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# Report of Experiment ExpE. k-Symmetry: Grammar Tuning and Language Tuning

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## Abstract

Grammar tuning adapts the language. Language tuning adds new language elements. In this experiment we compare the best grammar of experiment B with a grammar with symmetric pairs and an additional function.

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- Treatment BoolT5sgp3k
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## Definition

**Grammar tuning** means adding additional production rules to a context-free grammar with the goal of improving the learning performance of grammar-based genetic programming algorithms.
**Example:** Repeating production rules allows to change the distribution of programs (and their sizes) generated during the initialization a grammar-based genetic programming algorithm.

### Definition

**Language tuning** means adding additional language elements.
This means changing the grammar **and** the syntax of the language elements and changing the implementation of the language so that the semantics of the language is implemented.
**Example:** Adding a new base function. E.g. NAND.

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## Description of Experiment

The purpose of this computational experiment is to show the improvement of performance by grammar **and** language tuning.

The **problem environment** is the k-symmetry problem: Finding a boolean expression (with and, or, and not) which is TRUE for symmetric k-bit strings.

The **solution method** is grammar-based genetic programming (option `algorithm="sgp"` of `xegaRun`). The **solver** used is `xegaRun` from the R-package `xega`.

The experiment consists of 10 treatments, 2 grammars for 5 problem sizes $k \in 2, \ldots, 6$.

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## Description of Experiment

The two control variables in this experiment are

- The bit-length of the k-symmetry problem: 2, 3, 4, 5, and 6.
- The grammar for boolean expressions:
    - **T4**: With two rules for OR and two rules for variables replaced by symmetric pairs.
    - **T5**: With symmetric pairs and a new base function, the function sPair(x, y) which implements
      sPair $< -$ function)x,y)
      OR(AND(x,y),AND(NOT(x),NOT(y)))

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# Common Parameters of Experiment ExpE

|  | Parameter Value |
|---|---|
| Optimize | Minimize! |
| Trials | 80 |
| Algorithm | sgp |
| Max.Depth.of.DTs | 7 |
| Replay | 0 |
| Evaluation.Method | Deterministic |
| Execution.Model | MultiCore |
| Verbose | 1 |
| Semantics | byValue |
| Report.Eval.Errors | TRUE |
| Termination.Condition | AbsoluteError |
| Termination.Eps | -0.1 |
| Gene.Map | Bin2Dec |
| Init.Gene | InitGene |
| Codon.Precision | LCM |

Table: Common Parameters of Experiment ExpE (Part 1)

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## Common Parameters of Experiment ExpE

|  | Parameter Value |
|---|---|
| Population.Size | 200 |
| Max.Generations | 500 |
| 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 ExpE (Part 2)

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## Parameters of Treatments of Experiment ExpE

| | Experiment | Treatment | Problem Environment | Grammar | Worst |
|---|---|---|---|---|---|
| 1 | EB | BoolT4sgp2k | 2-Symmetry Problem | AndOrNotTuned4.txt | |
| 2 | EB | BoolT4sgp3k | 3-Symmetry Problem | AndOrNotTuned4.txt | |
| 3 | EB | BoolT4sgp4k | 4-Symmetry Problem | AndOrNotTuned4.txt | |
| 4 | EB | BoolT4sgp5k | 5-Symmetry Problem | AndOrNotTuned4.txt | |
| 5 | EB | BoolT4sgp6k | 6-Symmetry Problem | AndOrNotTuned4.txt | |
| 6 | EE | BoolT5sgp2k | 2-Symmetry Problem | AndOrNotTuned5.txt | |
| 7 | EE | BoolT5sgp3k | 3-Symmetry Problem | AndOrNotTuned5.txt | |
| 8 | EE | BoolT5sgp4k | 4-Symmetry Problem | AndOrNotTuned5.txt | |
| 9 | EE | BoolT5sgp5k | 5-Symmetry Problem | AndOrNotTuned5.txt | |
| 10 | EE | BoolT5sgp6k | 6-Symmetry Problem | AndOrNotTuned5.txt | |

Table: Parameters of Treatments of Experiment ExpE

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Do we always find an optimal solution?

## Matrix of Mean of Errors (Fitness). Rows: k=2, 3, 4, 5, 6)

|   | T4   | T5   |
|---|------|------|
| 1 | 0.00 | 0.00 |
| 2 | 0.00 | 0.00 |
| 3 | 0.00 | 0.00 |
| 4 | 0.00 | 0.00 |
| 5 | 3.33 | 0.00 |

Table: Matrix of Mean of Errors (Fitness). Rows: k=2, 3, 4, 5, 6)

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Do we always find an optimal solution?

## Matrix of Min of Errors (Fitness). Rows: k=2, 3, 4, 5, 6)

|   | T4   | T5   |
|---|------|------|
| 1 | 0.00 | 0.00 |
| 2 | 0.00 | 0.00 |
| 3 | 0.00 | 0.00 |
| 4 | 0.00 | 0.00 |
| 5 | 0.00 | 0.00 |

Table: Matrix of Min of Errors (Fitness). Rows: k=2, 3, 4, 5, 6)

# Do we always find the optimal program?

- For grammar T5: **Yes.** For grammar T4: **No.** (Not for the 6-symmetry problem with 500 generations.
- For the 6-symmetry problem, the grammar T4 has maximum of 6 errors.

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How long to find an optimal solution?

## Matrix of Mean of Seconds. Rows: k=2, 3, 4, 5, 6)

|   | T4 | T5 |
|---|-------:|------:|
| 1 | 0.24 | 0.22 |
| 2 | 0.30 | 0.25 |
| 3 | 17.93 | 0.31 |
| 4 | 18.16 | 0.34 |
| 5 | 193.42 | 1.93 |

Table: Matrix of Mean of Seconds. Rows: k=2, 3, 4, 5, 6)

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How long to find an optimal solution?

## Matrix of Mean of Generations. Rows: k=2, 3, 4, 5, 6)

|   | T4 | T5 |
|---|---|---|
| 1 | 1.00 | 1.00 |
| 2 | 1.01 | 1.00 |
| 3 | 77.01 | 1.23 |
| 4 | 73.10 | 1.20 |
| 5 | 460.68 | 7.22 |

Table: Matrix of Mean of Generations. Rows: k=2, 3, 4, 5, 6)

How long to find an optimal solution?

## Distribution of Number of Generations for Grammars. 2k symmetry.

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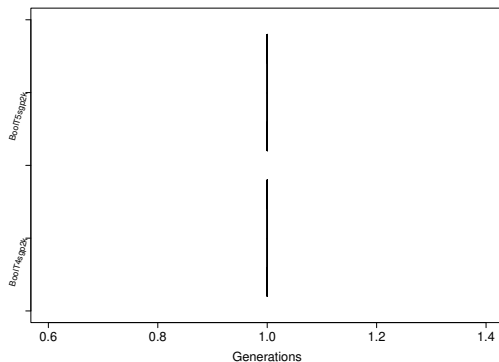
How long to find an optimal solution?

