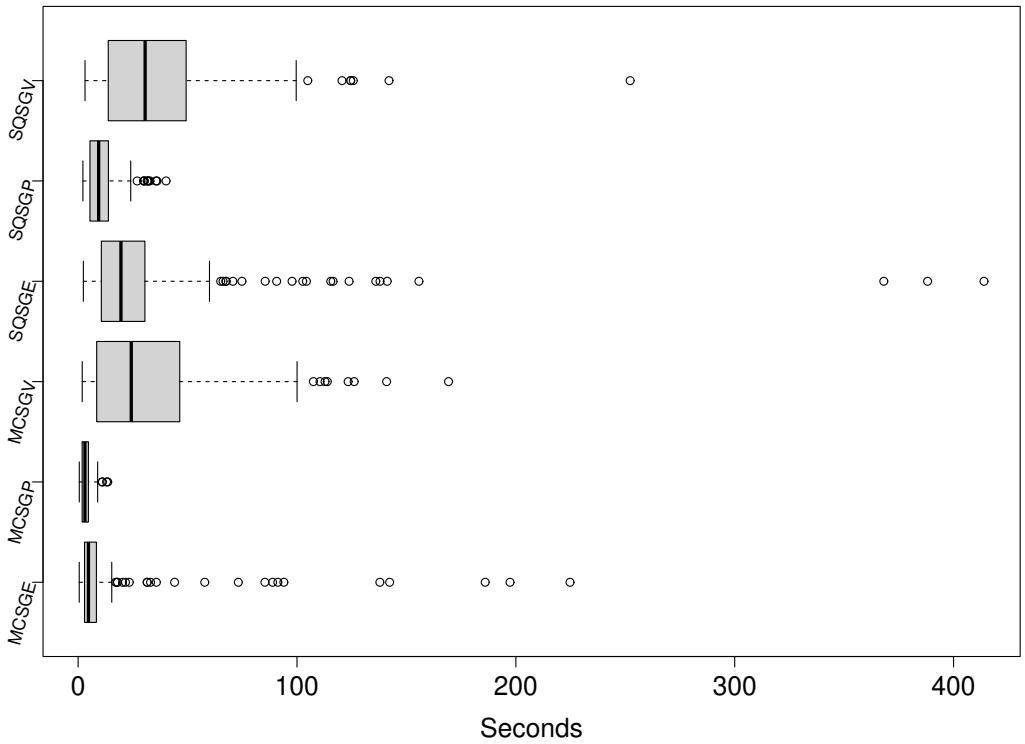
	Treatment	Trials	Variable	min	mean	sd	max
1	MCSGE	200	Fitness	0.00	0.02	0.20	2.00
5	MCSGP	200	Fitness	0.00	0.00	0.00	0.00
9	MCSGV	200	Fitness	0.00	0.00	0.00	0.00
13	SQSGE	200	Fitness	0.00	0.01	0.07	1.00
17	SQSGP	200	Fitness	0.00	0.00	0.00	0.00
21	SQSGV	200	Fitness	0.00	0.00	0.00	0.00

Table: Fitness (Number of errors).

Recommendation: New Experiment.

It is suggested to use the maximal number of generations as additional control variable. The goal is to find the (conditional) probability that the optimal solution is found given a resource constraint.

3-Symmetry: Sequential versus Multicore for GP, GE, and GE by DE.



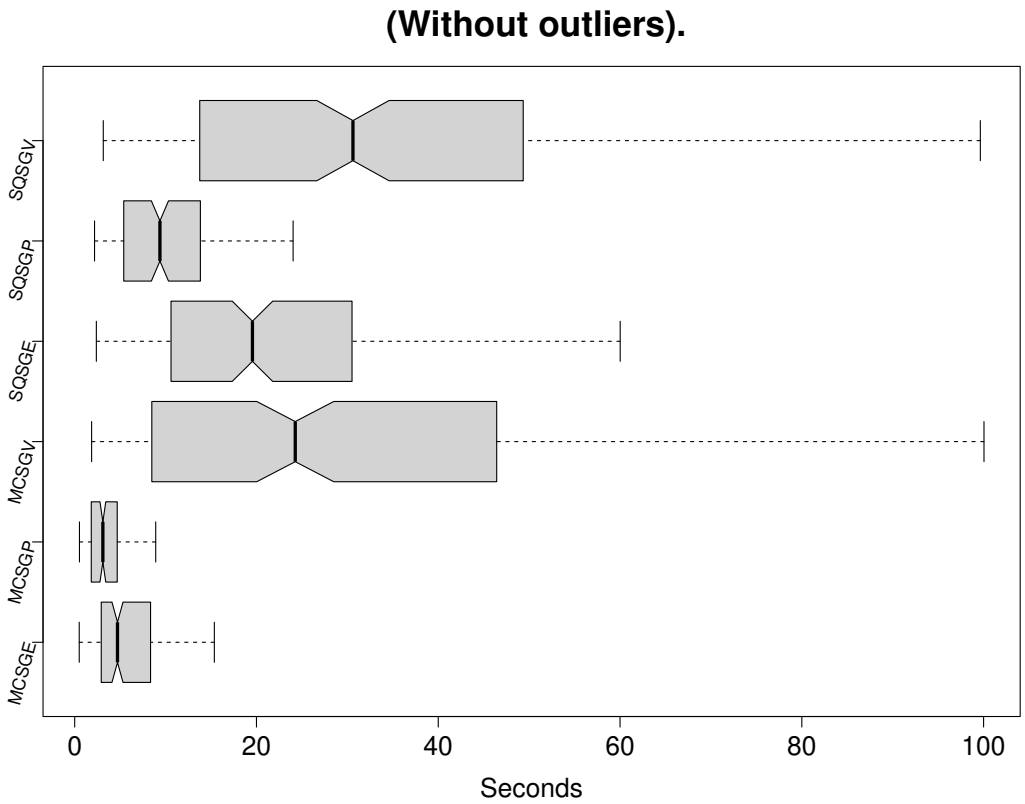
Time (s).

	Treatment	Trials	Variable	min	mean	sd	max
2	MCSGE	200	Seconds	0.50	12.95	30.61	224.75
6	MCSGP	200	Seconds	0.52	3.50	2.32	13.52
10	MCSGV	200	Seconds	1.86	32.84	30.21	169.25
14	SQSGE	200	Seconds	2.38	32.47	52.25	413.90
18	SQSGP	200	Seconds	2.18	10.70	7.42	40.17
22	SQSGV	200	Seconds	3.14	36.00	31.53	252.23

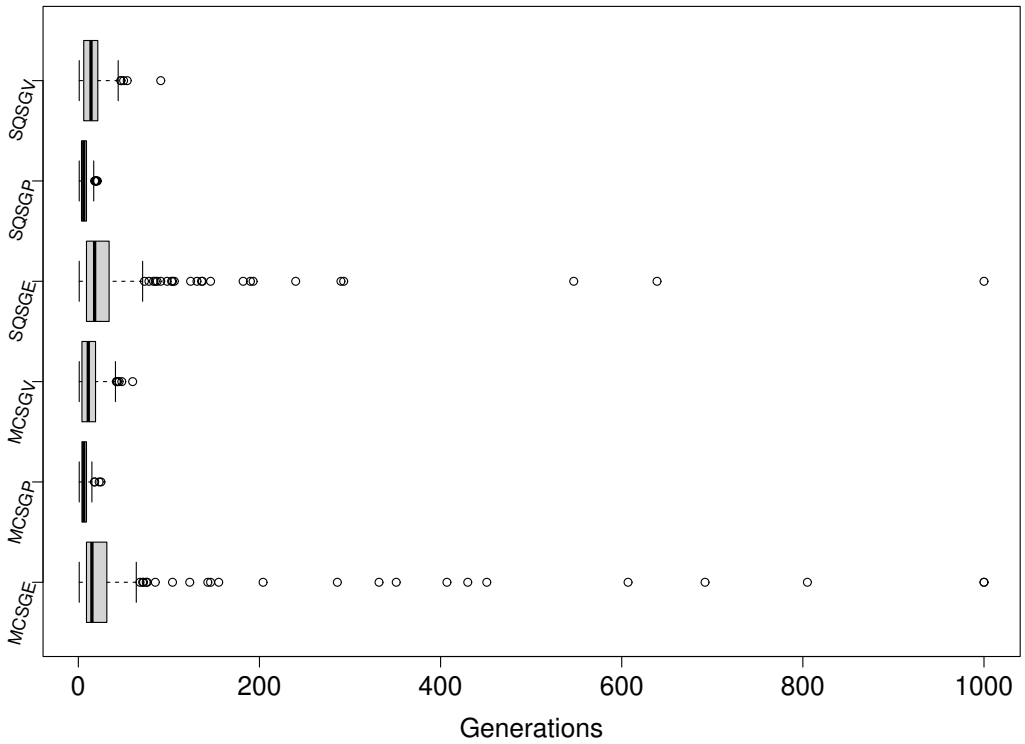
Table: Time (s).

Time of Treatments in Seconds:

3-Symmetry: Sequential versus Multicore for GP, GE, and GE by DE.



3-Symmetry: Sequential versus Multicore for GP, GE, and GE by DE.

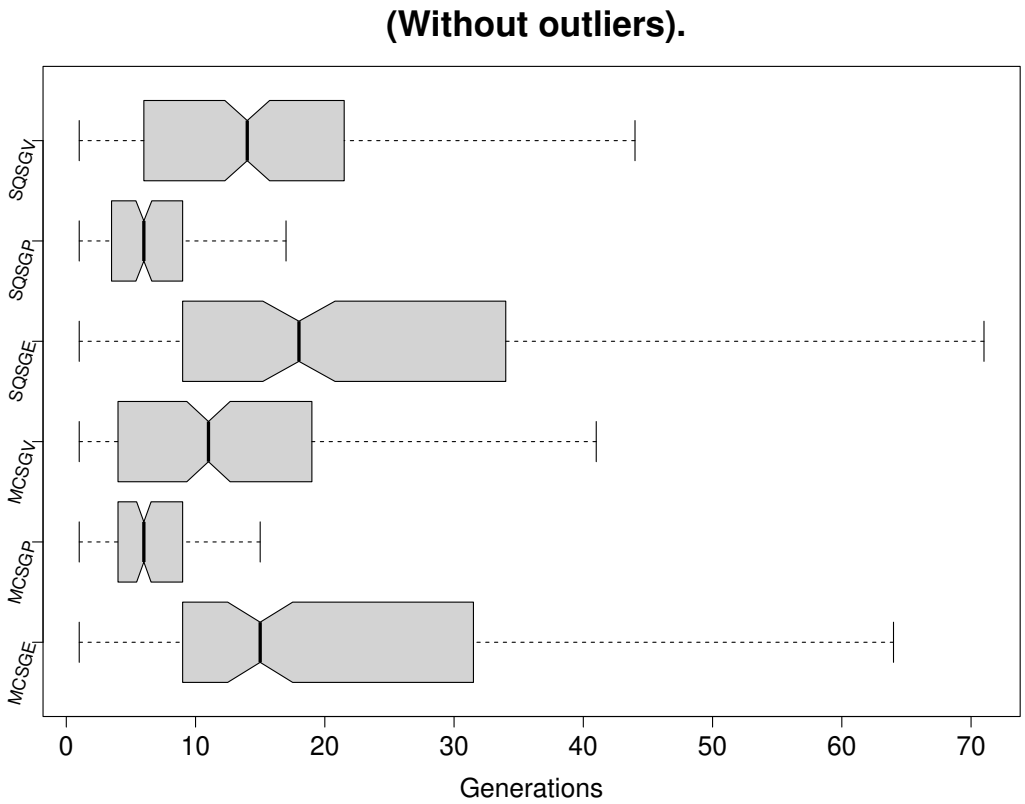


Generations

	Treatment	Trials	Variable	min	mean	sd	max
3	MCSGE	200	Generations	1.00	53.83	142.45	1000.00
7	MCSGP	200	Generations	1.00	6.70	4.15	25.00
11	MCSGV	200	Generations	1.00	13.69	11.18	60.00
15	SQSGE	200	Generations	1.00	42.26	99.14	1000.00
19	SQSGP	200	Generations	1.00	6.70	4.38	21.00
23	SQSGV	200	Generations	1.00	14.93	12.03	91.00

Table: Generations

3-Symmetry: Sequential versus Multicore for GP, GE, and GE by DE.