## Distribution of Number of Generations for Grammars. 3k symmetry.

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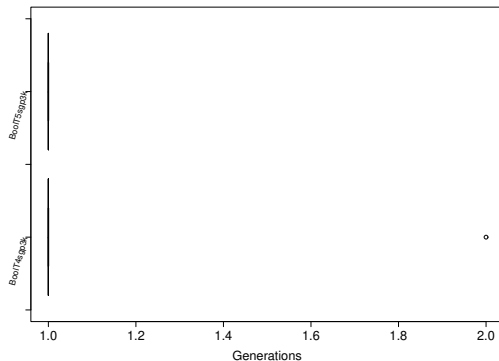
How long to find an optimal solution?

## Distribution of Number of Generations for Grammars. 4k symmetry.

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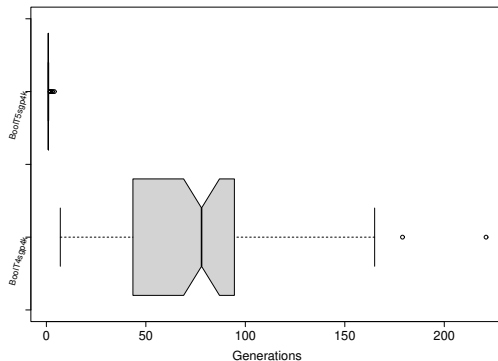
How long to find an optimal solution?

## Distribution of Number of Generations for Grammars. 5k symmetry.

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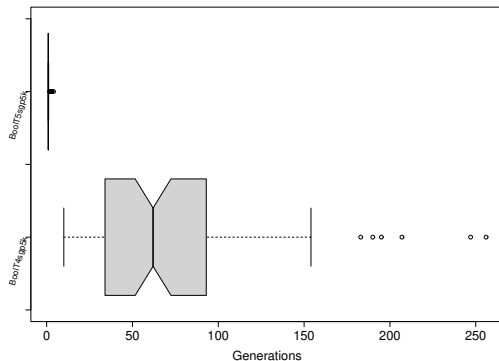
## Distribution of Number of Generations for Grammars. 6k symmetry.
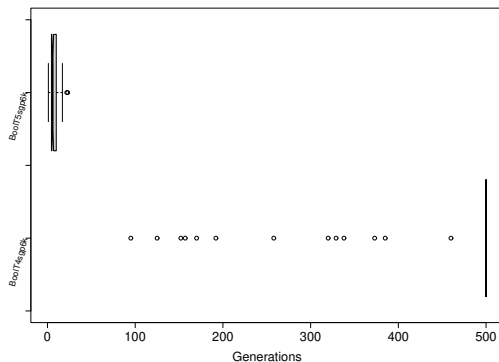
How long to find an optimal solution?

## Which grammar performs best?

- **Grammar T5** performs **best** (by two orders of magnitude).
  For the 6-symmetry problem:
  Grammar T4: 460.68 mean(Generations) 100.68
  std(Generations).
  Grammar T5: 7.22 mean(Generations) 4.27 std(Generations).
  $\max(\text{Generations}_{T5}) = 23.00$.
  $\min(\text{Generations}_{T4}) = 95.00$.
  Statistically significant? Not tested. Expect highly significant.

Computational Complexity?

## Distribution of Number of Generations for Grammar T4

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Computational Complexity?

## Distribution of Number of Generations for Grammar T5

Computational Complexity?
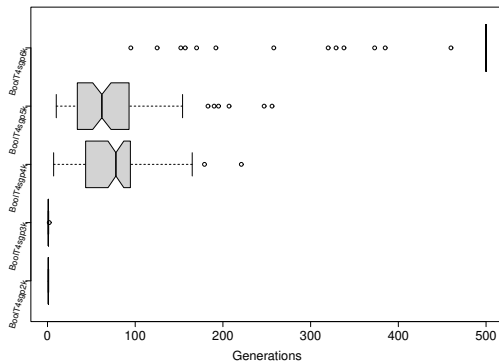
## Growth of Complexity?

- Complexity grows in steps of 2 of k. The 2- and 3-symmetry problem need the same boolean expression, but with different variables: For the 2-symmetry problem, D1 and D2. For the 3-symmetry problem, D1 and D3, D2 is ignored.

- Grammar T5 scales well with problem size growth.
  **Reason:** The combination of **grammar** and **language** tuning. The generation of pairs of symbols (grammar tuning) and the new function sPair. It takes a symbol pair as its arguments eliminates the need to expand a a non-terminal twice with the same symbol pair (language tuning).

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Computational Complexity?

### Further Research.

Integrate grammar and language tuning into grammar-based genetic programming algorithms.
**Mechanisms:** Automatic function definitions e.g. from from best solutions for small $k$.
Grammar evolution from frontiers of derivation trees.

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## Summary of statistics of experiment ExpE.

|    | Treatment  | Trials | Variable    | min      | mean     | sd       | max       |
|----|------------|--------|-------------|----------|----------|----------|-----------|
| 4  | BoolT4sgp2k | 80    | Evaluations | 200.00   | 200.00   | 0.00     | 200.00    |
| 8  | BoolT4sgp3k | 80    | Evaluations | 200.00   | 202.50   | 22.36    | 400.00    |
| 12 | BoolT4sgp4k | 80    | Evaluations | 1400.00  | 15402.50 | 8377.03  | 44200.00  |
| 16 | BoolT4sgp5k | 80    | Evaluations | 2000.00  | 14620.00 | 10549.35 | 51200.00  |
| 20 | BoolT4sgp6k | 80    | Evaluations | 19000.00 | 92135.00 | 20136.92 | 100000.00 |
| 24 | BoolT5sgp2k | 80    | Evaluations | 200.00   | 200.00   | 0.00     | 200.00    |
| 28 | BoolT5sgp3k | 80    | Evaluations | 200.00   | 200.00   | 0.00     | 200.00    |
| 32 | BoolT5sgp4k | 80    | Evaluations | 200.00   | 245.00   | 110.12   | 800.00    |
| 36 | BoolT5sgp5k | 80    | Evaluations | 200.00   | 240.00   | 112.06   | 800.00    |
| 40 | BoolT5sgp6k | 80    | Evaluations | 200.00   | 1445.00  | 853.27   | 4600.00   |
| 1  | BoolT4sgp2k | 80    | Fitness     | 0.00     | 0.00     | 0.00     | 0.00      |
| 5  | BoolT4sgp3k | 80    | Fitness     | 0.00     | 0.00     | 0.00     | 0.00      |
| 9  | BoolT4sgp4k | 80    | Fitness     | 0.00     | 0.00     | 0.00     | 0.00      |
| 13 | BoolT4sgp5k | 80    | Fitness     | 0.00     | 0.00     | 0.00     | 0.00      |
| 17 | BoolT4sgp6k | 80    | Fitness     | 0.00     | 3.33     | 1.61     | 6.00      |