Should we prefer multi-core or sequential processing?

For each agorithm we have to test:

1. Is the multi-core version faster (in seconds) than the sequential version?
2. Do both of them need the same resources (in generations)?

Multi-core processing is only preferable if it is faster (in seconds) when running for the same number of generations.
The evaluation of the population of genes is parallelized.

Time in (s) (SGP)

	Treatment	Trials	Variable	min	mean	sd	max
2	MCSGP	200	Seconds	0.52	3.50	2.32	13.52
6	SQSGP	200	Seconds	2.18	10.70	7.42	40.17

Table: Time in (s) (SGP)

Number of Generations (SGP)

	Treatment	Trials	Variable	min	mean	sd	max
3	MCSGP	200	Generations	1.00	6.70	4.15	25.00
7	SQSGP	200	Generations	1.00	6.70	4.38	21.00

Table: Number of Generations (SGP)

Test of H_0: Mean of treatment MCSGP is less than mean of SQSGP of variable Seconds

For variable Seconds of treatments SQSGP and MCSGP of experiment ExpA:

Hypothesis 0: mean(Seconds of SQSGP)=10.7 - mean(Seconds of MCSGP)=3.5 is equal or greater than 0.

is tested at a significance level 0.05 against:

Hypothesis 1: mean(Seconds of SQSGP)=10.7 - mean(Seconds of MCSGP)=3.5 is less than 0.

Outliers of treatment SQSGP are not removed (coef=0).
Outliers of treatment MCSGP are not removed (coef=0).

The test-statistic W of the Wilcoxon rank sum test with continuity correction is 34375 with a p-value of 1 . Since the p-value 1 is above the significance level $\alpha = 0.05$, for variable Seconds of treatments SQSGP and MCSGP of experiment ExpA **Hypothesis 0**: mean(Seconds of SQSGP)=10.7 - mean(Seconds of MCSGP)=3.5 is equal or greater than 0. is **accepted**.

Test of H_0: Means of treatments SQSGP and MCSGP of variable Seconds are equal.

For variable Seconds of treatments SQSGP and MCSGP of experiment ExpA:

Hypothesis 0: mean(Seconds of SQSGP)=10.7 - mean(Seconds of MCSGP)=3.5 is equal to 0.

is tested at a significance level 0.05 against:

Hypothesis 1: mean(Seconds of SQSGP)=10.7 - mean(Seconds of MCSGP)=3.5 is not equal to 0.

Outliers of treatment SQSGP are not removed (coef=0).
Outliers of treatment MCSGP are not removed (coef=0).

The test-statistic W of the Wilcoxon rank sum test with continuity correction is 34375 with a p-value of 0 . Since the p-value 0 is below the significance level $\alpha = 0.05$, for variable Seconds of treatments SQSGP and MCSGP of experiment ExpA **Hypothesis 0**: mean(Seconds of SQSGP)=10.7 - mean(Seconds of MCSGP)=3.5 is equal to 0. is **rejected**.

Test of H_0: Means of treatments MCSGP and SQSGP of variable Generations are equal.

For variable Generations of treatments MCSGP and SQSGP of experiment ExpA:

Hypothesis 0: mean(Generations of MCSGP)=6.41 - mean(Generations of SQSGP)=6.23 is equal to 0.

is tested at a significance level 0.05 against:

Hypothesis 1: mean(Generations of MCSGP)=6.41 - mean(Generations of SQSGP)=6.23 is not equal to 0.

4 outliers of treatment MCSGP are removed (coef=1.5).
7 outliers of treatment SQSGP are removed (coef=1.5).

The test-statistic W of the Wilcoxon rank sum test with continuity correction is 19458 with a p-value of 0.623 . Since the p-value 0.623 is above the significance level $\alpha = 0.05$, for variable Generations of treatments MCSGP and SQSGP of experiment ExpA **Hypothesis 0**: mean(Generations of MCSGP)=6.41 - mean(Generations of SQSGP)=6.23 is equal to 0. is **accepted**.

Time in (s) (SGE)

	Treatment	Trials	Variable	min	mean	sd	max
2	MCSGE	200	Seconds	0.50	12.95	30.61	224.75
6	SQSGE	200	Seconds	2.38	32.47	52.25	413.90

Table: Time in (s) (SGE)

Number of Generations (SGE)

	Treatment	Trials	Variable	min	mean	sd	max
3	MCSGE	200	Generations	1.00	53.83	142.45	1000.00
7	SQSGE	200	Generations	1.00	42.26	99.14	1000.00

Table: Number of Generations (SGE)

Test of H_0: Mean of treatment MCSGE is less than mean of SQSGE of variable Seconds

For variable Seconds of treatments SQSGE and MCSGE of experiment ExpA:

Hypothesis 0: mean(Seconds of SQSGE)=32.5 - mean(Seconds of MCSGE)=12.9 is equal or greater than 0.

is tested at a significance level 0.05 against:

Hypothesis 1: mean(Seconds of SQSGE)=32.5 - mean(Seconds of MCSGE)=12.9 is less than 0.

Outliers of treatment SQSGE are not removed (coef=0).
Outliers of treatment MCSGE are not removed (coef=0).

The test-statistic W of the Wilcoxon rank sum test with continuity correction is 33164 with a p-value of 1 . Since the p-value 1 is above the significance level $\alpha = 0.05$, for variable Seconds of treatments SQSGE and MCSGE of experiment ExpA **Hypothesis 0**: mean(Seconds of SQSGE)=32.5 - mean(Seconds of MCSGE)=12.9 is equal or greater than 0. is **accepted**.

Test of H_0: Means of treatments SQSGE and MCSGE of variable Seconds are equal.

For variable Seconds of treatments SQSGE and MCSGE of experiment ExpA:

Hypothesis 0: mean(Seconds of SQSGE)=32.5 - mean(Seconds of MCSGE)=12.9 is equal to 0.

is tested at a significance level 0.05 against:

Hypothesis 1: mean(Seconds of SQSGE)=32.5 - mean(Seconds of MCSGE)=12.9 is not equal to 0.

Outliers of treatment SQSGE are not removed (coef=0).
Outliers of treatment MCSGE are not removed (coef=0).

The test-statistic W of the Wilcoxon rank sum test with continuity correction is 33164 with a p-value of 0 . Since the p-value 0 is below the significance level $\alpha = 0.05$, for variable Seconds of treatments SQSGE and MCSGE of experiment ExpA **Hypothesis 0**: mean(Seconds of SQSGE)=32.5 - mean(Seconds of MCSGE)=12.9 is equal to 0. is **rejected**.

Test of H_0: Means of treatments MCSGE and SQSGE of variable Generations are equal.

For variable Generations of treatments MCSGE and SQSGE of experiment ExpA:

Hypothesis 0: mean(Generations of MCSGE)=17.4 - mean(Generations of SQSGE)=18.7 is equal to 0.

is tested at a significance level 0.05 against:

Hypothesis 1: mean(Generations of MCSGE)=17.4 - mean(Generations of SQSGE)=18.7 is not equal to 0.

23 outliers of treatment MCSGE are removed (coef=1.5).
24 outliers of treatment SQSGE are removed (coef=1.5).

The test-statistic W of the Wilcoxon rank sum test with continuity correction is 14638 with a p-value of 0.328 . Since the p-value 0.328 is above the significance level $\alpha = 0.05$, for variable Generations of treatments MCSGE and SQSGE of experiment ExpA **Hypothesis 0**: mean(Generations of MCSGE)=17.4 - mean(Generations of SQSGE)=18.7 is equal to 0. is **accepted**.

Time in (s) (SGV)

	Treatment	Trials	Variable	min	mean	sd	max
2	MCSGV	200	Seconds	1.86	32.84	30.21	169.25
6	SQSGV	200	Seconds	3.14	36.00	31.53	252.23

Table: Time in (s) (SGV)

Number of Generations (SGV)

	Treatment	Trials	Variable	min	mean	sd	max
3	MCSGV	200	Generations	1.00	13.69	11.18	60.00
7	SQSGV	200	Generations	1.00	14.93	12.03	91.00

Table: Number of Generations (SGV)

Test of H_0: Mean of treatment MCSGV is less than mean of SQSGV of variable Seconds

For variable Seconds of treatments SQSGV and MCSGV of experiment ExpA:

Hypothesis 0: mean(Seconds of SQSGV)=36 - mean(Seconds of MCSGV)=32.8 is equal or greater than 0.

is tested at a significance level 0.05 against:

Hypothesis 1: mean(Seconds of SQSGV)=36 - mean(Seconds of MCSGV)=32.8 is less than 0.

Outliers of treatment SQSGV are not removed (coef=0).
Outliers of treatment MCSGV are not removed (coef=0).

The test-statistic W of the Wilcoxon rank sum test with continuity correction is 21854 with a p-value of 0.946 . Since the p-value 0.946 is above the significance level $\alpha = 0.05$, for variable Seconds of treatments SQSGV and MCSGV of experiment ExpA **Hypothesis 0**: mean(Seconds of SQSGV)=36 - mean(Seconds of MCSGV)=32.8 is equal or greater than 0. is **accepted**.

Test of H_0: Means of treatments SQSGV and MCSGV of variable Seconds are equal.

For variable Seconds of treatments SQSGV and MCSGV of experiment ExpA:

Hypothesis 0: mean(Seconds of SQSGV)=36 - mean(Seconds of MCSGV)=32.8 is equal to 0.

is tested at a significance level 0.05 against:

Hypothesis 1: mean(Seconds of SQSGV)=36 - mean(Seconds of MCSGV)=32.8 is not equal to 0.

Outliers of treatment SQSGV are not removed (coef=0).
Outliers of treatment MCSGV are not removed (coef=0).

The test-statistic W of the Wilcoxon rank sum test with continuity correction is 21854 with a p-value of 0.109 . Since the p-value 0.109 is above the significance level $\alpha = 0.05$, for variable Seconds of treatments SQSGV and MCSGV of experiment ExpA **Hypothesis 0**: mean(Seconds of SQSGV)=36 - mean(Seconds of MCSGV)=32.8 is equal to 0. is **accepted**.

Test of H_0: Means of treatments MCSGV and SQSGV of variable Generations are equal.

For variable Generations of treatments MCSGV and SQSGV of experiment ExpA:

Hypothesis 0: mean(Generations of MCSGV)=12.7 - mean(Generations of SQSGV)=13.8 is equal to 0.

is tested at a significance level 0.05 against:

Hypothesis 1: mean(Generations of MCSGV)=12.7 - mean(Generations of SQSGV)=13.8 is not equal to 0.

6 outliers of treatment MCSGV are removed (coef=1.5).
5 outliers of treatment SQSGV are removed (coef=1.5).

The test-statistic W of the Wilcoxon rank sum test with continuity correction is 17416 with a p-value of 0.176 . Since the p-value 0.176 is above the significance level $\alpha = 0.05$, for variable Generations of treatments MCSGV and SQSGV of experiment ExpA **Hypothesis 0**: mean(Generations of MCSGV)=12.7 - mean(Generations of SQSGV)=13.8 is equal to 0. is **accepted**.

Multi-core or sequential processing?

Multi-core	SGP	SGE	SGV
... equal speed or faster ?	yes	yes	yes
... equal speed?	no	no	yes
... same resources?	yes	yes	yes

- **Recommendation:** Use multi-core for population sizes larger than 400.
- **New experiment:** Population size as control variable.

Which algorithm?

We compare the performance (time and resources used) of the three algorithms

1. for sequential processing and
2. for multi-core processing.

The evaluation of the population of genes is parallelized.

Time in (s) (Sequential)

	Treatment	Trials	Variable	min	mean	sd	max
2	SQSGE	200	Seconds	2.38	32.47	52.25	413.90
6	SQSGP	200	Seconds	2.18	10.70	7.42	40.17
10	SQSGV	200	Seconds	3.14	36.00	31.53	252.23

Table: Time in (s) (Sequential)

Test of H_0: Mean of treatment SQSGE is greater than mean of SQSGP of variable Seconds

For variable Seconds of treatments SQSGP and SQSGE of experiment ExpA:

Hypothesis 0: mean(Seconds of SQSGP)=10.7 - mean(Seconds of SQSGE)=32.5 is equal or less than 0.

is tested at a significance level 0.05 against:

Hypothesis 1: mean(Seconds of SQSGP)=10.7 - mean(Seconds of SQSGE)=32.5 is greater than 0.

Outliers of treatment SQSGP are not removed (coef=0).
Outliers of treatment SQSGE are not removed (coef=0).

The test-statistic W of the Wilcoxon rank sum test with continuity correction is 9899 with a p-value of 1 . Since the p-value 1 is above the significance level $\alpha = 0.05$, for variable Seconds of treatments SQSGP and SQSGE of experiment ExpA **Hypothesis 0**: mean(Seconds of SQSGP)=10.7 - mean(Seconds of SQSGE)=32.5 is equal or less than 0. is **accepted**.

Test of H_0: Means of treatments SQSGP and SQSGE of variable Seconds are equal.

For variable Seconds of treatments SQSGP and SQSGE of experiment ExpA:

Hypothesis 0: mean(Seconds of SQSGP)=10.7 - mean(Seconds of SQSGE)=32.5 is equal to 0.

is tested at a significance level 0.05 against:

Hypothesis 1: mean(Seconds of SQSGP)=10.7 - mean(Seconds of SQSGE)=32.5 is not equal to 0.

Outliers of treatment SQSGP are not removed (coef=0).
Outliers of treatment SQSGE are not removed (coef=0).

The test-statistic W of the Wilcoxon rank sum test with continuity correction is 9899 with a p-value of 0 . Since the p-value 0 is below the significance level $\alpha = 0.05$, for variable Seconds of treatments SQSGP and SQSGE of experiment ExpA **Hypothesis 0**: mean(Seconds of SQSGP)=10.7 - mean(Seconds of SQSGE)=32.5 is equal to 0. is **rejected**.

Test of H_0: Mean of treatment SQSGV is greater than mean of SQSGP of variable Seconds

For variable Seconds of treatments SQSGP and SQSGV of experiment ExpA:

Hypothesis 0: mean(Seconds of SQSGP)=10.7 - mean(Seconds of SQSGV)=36 is equal or less than 0.

is tested at a significance level 0.05 against:

Hypothesis 1: mean(Seconds of SQSGP)=10.7 - mean(Seconds of SQSGV)=36 is greater than 0.

Outliers of treatment SQSGP are not removed (coef=0).
Outliers of treatment SQSGV are not removed (coef=0).

The test-statistic W of the Wilcoxon rank sum test with continuity correction is 7796 with a p-value of 1 . Since the p-value 1 is above the significance level $\alpha = 0.05$, for variable Seconds of treatments SQSGP and SQSGV of experiment ExpA **Hypothesis 0**: mean(Seconds of SQSGP)=10.7 - mean(Seconds of SQSGV)=36 is equal or less than 0. is **accepted**.

Test of H_0: Means of treatments SQSGP and SQSGV of variable Seconds are equal.

For variable Seconds of treatments SQSGP and SQSGV of experiment ExpA:

Hypothesis 0: mean(Seconds of SQSGP)=10.7 - mean(Seconds of SQSGV)=36 is equal to 0.

is tested at a significance level 0.05 against:

Hypothesis 1: mean(Seconds of SQSGP)=10.7 - mean(Seconds of SQSGV)=36 is not equal to 0.

Outliers of treatment SQSGP are not removed (coef=0).
Outliers of treatment SQSGV are not removed (coef=0).

The test-statistic W of the Wilcoxon rank sum test with continuity correction is 7796 with a p-value of 0 . Since the p-value 0 is below the significance level $\alpha = 0.05$, for variable Seconds of treatments SQSGP and SQSGV of experiment ExpA **Hypothesis 0**: mean(Seconds of SQSGP)=10.7 - mean(Seconds of SQSGV)=36 is equal to 0. is **rejected**.

Test of H_0: Mean of treatment SQSGV is greater than mean of SQSGE of variable Seconds

For variable Seconds of treatments SQSGE and SQSGV of experiment ExpA:

Hypothesis 0: mean(Seconds of SQSGE)=32.5 - mean(Seconds of SQSGV)=36 is equal or less than 0.

is tested at a significance level 0.05 against:

Hypothesis 1: mean(Seconds of SQSGE)=32.5 - mean(Seconds of SQSGV)=36 is greater than 0.

Outliers of treatment SQSGE are not removed (coef=0).
Outliers of treatment SQSGV are not removed (coef=0).

The test-statistic W of the Wilcoxon rank sum test with continuity correction is 15850 with a p-value of 1 . Since the p-value 1 is above the significance level $\alpha = 0.05$, for variable Seconds of treatments SQSGE and SQSGV of experiment ExpA **Hypothesis 0**: mean(Seconds of SQSGE)=32.5 - mean(Seconds of SQSGV)=36 is equal or less than 0. is **accepted**.

Test of H_0: Means of treatments SQSGE and SQSGV of variable Seconds are equal.

For variable Seconds of treatments SQSGE and SQSGV of experiment ExpA:

Hypothesis 0: mean(Seconds of SQSGE)=32.5 - mean(Seconds of SQSGV)=36 is equal to 0.

is tested at a significance level 0.05 against:

Hypothesis 1: mean(Seconds of SQSGE)=32.5 - mean(Seconds of SQSGV)=36 is not equal to 0.

Outliers of treatment SQSGE are not removed (coef=0).
Outliers of treatment SQSGV are not removed (coef=0).

The test-statistic W of the Wilcoxon rank sum test with continuity correction is 15850 with a p-value of 0.00033 . Since the p-value 0.00033 is below the significance level $\alpha = 0.05$, for variable Seconds of treatments SQSGE and SQSGV of experiment ExpA **Hypothesis 0**: mean(Seconds of SQSGE)=32.5 - mean(Seconds of SQSGV)=36 is equal to 0. is **rejected**.

Number of Generations (Sequential)

	Treatment	Trials	Variable	min	mean	sd	max
3	SQSGE	200	Generations	1.00	42.26	99.14	1000.00
7	SQSGP	200	Generations	1.00	6.70	4.38	21.00
11	SQSGV	200	Generations	1.00	14.93	12.03	91.00

Table: Number of Generations (Sequential)

Test of H_0: Mean of treatment SQSGE is greater than mean of SQSGP of variable Generations

For variable Generations of treatments SQSGP and SQSGE of experiment ExpA:

Hypothesis 0: mean(Generations of SQSGP)=6.7 - mean(Generations of SQSGE)=42.3 is equal or less than 0.

is tested at a significance level 0.05 against:

Hypothesis 1: mean(Generations of SQSGP)=6.7 - mean(Generations of SQSGE)=42.3 is greater than 0.

Outliers of treatment SQSGP are not removed (coef=0).
Outliers of treatment SQSGE are not removed (coef=0).

The test-statistic W of the Wilcoxon rank sum test with continuity correction is 6978 with a p-value of 1 . Since the p-value 1 is above the significance level $\alpha = 0.05$, for variable Generations of treatments SQSGP and SQSGE of experiment ExpA **Hypothesis 0**: mean(Generations of SQSGP)=6.7 - mean(Generations of SQSGE)=42.3 is equal or less than 0. is **accepted**.

Test of H_0: Means of treatments SQSGP and SQSGE of variable Generations are equal.

For variable Generations of treatments SQSGP and SQSGE of experiment ExpA:

Hypothesis 0: mean(Generations of SQSGP)=6.7 - mean(Generations of SQSGE)=42.3 is equal to 0.

is tested at a significance level 0.05 against:

Hypothesis 1: mean(Generations of SQSGP)=6.7 - mean(Generations of SQSGE)=42.3 is not equal to 0.

Outliers of treatment SQSGP are not removed (coef=0).
Outliers of treatment SQSGE are not removed (coef=0).

The test-statistic W of the Wilcoxon rank sum test with continuity correction is 6978 with a p-value of 0 . Since the p-value 0 is below the significance level $\alpha = 0.05$, for variable Generations of treatments SQSGP and SQSGE of experiment ExpA
Hypothesis 0: mean(Generations of SQSGP)=6.7 - mean(Generations of SQSGE)=42.3 is equal to 0. is **rejected**.

Test of H_0: Mean of treatment SQSGV is greater than mean of SQSGP of variable Generations

For variable Generations of treatments SQSGP and SQSGV of experiment ExpA:

Hypothesis 0: mean(Generations of SQSGP)=6.7 - mean(Generations of SQSGV)=14.9 is equal or less than 0.

is tested at a significance level 0.05 against:

Hypothesis 1: mean(Generations of SQSGP)=6.7 - mean(Generations of SQSGV)=14.9 is greater than 0.

Outliers of treatment SQSGP are not removed (coef=0).
Outliers of treatment SQSGV are not removed (coef=0).

The test-statistic W of the Wilcoxon rank sum test with continuity correction is 10678 with a p-value of 1 . Since the p-value 1 is above the significance level $\alpha = 0.05$, for variable Generations of treatments SQSGP and SQSGV of experiment ExpA
Hypothesis 0: mean(Generations of SQSGP)=6.7 - mean(Generations of SQSGV)=14.9 is equal or less than 0. is **accepted**.

Test of H_0: Means of treatments SQSGP and SQSGV of variable Generations are equal.