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

## Summary of statistics of experiment ExpE.

|    | Treatment   | Trials | Variable    | min   | mean   | sd     | max    |
|----|-------------|--------|-------------|-------|--------|--------|--------|
| 21 | BoolT5sgp2k | 80     | Fitness     | 0.00  | 0.00   | 0.00   | 0.00   |
| 25 | BoolT5sgp3k | 80     | Fitness     | 0.00  | 0.00   | 0.00   | 0.00   |
| 29 | BoolT5sgp4k | 80     | Fitness     | 0.00  | 0.00   | 0.00   | 0.00   |
| 33 | BoolT5sgp5k | 80     | Fitness     | 0.00  | 0.00   | 0.00   | 0.00   |
| 37 | BoolT5sgp6k | 80     | Fitness     | 0.00  | 0.00   | 0.00   | 0.00   |
| 3  | BoolT4sgp2k | 80     | Generations | 1.00  | 1.00   | 0.00   | 1.00   |
| 7  | BoolT4sgp3k | 80     | Generations | 1.00  | 1.01   | 0.11   | 2.00   |
| 11 | BoolT4sgp4k | 80     | Generations | 7.00  | 77.01  | 41.89  | 221.00 |
| 15 | BoolT4sgp5k | 80     | Generations | 10.00 | 73.10  | 52.75  | 256.00 |
| 19 | BoolT4sgp6k | 80     | Generations | 95.00 | 460.68 | 100.68 | 500.00 |
| 23 | BoolT5sgp2k | 80     | Generations | 1.00  | 1.00   | 0.00   | 1.00   |
| 27 | BoolT5sgp3k | 80     | Generations | 1.00  | 1.00   | 0.00   | 1.00   |
| 31 | BoolT5sgp4k | 80     | Generations | 1.00  | 1.23   | 0.55   | 4.00   |
| 35 | BoolT5sgp5k | 80     | Generations | 1.00  | 1.20   | 0.56   | 4.00   |
| 39 | BoolT5sgp6k | 80     | Generations | 1.00  | 7.22   | 4.27   | 23.00  |

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

## Summary of statistics of experiment ExpE.

|    | Treatment  | Trials | Variable | min   | mean   | sd    | max    |
|----|------------|--------|----------|-------|--------|-------|--------|
| 2  | BoolT4sgp2k | 80     | Seconds  | 0.16  | 0.24   | 0.06  | 0.39   |
| 6  | BoolT4sgp3k | 80     | Seconds  | 0.21  | 0.30   | 0.06  | 0.68   |
| 10 | BoolT4sgp4k | 80     | Seconds  | 1.32  | 17.93  | 11.89 | 71.35  |
| 14 | BoolT4sgp5k | 80     | Seconds  | 1.50  | 18.16  | 17.35 | 103.10 |
| 18 | BoolT4sgp6k | 80     | Seconds  | 26.67 | 193.42 | 52.41 | 277.97 |
| 22 | BoolT5sgp2k | 80     | Seconds  | 0.17  | 0.22   | 0.02  | 0.29   |
| 26 | BoolT5sgp3k | 80     | Seconds  | 0.20  | 0.25   | 0.03  | 0.35   |
| 30 | BoolT5sgp4k | 80     | Seconds  | 0.20  | 0.31   | 0.11  | 0.91   |
| 34 | BoolT5sgp5k | 80     | Seconds  | 0.25  | 0.34   | 0.09  | 0.74   |
| 38 | BoolT5sgp6k | 80     | Seconds  | 0.38  | 1.93   | 1.38  | 9.60   |

Table: Summary of statistics of experiment ExpE. (Part 3)

## Parameters of treatment: BoolT4sgp2k

|  | Parameter Values |
|---:|---:|
| tRNG | L'Ecuyer-CMRG Inversion Rejection |
| tReplay | 0 |
| experimentName | EB |
| treatmentName | BoolT4sgp2k |
| trials | 20 |
| everyK | 10 |
| outpath | data |
| batchPath | . |
| tVerbose | 1 |

Table: Parameters of treatment: BoolT4sgp2k

Treatment BoolT4sgp2k

## Parameters of treatment BoolT4sgp2k passed to xegaRun

|  | Parameter Values |
|---|---|
| penv | 2-Symmetry Problem |
| grammar | /home/dj2333/dev/cran/kSymmetry/BNF/AndOrNotTuned4.txt |
| replay | 0 |
| algorithm | sgp |
| maxdepth | 7 |
| max | FALSE |
| worstFitness | -4 |
| popsize | 200 |
| generations | 500 |
| crossrate | 0.2 |
| mutrate | 0.4 |
| ivmutrate | Const |
| mutrate2 | 0.8 |
| ivcrossrate | Const |
| crossrate2 | 0.4 |

Table: Parameters of treatment BoolT4sgp2k passed to xegaRun (Part 1)

Treatment BoolT4sgp2k

## Parameters of treatment BoolT4sgp2k 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                 | 80               |
| codonPrecision         | LCM              |
| terminationEps         | -0.1             |
| terminationCondition   | AbsoluteError    |
| evalmethod             | Deterministic    |

Table: Parameters of treatment BoolT4sgp2k passed to xegaRun (Part 2)

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Treatment BoolT4sgp2k

# Parameters of treatment BoolT4sgp2k passed to xegaRun

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

Table: Parameters of treatment BoolT4sgp2k passed to xegaRun (Part 3)

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## The Production Table of Treatment BoolT4sgp2k of Experiment ExpE

|    | LHS | RHS |
|----|-----|-----|
| 1 | \<fe\> | \<f0\> |
| 2 | \<fe\> | \<f1\>(\<fe\>) |
| 3 | \<fe\> | \<f2\>(\<fe\>,\<fe\>) |
| 4 | \<f0\> | D1 |
| 5 | \<f0\> | D2 |
| 6 | \<fe\> | AND\<sympairs\> |
| 7 | \<fe\> | AND\<sympairs\> |
| 8 | \<sympairs\> | (D1,D2) |
| 9 | \<sympairs\> | (NOT(D1),NOT(D2)) |
| 10 | \<f1\> | NOT |
| 11 | \<f2\> | OR |
| 12 | \<f2\> | OR |
| 13 | \<f2\> | AND |

Table: The Production Table of Treatment BoolT4sgp2k of Experiment ExpE

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Treatment BoolT4sgp2k

# Treatment: BoolT4sgp2k

| | Treatment | Trials | Variable | min | mean | sd | max |
|---|---|---|---|---|---|---|---|
| 4 | BoolT4sgp2k | 80 | Evaluations | 200.00 | 200.00 | 0.00 | 200.00 |
| 1 | BoolT4sgp2k | 80 | Fitness | 0.00 | 0.00 | 0.00 | 0.00 |
| 3 | BoolT4sgp2k | 80 | Generations | 1.00 | 1.00 | 0.00 | 1.00 |
| 2 | BoolT4sgp2k | 80 | Seconds | 0.16 | 0.24 | 0.06 | 0.39 |

Table: Treatment: BoolT4sgp2k

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Treatment BoolT4sgp2k

The Solution Table of Treatment BoolT4sgp2k of Experiment ExpE. Fit: 0. Unique Shortest Solutions: 31.

| | Solution |
|---|---|
| 1 | OR(AND(NOT(D1), NOT(D2)), AND(D2, D1)) |

Table: The Solution Table of Treatment BoolT4sgp2k of Experiment ExpE. Fit: 0. Unique Shortest Solutions: 31.