For variable Generations of treatments SQSGP and SQSGV of experiment ExpA:

Hypothesis 0: mean(Generations of SQSGP)=6.7 - mean(Generations of SQSGV)=14.9 is equal to 0.

is tested at a significance level 0.05 against:

Hypothesis 1: mean(Generations of SQSGP)=6.7 - mean(Generations of SQSGV)=14.9 is not equal to 0.

Outliers of treatment SQSGP are not removed (coef=0).
Outliers of treatment SQSGV are not removed (coef=0).

The test-statistic W of the Wilcoxon rank sum test with continuity correction is 10678 with a p-value of 0 . Since the p-value 0 is below the significance level $\alpha = 0.05$, for variable Generations of treatments SQSGP and SQSGV of experiment ExpA
Hypothesis 0: mean(Generations of SQSGP)=6.7 - mean(Generations of SQSGV)=14.9 is equal to 0. is **rejected**.

Test of H_0: Mean of treatment SQSGV is greater than mean of SQSGE of variable Generations

For variable Generations of treatments SQSGE and SQSGV of experiment ExpA:

Hypothesis 0: mean(Generations of SQSGE)=42.3 - mean(Generations of SQSGV)=14.9 is equal or less than 0.

is tested at a significance level 0.05 against:

Hypothesis 1: mean(Generations of SQSGE)=42.3 - mean(Generations of SQSGV)=14.9 is greater than 0.

Outliers of treatment SQSGE are not removed (coef=0).
Outliers of treatment SQSGV are not removed (coef=0).

The test-statistic W of the Wilcoxon rank sum test with continuity correction is 25067 with a p-value of 0.00001 . Since the p-value 0.00001 is below the significance level $\alpha = 0.05$, for variable Generations of treatments SQSGE and SQSGV of experiment ExpA **Hypothesis 0**: mean(Generations of SQSGE)=42.3 - mean(Generations of SQSGV)=14.9 is equal or less than 0. is **rejected**.

Test of H_0: Means of treatments SQSGE and SQSGV of variable Generations are equal.

For variable Generations of treatments SQSGE and SQSGV of experiment ExpA:

Hypothesis 0: mean(Generations of SQSGE)=42.3 - mean(Generations of SQSGV)=14.9 is equal to 0.

is tested at a significance level 0.05 against:

Hypothesis 1: mean(Generations of SQSGE)=42.3 - mean(Generations of SQSGV)=14.9 is not equal to 0.

Outliers of treatment SQSGE are not removed (coef=0).
Outliers of treatment SQSGV are not removed (coef=0).

The test-statistic W of the Wilcoxon rank sum test with continuity correction is 25067 with a p-value of 0.00001 . Since the p-value 0.00001 is below the significance level $\alpha = 0.05$, for variable Generations of treatments SQSGE and SQSGV of experiment ExpA **Hypothesis 0**: mean(Generations of SQSGE)=42.3 - mean(Generations of SQSGV)=14.9 is equal to 0. is **rejected**.

Which algorithm? (Sequential)

The tests establish the following order of grammar-based genetic programming (SGP), grammatical evolution (SGE), and grammatical evolution by differential evolution (SGV):

$$\text{SGP} < \text{SGE} < \text{SGV} \qquad \text{Seconds}$$

$$\text{SGP} < \text{SGV} < \text{SGE} \qquad \text{Generations}$$

- **Recommendation:** Use grammar-based genetic programming.
- **Follow-Up:** Investigate the order reversal between SGV and SGE. **Conjecture:** Grammatical evolution by differential evolution (SGV) scales better than SGE.

Time in (s) (Multi-Core)

	Treatment	Trials	Variable	min	mean	sd	max
2	MCSGE	200	Seconds	0.50	12.95	30.61	224.75
6	MCSGP	200	Seconds	0.52	3.50	2.32	13.52
10	MCSGV	200	Seconds	1.86	32.84	30.21	169.25

Table: Time in (s) (Multi-Core)

Test of H_0: Mean of treatment MCSGE is greater than mean of MCSGP of variable Seconds

For variable Seconds of treatments MCSGP and MCSGE of experiment ExpA:

Hypothesis 0: mean(Seconds of MCSGP)=3.5 - mean(Seconds of MCSGE)=12.9 is equal or less than 0.

is tested at a significance level 0.05 against:

Hypothesis 1: mean(Seconds of MCSGP)=3.5 - mean(Seconds of MCSGE)=12.9 is greater than 0.

Outliers of treatment MCSGP are not removed (coef=0).
Outliers of treatment MCSGE are not removed (coef=0).

The test-statistic W of the Wilcoxon rank sum test with continuity correction is 12792 with a p-value of 1 . Since the p-value 1 is above the significance level $\alpha = 0.05$, for variable Seconds of treatments MCSGP and MCSGE of experiment ExpA **Hypothesis 0**: mean(Seconds of MCSGP)=3.5 - mean(Seconds of MCSGE)=12.9 is equal or less than 0. is **accepted**.

Test of H_0: Means of treatments MCSGP and MCSGE of variable Seconds are equal.

For variable Seconds of treatments MCSGP and MCSGE of experiment ExpA:

Hypothesis 0: mean(Seconds of MCSGP)=3.5 - mean(Seconds of MCSGE)=12.9 is equal to 0.

is tested at a significance level 0.05 against:

Hypothesis 1: mean(Seconds of MCSGP)=3.5 - mean(Seconds of MCSGE)=12.9 is not equal to 0.

Outliers of treatment MCSGP are not removed (coef=0).
Outliers of treatment MCSGE are not removed (coef=0).

The test-statistic W of the Wilcoxon rank sum test with continuity correction is 12792 with a p-value of 0 . Since the p-value 0 is below the significance level $\alpha = 0.05$, for variable Seconds of treatments MCSGP and MCSGE of experiment ExpA **Hypothesis 0**: mean(Seconds of MCSGP)=3.5 - mean(Seconds of MCSGE)=12.9 is equal to 0. is **rejected**.

Test of H_0: Mean of treatment MCSGV is greater than mean of MCSGP of variable Seconds

For variable Seconds of treatments MCSGP and MCSGV of experiment ExpA:

Hypothesis 0: mean(Seconds of MCSGP)=3.5 - mean(Seconds of MCSGV)=32.8 is equal or less than 0.

is tested at a significance level 0.05 against:

Hypothesis 1: mean(Seconds of MCSGP)=3.5 - mean(Seconds of MCSGV)=32.8 is greater than 0.

Outliers of treatment MCSGP are not removed (coef=0).
Outliers of treatment MCSGV are not removed (coef=0).

The test-statistic W of the Wilcoxon rank sum test with continuity correction is 3833 with a p-value of 1 . Since the p-value 1 is above the significance level $\alpha = 0.05$, for variable Seconds of treatments MCSGP and MCSGV of experiment ExpA **Hypothesis 0**: mean(Seconds of MCSGP)=3.5 - mean(Seconds of MCSGV)=32.8 is equal or less than 0. is **accepted**.

Test of H_0: Means of treatments MCSGP and MCSGV of variable Seconds are equal.

For variable Seconds of treatments MCSGP and MCSGV of experiment ExpA:

Hypothesis 0: mean(Seconds of MCSGP)=3.5 - mean(Seconds of MCSGV)=32.8 is equal to 0.

is tested at a significance level 0.05 against:

Hypothesis 1: mean(Seconds of MCSGP)=3.5 - mean(Seconds of MCSGV)=32.8 is not equal to 0.

Outliers of treatment MCSGP are not removed (coef=0).
Outliers of treatment MCSGV are not removed (coef=0).

The test-statistic W of the Wilcoxon rank sum test with continuity correction is 3833 with a p-value of 0 . Since the p-value 0 is below the significance level $\alpha = 0.05$, for variable Seconds of treatments MCSGP and MCSGV of experiment ExpA **Hypothesis 0**: mean(Seconds of MCSGP)=3.5 - mean(Seconds of MCSGV)=32.8 is equal to 0. is **rejected**.

Test of H_0: Mean of treatment MCSGV is greater than mean of MCSGE of variable Seconds

For variable Seconds of treatments MCSGE and MCSGV of experiment ExpA:

Hypothesis 0: mean(Seconds of MCSGE)=12.9 - mean(Seconds of MCSGV)=32.8 is equal or less than 0.

is tested at a significance level 0.05 against:

Hypothesis 1: mean(Seconds of MCSGE)=12.9 - mean(Seconds of MCSGV)=32.8 is greater than 0.

Outliers of treatment MCSGE are not removed (coef=0).
Outliers of treatment MCSGV are not removed (coef=0).

The test-statistic W of the Wilcoxon rank sum test with continuity correction is 8326 with a p-value of 1 . Since the p-value 1 is above the significance level $\alpha = 0.05$, for variable Seconds of treatments MCSGE and MCSGV of experiment ExpA **Hypothesis 0**: mean(Seconds of MCSGE)=12.9 - mean(Seconds of MCSGV)=32.8 is equal or less than 0. is **accepted**.

Test of H_0: Means of treatments MCSGE and MCSGV of variable Seconds are equal.

For variable Seconds of treatments MCSGE and MCSGV of experiment ExpA:

Hypothesis 0: mean(Seconds of MCSGE)=12.9 - mean(Seconds of MCSGV)=32.8 is equal to 0.

is tested at a significance level 0.05 against:

Hypothesis 1: mean(Seconds of MCSGE)=12.9 - mean(Seconds of MCSGV)=32.8 is not equal to 0.

Outliers of treatment MCSGE are not removed (coef=0).
Outliers of treatment MCSGV are not removed (coef=0).

The test-statistic W of the Wilcoxon rank sum test with continuity correction is 8326 with a p-value of 0 . Since the p-value 0 is below the significance level $\alpha = 0.05$, for variable Seconds of treatments MCSGE and MCSGV of experiment ExpA **Hypothesis 0**: mean(Seconds of MCSGE)=12.9 - mean(Seconds of MCSGV)=32.8 is equal to 0. is **rejected**.

Number of Generations (Multi-Core)

	Treatment	Trials	Variable	min	mean	sd	max
3	MCSGE	200	Generations	1.00	53.83	142.45	1000.00
7	MCSGP	200	Generations	1.00	6.70	4.15	25.00
11	MCSGV	200	Generations	1.00	13.69	11.18	60.00

Table: Number of Generations (Multi-Core)

Test of H_0: Mean of treatment MCSGE is greater than mean of MCSGP of variable Generations

For variable Generations of treatments MCSGP and MCSGE of experiment ExpA:

Hypothesis 0: mean(Generations of MCSGP)=6.7 - mean(Generations of MCSGE)=53.8 is equal or less than 0.

is tested at a significance level 0.05 against:

Hypothesis 1: mean(Generations of MCSGP)=6.7 - mean(Generations of MCSGE)=53.8 is greater than 0.

Outliers of treatment MCSGP are not removed (coef=0).
Outliers of treatment MCSGE are not removed (coef=0).

The test-statistic W of the Wilcoxon rank sum test with continuity correction is 7360 with a p-value of 1 . Since the p-value 1 is above the significance level $\alpha = 0.05$, for variable Generations of treatments MCSGP and MCSGE of experiment ExpA **Hypothesis 0**: mean(Generations of MCSGP)=6.7 - mean(Generations of MCSGE)=53.8 is equal or less than 0. is **accepted**.

Test of H_0: Means of treatments MCSGP and MCSGE of variable Generations are equal.

For variable Generations of treatments MCSGP and MCSGE of experiment ExpA:

Hypothesis 0: mean(Generations of MCSGP)=6.7 - mean(Generations of MCSGE)=53.8 is equal to 0.

is tested at a significance level 0.05 against:

Hypothesis 1: mean(Generations of MCSGP)=6.7 - mean(Generations of MCSGE)=53.8 is not equal to 0.

Outliers of treatment MCSGP are not removed (coef=0).
Outliers of treatment MCSGE are not removed (coef=0).

The test-statistic W of the Wilcoxon rank sum test with continuity correction is 7360 with a p-value of 0 . Since the p-value 0 is below the significance level $\alpha = 0.05$, for variable Generations of treatments MCSGP and MCSGE of experiment ExpA
Hypothesis 0: mean(Generations of MCSGP)=6.7 - mean(Generations of MCSGE)=53.8 is equal to 0. is **rejected**.

Test of H_0: Mean of treatment MCSGV is greater than mean of MCSGP of variable Generations

For variable Generations of treatments MCSGP and MCSGV of experiment ExpA:

Hypothesis 0: mean(Generations of MCSGP)=6.7 - mean(Generations of MCSGV)=13.7 is equal or less than 0.

is tested at a significance level 0.05 against:

Hypothesis 1: mean(Generations of MCSGP)=6.7 - mean(Generations of MCSGV)=13.7 is greater than 0.

Outliers of treatment MCSGP are not removed (coef=0).
Outliers of treatment MCSGV are not removed (coef=0).

The test-statistic W of the Wilcoxon rank sum test with continuity correction is 12576 with a p-value of 1 . Since the p-value 1 is above the significance level $\alpha = 0.05$, for variable Generations of treatments MCSGP and MCSGV of experiment ExpA **Hypothesis 0**: mean(Generations of MCSGP)=6.7 - mean(Generations of MCSGV)=13.7 is equal or less than 0. is **accepted**.

Test of H_0: Means of treatments MCSGP and MCSGV of variable Generations are equal.

For variable Generations of treatments MCSGP and MCSGV of experiment ExpA:

Hypothesis 0: mean(Generations of MCSGP)=6.7 - mean(Generations of MCSGV)=13.7 is equal to 0.

is tested at a significance level 0.05 against:

Hypothesis 1: mean(Generations of MCSGP)=6.7 - mean(Generations of MCSGV)=13.7 is not equal to 0.

Outliers of treatment MCSGP are not removed (coef=0).
Outliers of treatment MCSGV are not removed (coef=0).

The test-statistic W of the Wilcoxon rank sum test with continuity correction is 12576 with a p-value of 0 . Since the p-value 0 is below the significance level $\alpha = 0.05$, for variable Generations of treatments MCSGP and MCSGV of experiment ExpA **Hypothesis 0**: mean(Generations of MCSGP)=6.7 - mean(Generations of MCSGV)=13.7 is equal to 0. is **rejected**.

Test of H_0: Mean of treatment MCSGV is greater than mean of MCSGE of variable Generations

For variable Generations of treatments MCSGE and MCSGV of experiment ExpA:

Hypothesis 0: mean(Generations of MCSGE)=53.8 - mean(Generations of MCSGV)=13.7 is equal or less than 0.

is tested at a significance level 0.05 against:

Hypothesis 1: mean(Generations of MCSGE)=53.8 - mean(Generations of MCSGV)=13.7 is greater than 0.

Outliers of treatment MCSGE are not removed (coef=0).
Outliers of treatment MCSGV are not removed (coef=0).

The test-statistic W of the Wilcoxon rank sum test with continuity correction is 25130 with a p-value of 0 . Since the p-value 0 is below the significance level $\alpha = 0.05$, for variable Generations of treatments MCSGE and MCSGV of experiment ExpA **Hypothesis 0**: mean(Generations of MCSGE)=53.8 - mean(Generations of MCSGV)=13.7 is equal or less than 0. is **rejected**.

Test of H_0: Means of treatments MCSGE and MCSGV of variable Generations are equal.

For variable Generations of treatments MCSGE and MCSGV of experiment ExpA:

Hypothesis 0: mean(Generations of MCSGE)=53.8 - mean(Generations of MCSGV)=13.7 is equal to 0.

is tested at a significance level 0.05 against:

Hypothesis 1: mean(Generations of MCSGE)=53.8 - mean(Generations of MCSGV)=13.7 is not equal to 0.

Outliers of treatment MCSGE are not removed (coef=0).
Outliers of treatment MCSGV are not removed (coef=0).

The test-statistic W of the Wilcoxon rank sum test with continuity correction is 25130 with a p-value of 0.00001 . Since the p-value 0.00001 is below the significance level $\alpha = 0.05$, for variable Generations of treatments MCSGE and MCSGV of experiment ExpA **Hypothesis 0**: mean(Generations of MCSGE)=53.8 - mean(Generations of MCSGV)=13.7 is equal to 0. is **rejected**.

Which algorithm? (Multi-core)

The tests establish the following order of grammar-based genetic programming (SGP), grammatical evolution (SGE), and grammatical evolution by differential evolution (SGV):

$$\text{SGP} < \text{SGE} < \text{SGV} \qquad \text{Seconds}$$

$$\text{SGP} < \text{SGV} < \text{SGE} \qquad \text{Generations}$$

The multi-core and the sequential setting result in the same orders of the algorithms.

- **Recommendation:** Use grammar-based genetic programming.
- **Follow-Up:** Investigate the order reversal between SGV and SGE. **Conjecture:** Grammatical evolution by differential evolution (SGV) scales better than SGE. Investigate the parallelization strategy.

Summary of statistics of experiment ExpA.

	Treatment	Trials	Variable	min	mean	sd	max
4	MCSGE	200	Evaluations	400.00	21532.00	56980.21	400000.00
8	MCSGP	200	Evaluations	400.00	2680.00	1660.66	10000.00
12	MCSGV	200	Evaluations	400.00	5474.00	4470.53	24000.00
16	SQSGE	200	Evaluations	400.00	16902.00	39654.41	400000.00
20	SQSGP	200	Evaluations	400.00	2680.00	1752.07	8400.00
24	SQSGV	200	Evaluations	400.00	5970.00	4812.87	36400.00
1	MCSGE	200	Fitness	0.00	0.02	0.20	2.00
5	MCSGP	200	Fitness	0.00	0.00	0.00	0.00
9	MCSGV	200	Fitness	0.00	0.00	0.00	0.00
13	SQSGE	200	Fitness	0.00	0.01	0.07	1.00
17	SQSGP	200	Fitness	0.00	0.00	0.00	0.00
21	SQSGV	200	Fitness	0.00	0.00	0.00	0.00
3	MCSGE	200	Generations	1.00	53.83	142.45	1000.00
7	MCSGP	200	Generations	1.00	6.70	4.15	25.00
11	MCSGV	200	Generations	1.00	13.69	11.18	60.00

Table: Summary of statistics of experiment ExpA. (Part 1)

Summary of statistics of experiment ExpA.

	Treatment	Trials	Variable	min	mean	sd	max
15	SQSGE	200	Generations	1.00	42.26	99.14	1000.00
19	SQSGP	200	Generations	1.00	6.70	4.38	21.00
23	SQSGV	200	Generations	1.00	14.93	12.03	91.00
2	MCSGE	200	Seconds	0.50	12.95	30.61	224.75
6	MCSGP	200	Seconds	0.52	3.50	2.32	13.52
10	MCSGV	200	Seconds	1.86	32.84	30.21	169.25
14	SQSGE	200	Seconds	2.38	32.47	52.25	413.90
18	SQSGP	200	Seconds	2.18	10.70	7.42	40.17
22	SQSGV	200	Seconds	3.14	36.00	31.53	252.23

Table: Summary of statistics of experiment ExpA. (Part 2)

Parameters of treatment: MCSGE

	Parameter Values
tRNG	L'Ecuyer-CMRG Inversion Rejection
tReplay	0
experimentName	ExpA
treatmentName	MCSGE
trials	200
everyK	10
outpath	data
batchPath	.
tVerbose	1

Table: Parameters of treatment: MCSGE

Parameters of treatment MCSGE passed to xegaRun

	Parameter Values
penv	3-Symmetry Problem
grammar	/home/dj2333/dev/cran/kSymmetry/BNF/Nand.txt
replay	0
algorithm	sge
maxdepth	7
max	FALSE
worstFitness	-8
popsize	400
generations	1000
crossrate	0.2
mutrate	0.4
ivmutrate	Const
mutrate2	0.8
ivcrossrate	Const
crossrate2	0.4

Table: Parameters of treatment MCSGE passed to xegaRun (Part 1)

Parameters of treatment MCSGE passed to xegaRun

	Parameter Values
scalefactor	Uniform
genemap	Mod
initgene	InitGene
selection	SUS
mateselection	SUS
replication	Kid2
crossover	Cross2Gene
mutation	MutateGene
accept	All
reportEvalErrors	TRUE
codons	120
codonPrecision	LCM
terminationEps	-0.1
terminationCondition	AbsoluteError
evalmethod	Deterministic

Table: Parameters of treatment MCSGE passed to xegaRun (Part 2)

Parameters of treatment MCSGE passed to xegaRun

	Parameter Values
executionModel	MultiCore
verbose	1
batch	FALSE
semantics	byValue
path	.

Table: Parameters of treatment MCSGE passed to xegaRun (Part 3)

Treatment: MCSGE

	Treatment	Trials	Variable	min	mean	sd	max
4	MCSGE	200	Evaluations	400.00	21532.00	56980.21	400000.00
1	MCSGE	200	Fitness	0.00	0.02	0.20	2.00
3	MCSGE	200	Generations	1.00	53.83	142.45	1000.00
2	MCSGE	200	Seconds	0.50	12.95	30.61	224.75

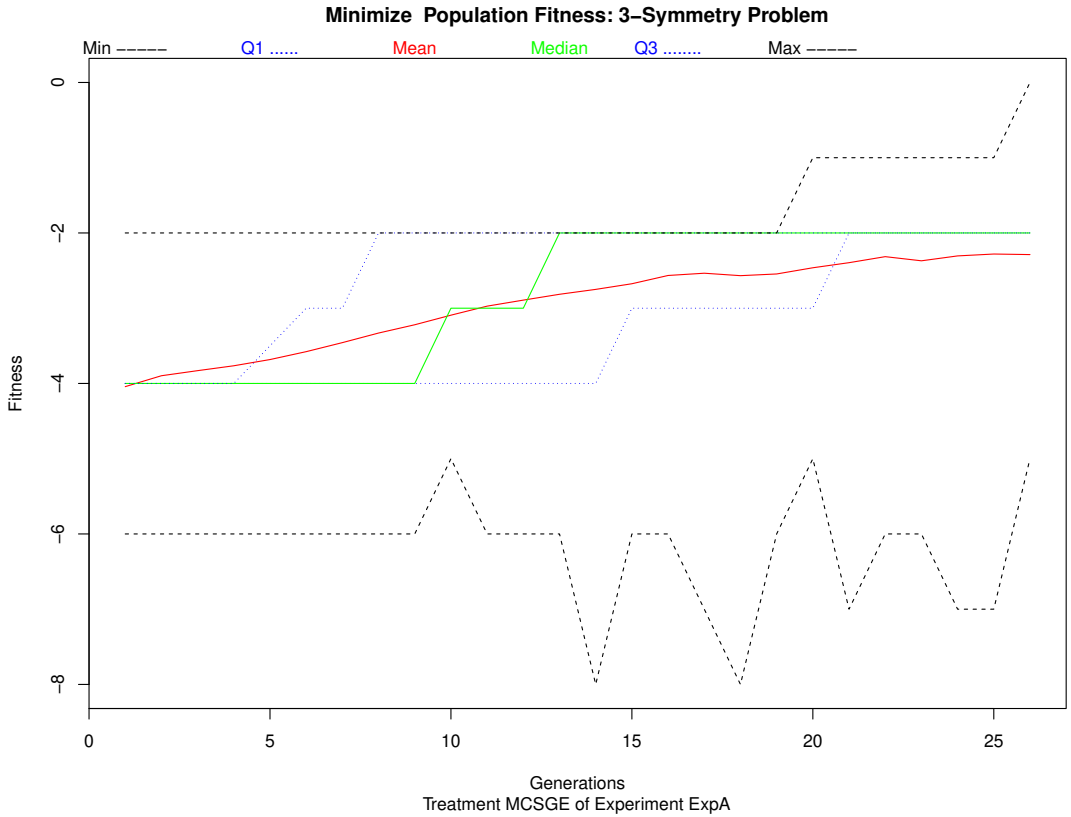
Table: Treatment: MCSGE

The Solution Table of Treatment MCSGE of Experiment ExpA. Fit: 0. Unique Shortest Solutions: 194.