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Treatment BoolT4sgp2k

# The Derivation Tree of a Solution of Treatment BoolT4sgp2k of Experiment ExpE

Design of Experiment
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Exploratory Analysis
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A Summary
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B Treatments
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C xega
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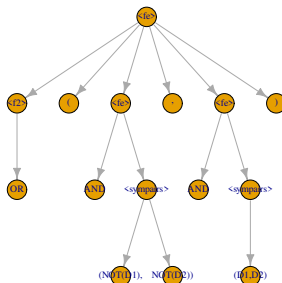
Treatment BoolT4sgp2k

# Plot of last xegaRun for Treatment BoolT4sgp2k of Experiment ExpE

Design of Experiment
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Exploratory Analysis
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A Summary
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B Treatments
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C xega
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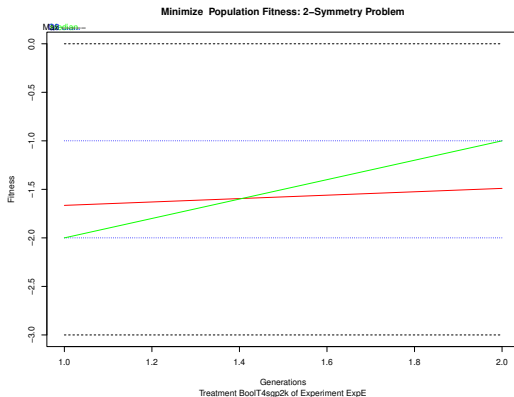
Treatment BoolT4sgp3k

## Parameters of treatment: BoolT4sgp3k

|  | Parameter Values |
|---|---|
| tRNG | L'Ecuyer-CMRG Inversion Rejection |
| tReplay | 0 |
| experimentName | EB |
| treatmentName | BoolT4sgp3k |
| trials | 20 |
| everyK | 10 |
| outpath | data |
| batchPath | . |
| tVerbose | 1 |

Table: Parameters of treatment: BoolT4sgp3k

Treatment BoolT4sgp3k

## Parameters of treatment BoolT4sgp3k passed to xegaRun

| | Parameter Values |
|---|---|
| penv | 3-Symmetry Problem |
| grammar | /home/dj2333/dev/cran/kSymmetry/BNF/AndOrNotTuned4.txt |
| replay | 0 |
| algorithm | sgp |
| maxdepth | 7 |
| max | FALSE |
| worstFitness | -8 |
| popsize | 200 |
| generations | 500 |
| crossrate | 0.2 |
| mutrate | 0.4 |
| ivmutrate | Const |
| mutrate2 | 0.8 |
| ivcrossrate | Const |
| crossrate2 | 0.4 |

Table: Parameters of treatment BoolT4sgp3k passed to xegaRun (Part 1)

Treatment BoolT4sgp3k

## Parameters of treatment BoolT4sgp3k 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 BoolT4sgp3k passed to xegaRun (Part 2)

Design of Experiment
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Exploratory Analysis
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A Summary
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B Treatments
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C xega
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Treatment BoolT4sgp3k

## Parameters of treatment BoolT4sgp3k passed to xegaRun

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

Table: Parameters of treatment BoolT4sgp3k passed to xegaRun (Part 3)

# The Production Table of Treatment BoolT4sgp3k of Experiment ExpE

|    | LHS | RHS |
|----|-----|-----|
| 1  | \<fe\> | \<f0\> |
| 2  | \<fe\> | \<f1\>(\<fe\>) |
| 3  | \<fe\> | \<f2\>(\<fe\>,\<fe\>) |
| 4  | \<f0\> | D1 |
| 5  | \<f0\> | D2 |
| 6  | \<f0\> | D3 |
| 7  | \<fe\> | AND\<sympairs\> |
| 8  | \<fe\> | AND\<sympairs\> |
| 9  | \<sympairs\> | (D1,D3) |
| 10 | \<sympairs\> | (NOT(D1),NOT(D3)) |
| 11 | \<f1\> | NOT |
| 12 | \<f2\> | OR |
| 13 | \<f2\> | OR |
| 14 | \<f2\> | AND |

Table: The Production Table of Treatment BoolT4sgp3k of Experiment ExpE

Design of Experiment
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Exploratory Analysis
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A Summary
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B Treatments
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C xega
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Treatment BoolT4sgp3k

## Treatment: BoolT4sgp3k

|   | Treatment | Trials | Variable | min | mean | sd | max |
|---|-----------|--------|----------|-----|------|-----|-----|
| 8 | BoolT4sgp3k | 80 | Evaluations | 200.00 | 202.50 | 22.36 | 400.00 |
| 5 | BoolT4sgp3k | 80 | Fitness | 0.00 | 0.00 | 0.00 | 0.00 |
| 7 | BoolT4sgp3k | 80 | Generations | 1.00 | 1.01 | 0.11 | 2.00 |
| 6 | BoolT4sgp3k | 80 | Seconds | 0.21 | 0.30 | 0.06 | 0.68 |

Table: Treatment: BoolT4sgp3k

Design of Experiment
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Exploratory Analysis
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A Summary
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B Treatments
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C xega
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Treatment BoolT4sgp3k

The Solution Table of Treatment BoolT4sgp3k of Experiment ExpE. Fit: 0. Unique Shortest Solutions: 28.

|   | Solution |
|---|----------|
| 1 | OR(AND(NOT(D1), NOT(D3)), AND(D1, D3)) |

Table: The Solution Table of Treatment BoolT4sgp3k of Experiment ExpE. Fit: 0. Unique Shortest Solutions: 28.