	Solution
1	NAND(NAND(NAND(D1, D1), NAND(D3, D3)), NAND(D1, D3))

Table: The Solution Table of Treatment MCSGE of Experiment ExpA. Fit: 0. Unique Shortest Solutions: 194.

Plot of last xegaRun for Treatment MCSGE of Experiment ExpA



Parameters of treatment: MCSGP

	Parameter Values
tRNG	L'Ecuyer-CMRG Inversion Rejection
tReplay	0
experimentName	ExpA
treatmentName	MCSGP
trials	200
everyK	10
outpath	data
batchPath	.
tVerbose	1

Table: Parameters of treatment: MCSGP

Parameters of treatment MCSGP passed to xegaRun

	Parameter Values
penv	3-Symmetry Problem
grammar	/home/dj2333/dev/cran/kSymmetry/BNF/Nand.txt
replay	0
algorithm	sgp
maxdepth	7
max	FALSE
worstFitness	-8
popsize	400
generations	1000
crossrate	0.2
mutrate	0.4
ivmutrate	Const
mutrate2	0.8
ivcrossrate	Const
crossrate2	0.4

Table: Parameters of treatment MCSGP passed to xegaRun (Part 1)

Parameters of treatment MCSGP passed to xegaRun

	Parameter Values
scalefactor	Uniform
genemap	Bin2Dec
initgene	InitGene
selection	SUS
mateselection	SUS
replication	Kid2
crossover	Cross2Gene
mutation	MutateGene
accept	All
reportEvalErrors	TRUE
codons	120
codonPrecision	LCM
terminationEps	-0.1
terminationCondition	AbsoluteError
evalmethod	Deterministic

Table: Parameters of treatment MCSGP passed to xegaRun (Part 2)

Parameters of treatment MCSGP passed to xegaRun

	Parameter Values
executionModel	MultiCore
verbose	1
batch	FALSE
semantics	byValue
path	.

Table: Parameters of treatment MCSGP passed to xegaRun (Part 3)

Treatment: MCSGP

	Treatment	Trials	Variable	min	mean	sd	max
8	MCSGP	200	Evaluations	400.00	2680.00	1660.66	10000.00
5	MCSGP	200	Fitness	0.00	0.00	0.00	0.00
7	MCSGP	200	Generations	1.00	6.70	4.15	25.00
6	MCSGP	200	Seconds	0.52	3.50	2.32	13.52

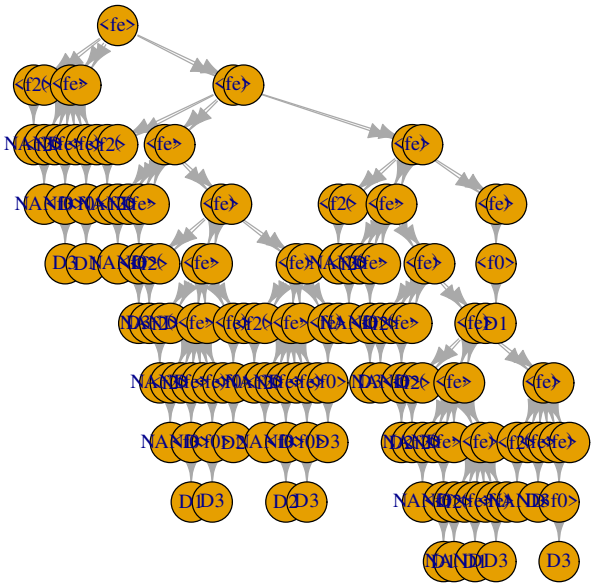
Table: Treatment: MCSGP

The Solution Table of Treatment MCSGP of Experiment ExpA. Fit: 0. Unique Shortest Solutions: 198.

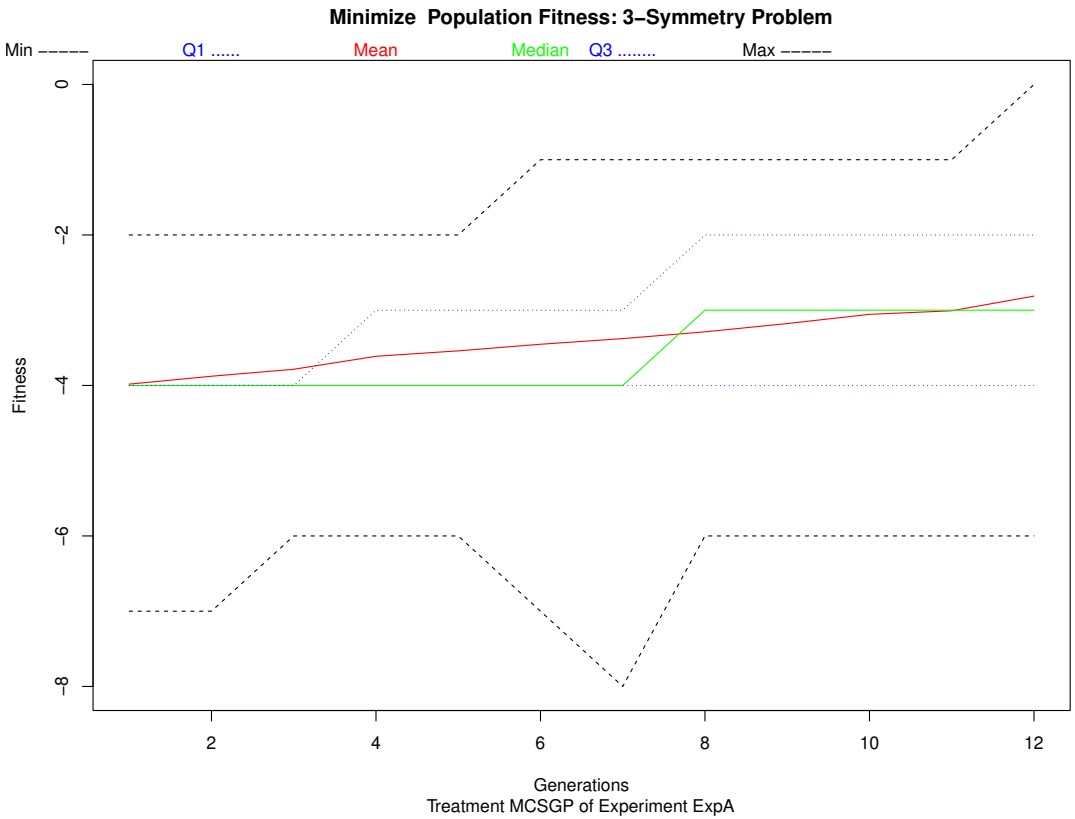
	Solution
1	NAND(NAND(D1, D3), NAND(NAND(D3, D3), NAND(D1, D1)))

Table: The Solution Table of Treatment MCSGP of Experiment ExpA. Fit: 0. Unique Shortest Solutions: 198.

The Derivation Tree of a Solution of Treatment MCSGP of Experiment ExpA



Plot of last xegaRun for Treatment MCSGP of Experiment ExpA



Parameters of treatment: MCSGV

	Parameter Values
tRNG	L'Ecuyer-CMRG Inversion Rejection
tReplay	0
experimentName	ExpA
treatmentName	MCSGV
trials	200
everyK	10
outpath	data
batchPath	.
tVerbose	1

Table: Parameters of treatment: MCSGV

Parameters of treatment MCSGV passed to xegaRun

	Parameter Values
penv	3-Symmetry Problem
grammar	/home/dj2333/dev/cran/kSymmetry/BNF/Nand.txt
replay	0
algorithm	sgede
maxdepth	7
max	FALSE
worstFitness	-8
popsize	400
generations	1000
crossrate	0.2
mutrate	0.4
ivmutrate	Const
mutrate2	0.8
ivcrossrate	Const
crossrate2	0.4

Table: Parameters of treatment MCSGV passed to xegaRun (Part 1)

Parameters of treatment MCSGV passed to xegaRun

	Parameter Values
scalefactor	Uniform
genemap	Identity
initgene	InitGene
selection	UniformP
mateselection	UniformP
replication	DE
crossover	UCrossGene
mutation	MutateGeneDE
accept	Best
reportEvalErrors	TRUE
codons	120
codonPrecision	LCM
terminationEps	-0.1
terminationCondition	AbsoluteError
evalmethod	Deterministic

Table: Parameters of treatment MCSGV passed to xegaRun (Part 2)

Parameters of treatment MCSGV passed to xegaRun

	Parameter Values
executionModel	MultiCore
verbose	1
batch	FALSE
semantics	byValue
path	.