Design of Experiment
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Exploratory Analysis
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A Summary
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B Treatments
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C xega
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Treatment BoolT4sgp3k

# The Derivation Tree of a Solution of Treatment BoolT4sgp3k of Experiment ExpE

Design of Experiment
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Exploratory Analysis
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A Summary
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**B Treatments**
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C xega
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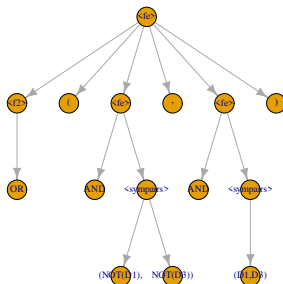
Treatment BoolT4sgp3k

# Plot of last xegaRun for Treatment BoolT4sgp3k of Experiment ExpE
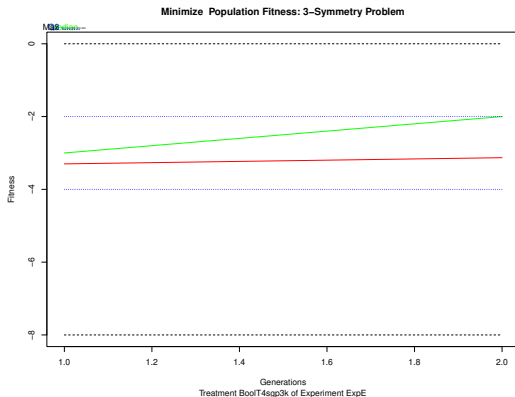
## Parameters of treatment: BoolT4sgp4k

|  | Parameter Values |
|---:|---:|
| tRNG | L'Ecuyer-CMRG Inversion Rejection |
| tReplay | 0 |
| experimentName | EB |
| treatmentName | BoolT4sgp4k |
| trials | 20 |
| everyK | 10 |
| outpath | data |
| batchPath | . |
| tVerbose | 1 |

Table: Parameters of treatment: BoolT4sgp4k

Design of Experiment
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Exploratory Analysis
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A Summary
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B Treatments

C xega
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Treatment BoolT4sgp4k

## Parameters of treatment BoolT4sgp4k passed to xegaRun

|  | Parameter Values |
|---|---|
| penv | 4-Symmetry Problem |
| grammar | /home/dj2333/dev/cran/kSymmetry/BNF/AndOrNotTuned4.txt |
| replay | 0 |
| algorithm | sgp |
| maxdepth | 7 |
| max | FALSE |
| worstFitness | -16 |
| popsize | 200 |
| generations | 500 |
| crossrate | 0.2 |
| mutrate | 0.4 |
| ivmutrate | Const |
| mutrate2 | 0.8 |
| ivcrossrate | Const |
| crossrate2 | 0.4 |

Table: Parameters of treatment BoolT4sgp4k passed to xegaRun (Part 1)

Treatment BoolT4sgp4k

## Parameters of treatment BoolT4sgp4k 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 | 160 |
| codonPrecision | LCM |
| terminationEps | -0.1 |
| terminationCondition | AbsoluteError |
| evalmethod | Deterministic |

Table: Parameters of treatment BoolT4sgp4k passed to xegaRun (Part 2)

Design of Experiment
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Exploratory Analysis
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A Summary
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B Treatments
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C xega
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Treatment BoolT4sgp4k

# Parameters of treatment BoolT4sgp4k passed to xegaRun

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

Table: Parameters of treatment BoolT4sgp4k passed to xegaRun (Part 3)

Design of Experiment
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Exploratory Analysis
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A Summary
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B Treatments
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C xega
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Treatment BoolT4sgp4k

## The Production Table of Treatment BoolT4sgp4k of Experiment ExpE

|    | LHS | RHS |
|----|-----|-----|
| 1  | <fe> | <f0> |
| 2  | <fe> | <f1>(<fe>) |
| 3  | <fe> | <f2>(<fe>,<fe>) |
| 4  | <f0> | D1 |
| 5  | <f0> | D2 |
| 6  | <f0> | D3 |
| 7  | <f0> | D4 |
| 8  | <fe> | AND<sympairs> |
| 9  | <fe> | AND<sympairs> |
| 10 | <sympairs> | (D1,D4) |
| 11 | <sympairs> | (NOT(D1),NOT(D4)) |
| 12 | <sympairs> | (D2,D3) |
| 13 | <sympairs> | (NOT(D2),NOT(D3)) |
| 14 | <f1> | NOT |
| 15 | <f2> | OR |

Table: The Production Table of Treatment BoolT4sgp4k of Experiment
ExpE (Part 1)

# The Production Table of Treatment BoolT4sgp4k of Experiment ExpE

|    | LHS    | RHS |
|----|--------|-----|
| 16 | <f2>   | OR  |
| 17 | <f2>   | AND |

Table: The Production Table of Treatment BoolT4sgp4k of Experiment ExpE (Part 2)

Design of Experiment
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Exploratory Analysis
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A Summary
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B Treatments
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C xega
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Treatment BoolT4sgp4k

# Treatment: BoolT4sgp4k

|    | Treatment   | Trials | Variable    | min     | mean     | sd      | max      |
|----|-------------|--------|-------------|---------|----------|---------|----------|
| 12 | BoolT4sgp4k | 80     | Evaluations | 1400.00 | 15402.50 | 8377.03 | 44200.00 |
| 9  | BoolT4sgp4k | 80     | Fitness     | 0.00    | 0.00     | 0.00    | 0.00     |
| 11 | BoolT4sgp4k | 80     | Generations | 7.00    | 77.01    | 41.89   | 221.00   |
| 10 | BoolT4sgp4k | 80     | Seconds     | 1.32    | 17.93    | 11.89   | 71.35    |

Table: Treatment: BoolT4sgp4k

Treatment BoolT4sgp4k

The Solution Table of Treatment BoolT4sgp4k of Experiment ExpE. Fit: 0. Unique Shortest Solutions: 68.

| | Solution |
|---|---|
| 1 | AND(OR(AND(NOT(D2), NOT(D3)), AND(D2, D3)), OR(AND(D1, D4), AND(NOT(D1), NOT(D4)))) |

Table: The Solution Table of Treatment BoolT4sgp4k of Experiment ExpE. Fit: 0. Unique Shortest Solutions: 68.

Design of Experiment
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Exploratory Analysis
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A Summary
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B Treatments
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C xega
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Treatment BoolT4sgp4k

# The Derivation Tree of a Solution of Treatment BoolT4sgp4k of Experiment ExpE

Design of Experiment
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Exploratory Analysis
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A Summary
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B Treatments
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C xega
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Treatment BoolT4sgp4k

# Plot of last xegaRun for Treatment BoolT4sgp4k of Experiment ExpE
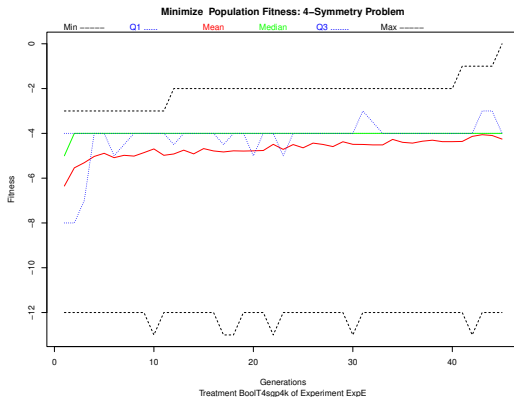
## Parameters of treatment: BoolT4sgp5k

|  | Parameter Values |
|---|---|
| tRNG | L'Ecuyer-CMRG Inversion Rejection |
| tReplay | 0 |
| experimentName | EB |
| treatmentName | BoolT4sgp5k |
| trials | 20 |
| everyK | 10 |
| outpath | data |
| batchPath | . |
| tVerbose | 1 |

Table: Parameters of treatment: BoolT4sgp5k

Design of Experiment
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Exploratory Analysis
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A Summary
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B Treatments
C xega
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Treatment BoolT4sgp5k

## Parameters of treatment BoolT4sgp5k passed to xegaRun

| | Parameter Values |
|---|---|
| penv | 5-Symmetry Problem |
| grammar | /home/dj2333/dev/cran/kSymmetry/BNF/AndOrNotTuned4.txt |
| replay | 0 |
| algorithm | sgp |
| maxdepth | 7 |
| max | FALSE |
| worstFitness | -32 |
| popsize | 200 |
| generations | 500 |
| crossrate | 0.2 |
| mutrate | 0.4 |
| ivmutrate | Const |
| mutrate2 | 0.8 |
| ivcrossrate | Const |
| crossrate2 | 0.4 |

Table: Parameters of treatment BoolT4sgp5k passed to xegaRun (Part 1)

Treatment BoolT4sgp5k

## Parameters of treatment BoolT4sgp5k 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 | 200 |
| codonPrecision | LCM |
| terminationEps | -0.1 |
| terminationCondition | AbsoluteError |
| evalmethod | Deterministic |

Table: Parameters of treatment BoolT4sgp5k passed to xegaRun (Part 2)

Design of Experiment
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Exploratory Analysis
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A Summary
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B Treatments
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C xega
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Treatment BoolT4sgp5k

# Parameters of treatment BoolT4sgp5k passed to xegaRun

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

Table: Parameters of treatment BoolT4sgp5k passed to xegaRun (Part 3)

Design of Experiment    Exploratory Analysis    A Summary    B Treatments    C xega
○○○○○○○                 ○○○                     ○○○           **B Treatments**  ○○○○○○
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                        ○○○○

Treatment BoolT4sgp5k

# The Production Table of Treatment BoolT4sgp5k of Experiment ExpE

|    | LHS | RHS |
|----|-----|-----|
| 1 | \<fe\> | \<f0\> |
| 2 | \<fe\> | \<f1\>(\<fe\>) |
| 3 | \<fe\> | \<f2\>(\<fe\>,\<fe\>) |
| 4 | \<f0\> | D1 |
| 5 | \<f0\> | D2 |
| 6 | \<f0\> | D3 |
| 7 | \<f0\> | D4 |
| 8 | \<f0\> | D5 |
| 9 | \<fe\> | AND\<sympairs\> |
| 10 | \<fe\> | AND\<sympairs\> |
| 11 | \<sympairs\> | (D1,D5) |
| 12 | \<sympairs\> | (NOT(D1),NOT(D5)) |
| 13 | \<sympairs\> | (D2,D4) |
| 14 | \<sympairs\> | (NOT(D2),NOT(D4)) |
| 15 | \<f1\> | NOT |

Table: The Production Table of Treatment BoolT4sgp5k of Experiment ExpE (Part 1)

Design of Experiment

Exploratory Analysis

A Summary

B Treatments

C xega

Treatment BoolT4sgp5k

# The Production Table of Treatment BoolT4sgp5k of Experiment ExpE

|    | LHS      | RHS  |
|----|----------|------|
| 16 | \<f2\>   | OR   |
| 17 | \<f2\>   | OR   |
| 18 | \<f2\>   | AND  |

Table: The Production Table of Treatment BoolT4sgp5k of Experiment ExpE (Part 2)

Design of Experiment
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Exploratory Analysis
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A Summary
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B Treatments

C xega
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Treatment BoolT4sgp5k

# Treatment: BoolT4sgp5k

|    | Treatment    | Trials | Variable    | min     | mean     | sd       | max      |
|----|--------------|--------|-------------|---------|----------|----------|----------|
| 16 | BoolT4sgp5k  | 80     | Evaluations | 2000.00 | 14620.00 | 10549.35 | 51200.00 |
| 13 | BoolT4sgp5k  | 80     | Fitness     | 0.00    | 0.00     | 0.00     | 0.00     |
| 15 | BoolT4sgp5k  | 80     | Generations | 10.00   | 73.10    | 52.75    | 256.00   |
| 14 | BoolT4sgp5k  | 80     | Seconds     | 1.50    | 18.16    | 17.35    | 103.10   |

Table: Treatment: BoolT4sgp5k

Treatment BoolT4sgp5k

The Solution Table of Treatment BoolT4sgp5k of Experiment ExpE. Fit: 0. Unique Shortest Solutions: 71.

| | Solution |
|---|---|
| 1 | AND(OR(AND(NOT(D2), NOT(D4)), AND(D2, D4)), OR(AND(NOT(D1), NOT(D5)), AND(D1, D5))) |

Table: The Solution Table of Treatment BoolT4sgp5k of Experiment ExpE. Fit: 0. Unique Shortest Solutions: 71.

Design of Experiment
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Exploratory Analysis
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A Summary
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B Treatments
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C xega
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Treatment BoolT4sgp5k

# The Derivation Tree of a Solution of Treatment BoolT4sgp5k of Experiment ExpE

Design of Experiment
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Exploratory Analysis
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A Summary
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B Treatments
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C xega
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Treatment BoolT4sgp5k

# Plot of last xegaRun for Treatment BoolT4sgp5k of Experiment ExpE
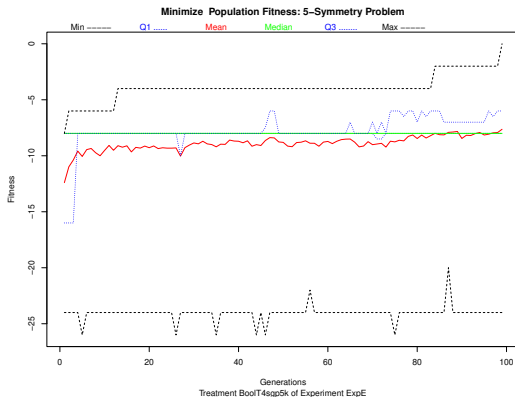
## Parameters of treatment: BoolT4sgp6k

|  | Parameter Values |
|---:|---:|
| tRNG | L'Ecuyer-CMRG Inversion Rejection |
| tReplay | 0 |
| experimentName | EB |
| treatmentName | BoolT4sgp6k |
| trials | 20 |
| everyK | 10 |
| outpath | data |
| batchPath | . |
| tVerbose | 1 |

Table: Parameters of treatment: BoolT4sgp6k

Treatment BoolT4sgp6k

## Parameters of treatment BoolT4sgp6k passed to xegaRun

| | Parameter Values |
|---|---|
| penv | 6-Symmetry Problem |
| grammar | /home/dj2333/dev/cran/kSymmetry/BNF/AndOrNotTuned4.txt |
| replay | 0 |
| algorithm | sgp |
| maxdepth | 7 |
| max | FALSE |
| worstFitness | -64 |
| popsize | 200 |
| generations | 500 |
| crossrate | 0.2 |
| mutrate | 0.4 |
| ivmutrate | Const |
| mutrate2 | 0.8 |
| ivcrossrate | Const |
| crossrate2 | 0.4 |