Table: Parameters of treatment MCSGV passed to xegaRun (Part 3)

Treatment: MCSGV

	Treatment	Trials	Variable	min	mean	sd	max
12	MCSGV	200	Evaluations	400.00	5474.00	4470.53	24000.00
9	MCSGV	200	Fitness	0.00	0.00	0.00	0.00
11	MCSGV	200	Generations	1.00	13.69	11.18	60.00
10	MCSGV	200	Seconds	1.86	32.84	30.21	169.25

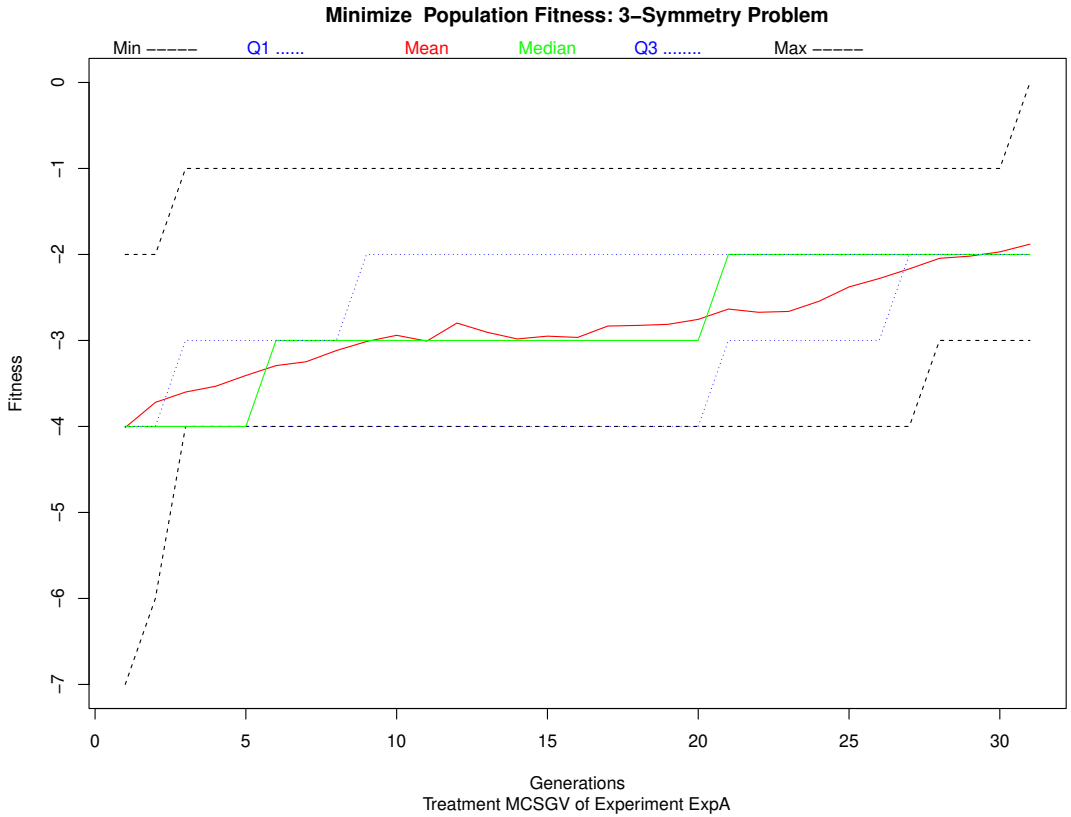
Table: Treatment: MCSGV

The Solution Table of Treatment MCSGV of Experiment ExpA. Fit: 0. Unique Shortest Solutions: 190.

	Solution
1	NAND(NAND(NAND(D3, D3), NAND(D1, D1)), NAND(D1, D3))

Table: The Solution Table of Treatment MCSGV of Experiment ExpA. Fit: 0. Unique Shortest Solutions: 190.

Plot of last xegaRun for Treatment MCSGV of Experiment ExpA



Parameters of treatment: SQSGE

	Parameter Values
tRNG	L'Ecuyer-CMRG Inversion Rejection
tReplay	0
experimentName	ExpA
treatmentName	SQSGE
trials	200
everyK	10
outpath	data
batchPath	.
tVerbose	1

Table: Parameters of treatment: SQSGE

Parameters of treatment SQSGE passed to xegaRun

	Parameter Values
penv	3-Symmetry Problem
grammar	/home/dj2333/dev/cran/kSymmetry/BNF/Nand.txt
replay	0
algorithm	sge
maxdepth	7
max	FALSE
worstFitness	-8
popsize	400
generations	1000
crossrate	0.2
mutrate	0.4
ivmutrate	Const
mutrate2	0.8
ivcrossrate	Const
crossrate2	0.4

Table: Parameters of treatment SQSGE passed to xegaRun (Part 1)

Parameters of treatment SQSGE passed to xegaRun

	Parameter Values
scalefactor	Uniform
genemap	Mod
initgene	InitGene
selection	SUS
mateselection	SUS
replication	Kid2
crossover	Cross2Gene
mutation	MutateGene
accept	All
reportEvalErrors	TRUE
codons	120
codonPrecision	LCM
terminationEps	-0.1
terminationCondition	AbsoluteError
evalmethod	Deterministic

Table: Parameters of treatment SQSGE passed to xegaRun (Part 2)

Parameters of treatment SQSGE passed to xegaRun

	Parameter Values
executionModel	Sequential
verbose	1
batch	FALSE
semantics	byValue
path	.

Table: Parameters of treatment SQSGE passed to xegaRun (Part 3)

Treatment: SQSGE

	Treatment	Trials	Variable	min	mean	sd	max
16	SQSGE	200	Evaluations	400.00	16902.00	39654.41	400000.00
13	SQSGE	200	Fitness	0.00	0.01	0.07	1.00
15	SQSGE	200	Generations	1.00	42.26	99.14	1000.00
14	SQSGE	200	Seconds	2.38	32.47	52.25	413.90

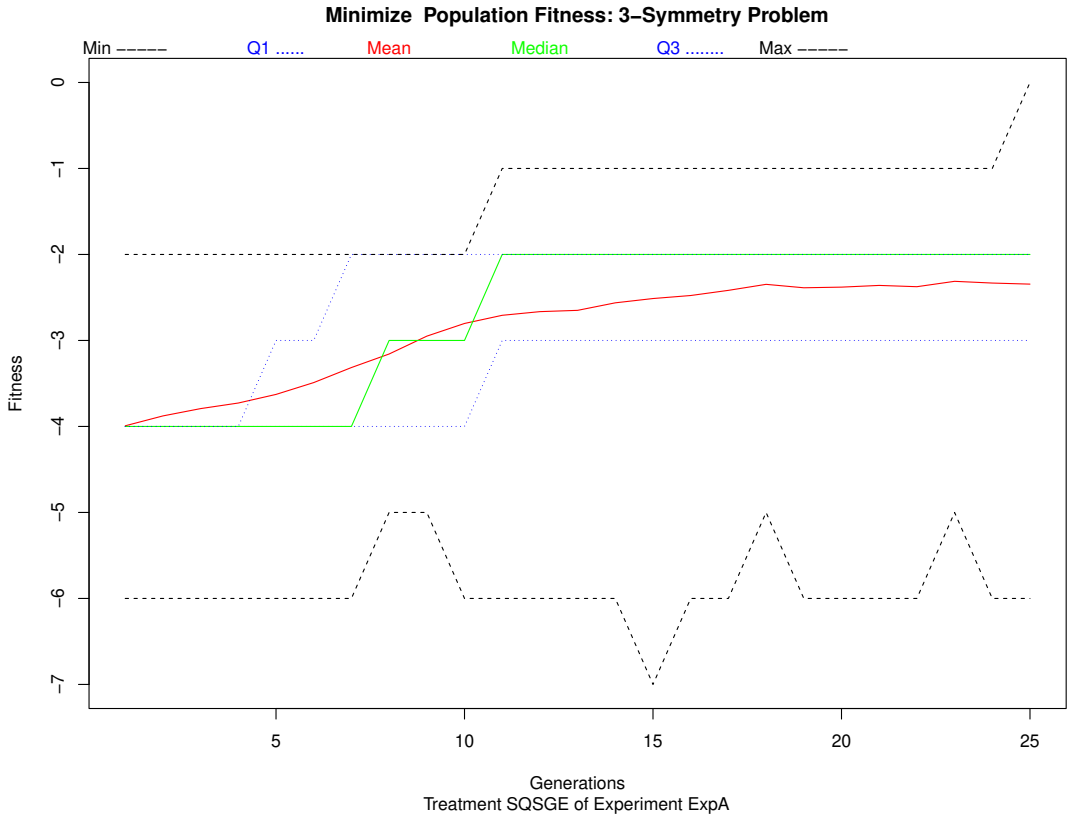
Table: Treatment: SQSGE

The Solution Table of Treatment SQSGE of Experiment ExpA. Fit: 0. Unique Shortest Solutions: 198.

	Solution
1	NAND(NAND(D3, D1), NAND(NAND(D1, D1), NAND(D3, D3)))

Table: The Solution Table of Treatment SQSGE of Experiment ExpA. Fit: 0. Unique Shortest Solutions: 198.

Plot of last xegaRun for Treatment SQSGE of Experiment ExpA



Parameters of treatment: SQSGP

	Parameter Values
tRNG	L'Ecuyer-CMRG Inversion Rejection
tReplay	0
experimentName	ExpA
treatmentName	SQSGP
trials	200
everyK	10
outpath	data
batchPath	.
tVerbose	1

Table: Parameters of treatment: SQSGP

Parameters of treatment SQSGP passed to xegaRun

	Parameter Values
penv	3-Symmetry Problem
grammar	/home/dj2333/dev/cran/kSymmetry/BNF/Nand.txt
replay	0
algorithm	sgp
maxdepth	7
max	FALSE
worstFitness	-8
popsize	400
generations	1000
crossrate	0.2
mutrate	0.4
ivmutrate	Const
mutrate2	0.8
ivcrossrate	Const
crossrate2	0.4

Table: Parameters of treatment SQSGP passed to xegaRun (Part 1)

Parameters of treatment SQSGP passed to xegaRun

	Parameter Values
scalefactor	Uniform
genemap	Bin2Dec
initgene	InitGene
selection	SUS
mateselection	SUS
replication	Kid2
crossover	Cross2Gene
mutation	MutateGene
accept	All
reportEvalErrors	TRUE
codons	120
codonPrecision	LCM
terminationEps	-0.1
terminationCondition	AbsoluteError
evalmethod	Deterministic

Table: Parameters of treatment SQSGP passed to xegaRun (Part 2)

Parameters of treatment SQSGP passed to xegaRun

	Parameter Values
executionModel	Sequential
verbose	1
batch	FALSE
semantics	byValue
path	.

Table: Parameters of treatment SQSGP passed to xegaRun (Part 3)

Treatment: SQSGP

	Treatment	Trials	Variable	min	mean	sd	max
20	SQSGP	200	Evaluations	400.00	2680.00	1752.07	8400.00
17	SQSGP	200	Fitness	0.00	0.00	0.00	0.00
19	SQSGP	200	Generations	1.00	6.70	4.38	21.00
18	SQSGP	200	Seconds	2.18	10.70	7.42	40.17

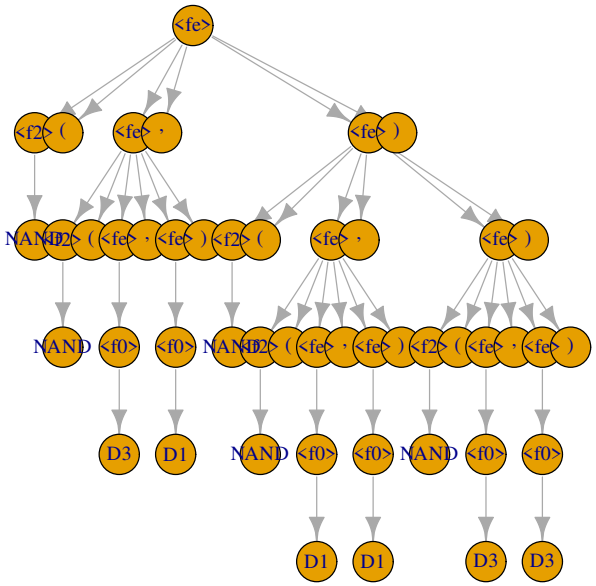
Table: Treatment: SQSGP

The Solution Table of Treatment SQSGP of Experiment ExpA. Fit: 0. Unique Shortest Solutions: 198.