Table: Parameters of treatment BoolT4sgp6k passed to xegaRun (Part 1)

Design of Experiment
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Exploratory Analysis
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A Summary
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B Treatments
OOOOOOO

C xega
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Treatment BoolT4sgp6k

## Parameters of treatment BoolT4sgp6k 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 | 240 |
| codonPrecision | LCM |
| terminationEps | -0.1 |
| terminationCondition | AbsoluteError |
| evalmethod | Deterministic |

Table: Parameters of treatment BoolT4sgp6k passed to xegaRun (Part 2)

Design of Experiment
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Exploratory Analysis
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A Summary
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B Treatments
oooooo

C xega
oooooo

Treatment BoolT4sgp6k

# Parameters of treatment BoolT4sgp6k passed to xegaRun

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

Table: Parameters of treatment BoolT4sgp6k passed to xegaRun (Part 3)

## The Production Table of Treatment BoolT4sgp6k of Experiment ExpE

| | LHS | RHS |
|---|---|---|
| 1 | \<fe\> | \<f0\> |
| 2 | \<fe\> | \<f1\>(\<fe\>) |
| 3 | \<fe\> | \<f2\>(\<fe\>,\<fe\>) |
| 4 | \<f0\> | D1 |
| 5 | \<f0\> | D2 |
| 6 | \<f0\> | D3 |
| 7 | \<f0\> | D4 |
| 8 | \<f0\> | D5 |
| 9 | \<f0\> | D6 |
| 10 | \<fe\> | AND\<sympairs\> |
| 11 | \<fe\> | AND\<sympairs\> |
| 12 | \<sympairs\> | (D1,D6) |
| 13 | \<sympairs\> | (NOT(D1),NOT(D6)) |
| 14 | \<sympairs\> | (D2,D5) |
| 15 | \<sympairs\> | (NOT(D2),NOT(D5)) |

Table: The Production Table of Treatment BoolT4sgp6k of Experiment ExpE (Part 1)

## The Production Table of Treatment BoolT4sgp6k of Experiment ExpE

|    | LHS | RHS |
|----|-----|-----|
| 16 | <sympairs> | (D3,D4) |
| 17 | <sympairs> | (NOT(D3),NOT(D4)) |
| 18 | <f1> | NOT |
| 19 | <f2> | OR |
| 20 | <f2> | OR |
| 21 | <f2> | AND |

Table: The Production Table of Treatment BoolT4sgp6k of Experiment ExpE (Part 2)

Design of Experiment        Exploratory Analysis        A Summary        **B Treatments**        C xega
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                            ooooooooo
                            oooo

Treatment BoolT4sgp6k

## Treatment: BoolT4sgp6k

|     | Treatment   | Trials | Variable    | min      | mean     | sd       | max       |
|-----|-------------|--------|-------------|----------|----------|----------|-----------|
| 20  | BoolT4sgp6k | 80     | Evaluations | 19000.00 | 92135.00 | 20136.92 | 100000.00 |
| 17  | BoolT4sgp6k | 80     | Fitness     | 0.00     | 3.33     | 1.61     | 6.00      |
| 19  | BoolT4sgp6k | 80     | Generations | 95.00    | 460.68   | 100.68   | 500.00    |
| 18  | BoolT4sgp6k | 80     | Seconds     | 26.67    | 193.42   | 52.41    | 277.97    |

Table: Treatment: BoolT4sgp6k

Treatment BoolT4sgp6k

The Solution Table of Treatment BoolT4sgp6k of Experiment ExpE. Fit: 0. Unique Shortest Solutions: 13.

|   | Solution |
|---|----------|
| 1 | AND(AND(OR(AND(NOT(D1), NOT(D6)), AND(D1, D6)), OR(AND(NOT(D3), NOT(D4)), AND(D3, D4))), OR(AND(D2, D5), AND(NOT(D2), NOT(D5)))) |

Table: The Solution Table of Treatment BoolT4sgp6k of Experiment ExpE. Fit: 0. Unique Shortest Solutions: 13.

Design of Experiment
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Exploratory Analysis
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A Summary
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B Treatments
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C xega
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Treatment BoolT4sgp6k

# The Derivation Tree of a Solution of Treatment BoolT4sgp6k of Experiment ExpE

Design of Experiment
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Exploratory Analysis
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A Summary
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B Treatments
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C xega
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Treatment BoolT4sgp6k

# Plot of last xegaRun for Treatment BoolT4sgp6k of Experiment ExpE



Minimize Population Fitness: 6–Symmetry Problem

Generations
Treatment BoolT4sgp6k of Experiment ExpE

Design of Experiment
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Exploratory Analysis
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A Summary
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B Treatments

C xega
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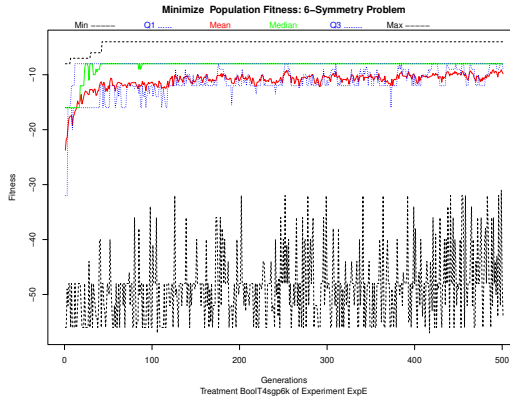
## Parameters of treatment: BoolT5sgp2k

| | Parameter Values |
|---|---|
| tRNG | L'Ecuyer-CMRG Inversion Rejection |
| tReplay | 0 |
| experimentName | EE |
| treatmentName | BoolT5sgp2k |
| trials | 20 |
| everyK | 10 |
| outpath | data |
| batchPath | . |
| tVerbose | 1 |

Table: Parameters of treatment: BoolT5sgp2k

Treatment BoolT5sgp2k

## Parameters of treatment BoolT5sgp2k passed to xegaRun

| | Parameter Values |
|---|---|
| penv | 2-Symmetry Problem |
| grammar | /home/dj2333/dev/cran/kSymmetry/BNF/AndOrNotTuned5.txt |
| replay | 0 |
| algorithm | sgp |
| maxdepth | 7 |
| max | FALSE |
| worstFitness | -4 |
| popsize | 200 |
| generations | 500 |
| crossrate | 0.2 |
| mutrate | 0.4 |
| ivmutrate | Const |
| mutrate2 | 0.8 |
| ivcrossrate | Const |
| crossrate2 | 0.4 |

Table: Parameters of treatment BoolT5sgp2k passed to xegaRun (Part 1)

Design of Experiment
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Exploratory Analysis
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A Summary
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B Treatments
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C xega
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Treatment BoolT5sgp2k

## Parameters of treatment BoolT5sgp2k 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 | 80 |
| codonPrecision | LCM |
| terminationEps | -0.1 |
| terminationCondition | AbsoluteError |
| evalmethod | Deterministic |