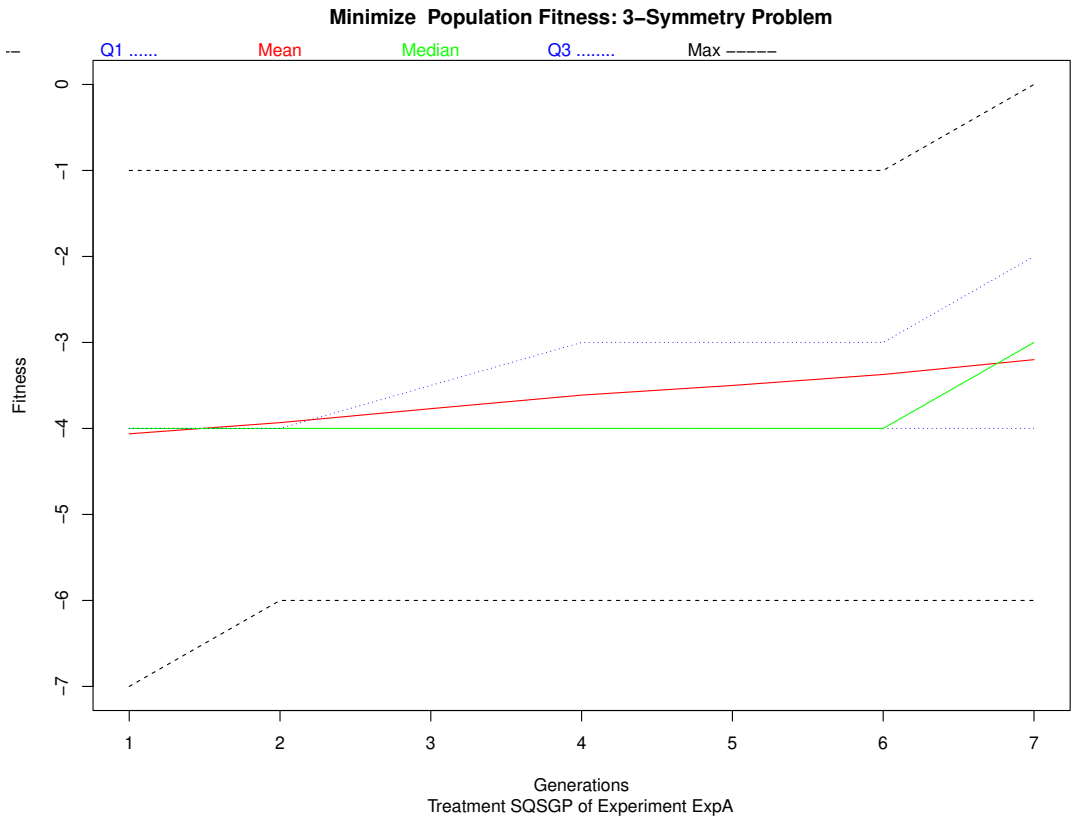
	Solution
1	NAND(NAND(D3, D1), NAND(NAND(D3, D3), NAND(D1, D1)))

Table: The Solution Table of Treatment SQSGP of Experiment ExpA. Fit: 0. Unique Shortest Solutions: 198.

The Derivation Tree of a Solution of Treatment SQSGP of Experiment ExpA



Plot of last xegaRun for Treatment SQSGP of Experiment ExpA



Parameters of treatment: SQSGV

	Parameter Values
tRNG	L'Ecuyer-CMRG Inversion Rejection
tReplay	0
experimentName	ExpA
treatmentName	SQSGV
trials	200
everyK	10
outpath	data
batchPath	.
tVerbose	1

Table: Parameters of treatment: SQSGV

Parameters of treatment SQSGV passed to xegaRun

	Parameter Values
penv	3-Symmetry Problem
grammar	/home/dj2333/dev/cran/kSymmetry/BNF/Nand.txt
replay	0
algorithm	sgede
maxdepth	7
max	FALSE
worstFitness	-8
popsize	400
generations	1000
crossrate	0.2
mutrate	0.4
ivmutrate	Const
mutrate2	0.8
ivcrossrate	Const
crossrate2	0.4

Table: Parameters of treatment SQSGV passed to xegaRun (Part 1)

Parameters of treatment SQSGV passed to xegaRun

	Parameter Values
scalefactor	Uniform
genemap	Identity
initgene	InitGene
selection	UniformP
mateselection	UniformP
replication	DE
crossover	UCrossGene
mutation	MutateGeneDE
accept	Best
reportEvalErrors	TRUE
codons	120
codonPrecision	LCM
terminationEps	-0.1
terminationCondition	AbsoluteError
evalmethod	Deterministic

Table: Parameters of treatment SQSGV passed to xegaRun (Part 2)

Parameters of treatment SQSGV passed to xegaRun

	Parameter Values
executionModel	Sequential
verbose	1
batch	FALSE
semantics	byValue
path	.

Table: Parameters of treatment SQSGV passed to xegaRun (Part 3)

Treatment: SQSGV

	Treatment	Trials	Variable	min	mean	sd	max
24	SQSGV	200	Evaluations	400.00	5970.00	4812.87	36400.00
21	SQSGV	200	Fitness	0.00	0.00	0.00	0.00
23	SQSGV	200	Generations	1.00	14.93	12.03	91.00
22	SQSGV	200	Seconds	3.14	36.00	31.53	252.23

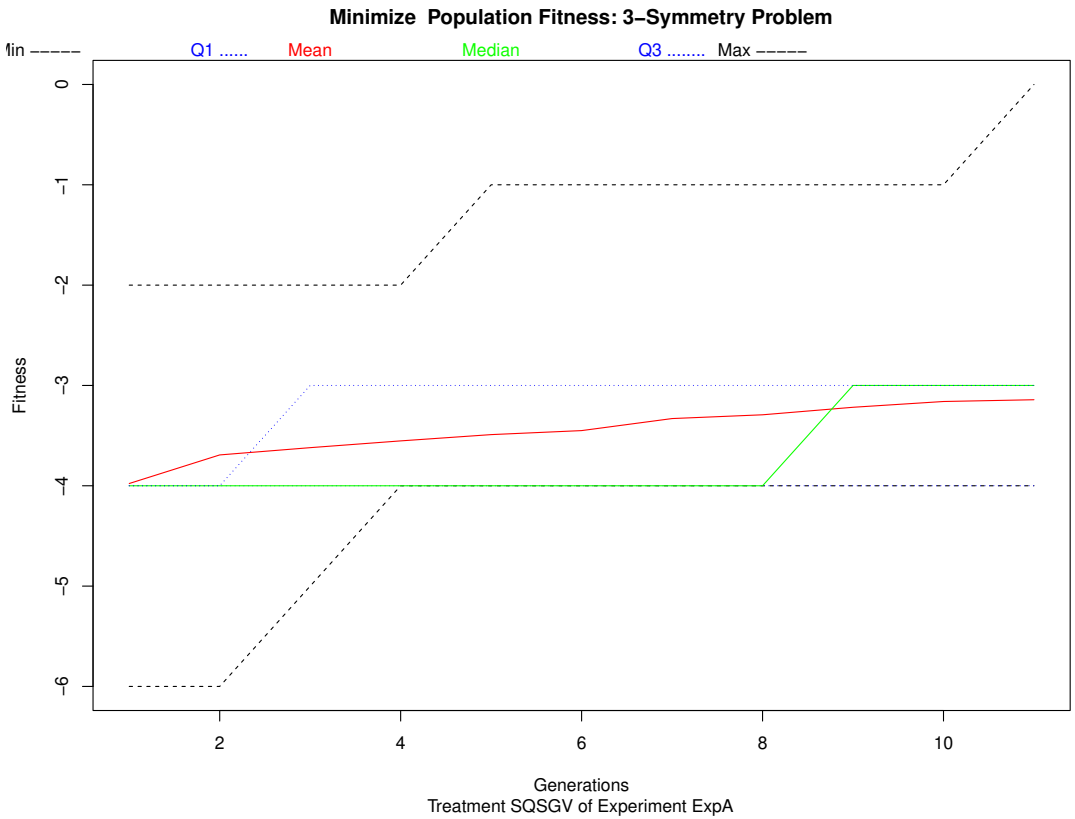
Table: Treatment: SQSGV

The Solution Table of Treatment SQSGV of Experiment ExpA. Fit: 0. Unique Shortest Solutions: 194.

	Solution
1	NAND(NAND(D3, D1), NAND(NAND(D3, D3), NAND(D1, D1)))

Table: The Solution Table of Treatment SQSGV of Experiment ExpA. Fit: 0. Unique Shortest Solutions: 194.

Plot of last xegaRun for Treatment SQSGV of Experiment ExpA



All parameters of xegaRun of treatment MCSGE

	Parameter Values
penv	3-Symmetry Problem
grammar	/home/dj2333/dev/cran/kSymmetry/BNF/Nand.txt
max	FALSE
algorithm	sge
popsize	400
generations	1000
crossrate	0.2
mutrate	0.4
elitist	TRUE
replay	0
maxdepth	7
maxtrials	5
codons	120
codonBits	0
codonPrecision	LCM

Table: All parameters of xegaRun of treatment MCSGE (Part 1)

All parameters of xegaRun of treatment MCSGE

	Parameter Values
maxPBias	0.01
evalmethod	Deterministic
evalrep	1
reportEvalErrors	TRUE
genemap	Mod
decoder	DecodeGene
crossrate2	0.4
ivcrossrate	Const
crossover	Cross2Gene
uCrossSwap	0.2
mincrossdepth	1
maxcrossdepth	7
ivmutrate	Const
mutrate2	0.8
bitmutrate	0.005

Table: All parameters of xegaRun of treatment MCSGE (Part 2)

All parameters of xegaRun of treatment MCSGE

	Parameter Values
bitmutrate2	0.01
maxmutdepth	3
minmutinsertiondepth	1
maxmutinsertiondepth	7
lambda	0.05
max2opt	100
scalefactor1	0.9
scalefactor2	0.3
scalefactor	Uniform
cutoffFit	0.5
mutation	MutateGene
replication	Kid2
initgene	InitGene
offset	1
eps	0.01

Table: All parameters of xegaRun of treatment MCSGE (Part 3)

All parameters of xegaRun of treatment MCSGE

	Parameter Values
tournamentSize	2
selectionBias	1.5
maxTSR	1.5
selection	SUS
mateselection	SUS
selectionContinuation	TRUE
scaling	NoScaling
scalingThreshold	0
scalingExp	1
scalingExp2	1
rdmWeight	1
drMax	2
drMin	0.5
dispersionMeasure	var
scalingDelay	1

Table: All parameters of xegaRun of treatment MCSGE (Part 4)

All parameters of xegaRun of treatment MCSGE

	Parameter Values
accept	All
alpha	0.99
beta	2
cooling	ExponentialMultiplicative
coolingPower	1
temp0	40
tempN	0.01
verbose	1
logevals	FALSE
allsolutions	FALSE
early	FALSE
terminationCondition	AbsoluteError
terminationEps	-0.1
terminationThreshold	0
worstFitness	-8

Table: All parameters of xegaRun of treatment MCSGE (Part 5)

All parameters of xegaRun of treatment MCSGE

	Parameter Values
PACdelta	0.01
fSpace	Hilbert
cores	16
executionModel	MultiCore
uParApply	NULL
Cluster	NULL
profile	FALSE
batch	FALSE
path	.
semantics	byValue

Table: All parameters of xegaRun of treatment MCSGE (Part 6)