Table: Parameters of treatment BoolT5sgp2k passed to xegaRun (Part 2)

Design of Experiment ○○○○○○○

Exploratory Analysis ○○○ ○○○○○○○○ ○○○○

A Summary ○○○

B Treatments ○○○○○○

C xega ○○○○○○

Treatment BoolT5sgp2k

## Parameters of treatment BoolT5sgp2k passed to xegaRun

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

Table: Parameters of treatment BoolT5sgp2k passed to xegaRun (Part 3)

Design of Experiment
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Exploratory Analysis
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A Summary
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B Treatments
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C xega
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Treatment BoolT5sgp2k

## The Production Table of Treatment BoolT5sgp2k of Experiment ExpE

|    | LHS         | RHS                          |
|----|-------------|------------------------------|
| 1  | \<fe\>      | \<f0\>                       |
| 2  | \<fe\>      | \<f1\>(\<fe\>)               |
| 3  | \<fe\>      | \<f2\>(\<fe\>,\<fe\>)        |
| 4  | \<f0\>      | D1                           |
| 5  | \<f0\>      | D2                           |
| 6  | \<fe\>      | sPair\<sympairs\>            |
| 7  | \<sympairs\>| (D1,D2)                      |
| 8  | \<sympairs\>| (NOT(D1),NOT(D2))            |
| 9  | \<f1\>      | NOT                          |
| 10 | \<f2\>      | OR                           |
| 11 | \<f2\>      | AND                          |

Table: The Production Table of Treatment BoolT5sgp2k of Experiment ExpE

Design of Experiment
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Exploratory Analysis
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A Summary
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B Treatments

C xega
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Treatment BoolT5sgp2k

# Treatment: BoolT5sgp2k

| | Treatment | Trials | Variable | min | mean | sd | max |
|---|---|---|---|---|---|---|---|
| 24 | BoolT5sgp2k | 80 | Evaluations | 200.00 | 200.00 | 0.00 | 200.00 |
| 21 | BoolT5sgp2k | 80 | Fitness | 0.00 | 0.00 | 0.00 | 0.00 |
| 23 | BoolT5sgp2k | 80 | Generations | 1.00 | 1.00 | 0.00 | 1.00 |
| 22 | BoolT5sgp2k | 80 | Seconds | 0.17 | 0.22 | 0.02 | 0.29 |

Table: Treatment: BoolT5sgp2k

Design of Experiment
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Exploratory Analysis
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A Summary
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B Treatments
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C xega
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Treatment BoolT5sgp2k

The Solution Table of Treatment BoolT5sgp2k of Experiment ExpE. Fit: 0. Unique Shortest Solutions: 13.

| | Solution |
|---|---|
| 1 | sPair(D1, D2) |

Table: The Solution Table of Treatment BoolT5sgp2k of Experiment ExpE. Fit: 0. Unique Shortest Solutions: 13.

Design of Experiment
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Exploratory Analysis
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A Summary
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B Treatments
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C xega
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Treatment BoolT5sgp2k

# The Derivation Tree of a Solution of Treatment BoolT5sgp2k of Experiment ExpE

Design of Experiment
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Exploratory Analysis
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A Summary
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**B Treatments**
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C xega
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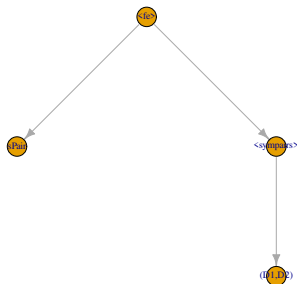
Treatment BoolT5sgp2k

# Plot of last xegaRun for Treatment BoolT5sgp2k of Experiment ExpE



Minimize Population Fitness: 2−Symmetry Problem

Generations
Treatment BoolT5sgp2k of Experiment ExpE
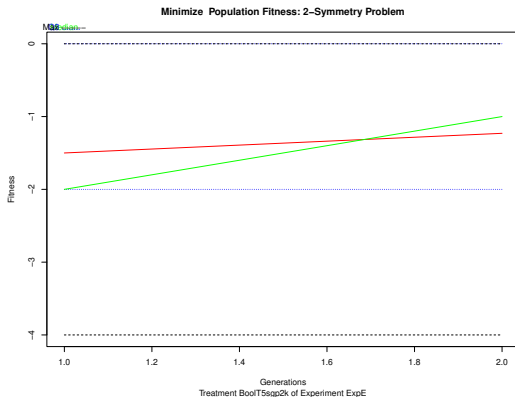
Treatment BoolT5sgp3k

## Parameters of treatment: BoolT5sgp3k

|  | Parameter Values |
|---:|---:|
| tRNG | L'Ecuyer-CMRG Inversion Rejection |
| tReplay | 0 |
| experimentName | EE |
| treatmentName | BoolT5sgp3k |
| trials | 20 |
| everyK | 10 |
| outpath | data |
| batchPath | . |
| tVerbose | 1 |

Table: Parameters of treatment: BoolT5sgp3k

Design of Experiment
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Exploratory Analysis
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A Summary
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B Treatments
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C xega
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Treatment BoolT5sgp3k

## Parameters of treatment BoolT5sgp3k passed to xegaRun

| | Parameter Values |
|---|---|
| penv | 3-Symmetry Problem |
| grammar | /home/dj2333/dev/cran/kSymmetry/BNF/AndOrNotTuned5.txt |
| replay | 0 |
| algorithm | sgp |
| maxdepth | 7 |
| max | FALSE |
| worstFitness | -8 |
| popsize | 200 |
| generations | 500 |
| crossrate | 0.2 |
| mutrate | 0.4 |
| ivmutrate | Const |
| mutrate2 | 0.8 |
| ivcrossrate | Const |
| crossrate2 | 0.4 |

Table: Parameters of treatment BoolT5sgp3k passed to xegaRun (Part 1)

Design of Experiment
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Exploratory Analysis
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A Summary
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B Treatments
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C xega
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Treatment BoolT5sgp3k

## Parameters of treatment BoolT5sgp3k 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 BoolT5sgp3k passed to xegaRun (Part 2)

Design of Experiment
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Exploratory Analysis
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A Summary
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B Treatments
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C xega
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Treatment BoolT5sgp3k

## Parameters of treatment BoolT5sgp3k passed to xegaRun

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

Table: Parameters of treatment BoolT5sgp3k passed to xegaRun (Part 3)

## The Production Table of Treatment BoolT5sgp3k of Experiment ExpE

| | LHS | RHS |
|---|---|---|
| 1 | <fe> | <f0> |
| 2 | <fe> | <f1>(<fe>) |
| 3 | <fe> | <f2>(<fe>,<fe>) |
| 4 | <f0> | D1 |
| 5 | <f0> | D2 |
| 6 | <f0> | D3 |
| 7 | <fe> | sPair<sympairs> |
| 8 | <sympairs> | (D1,D3) |
| 9 | <sympairs> | (NOT(D1),NOT(D3)) |
| 10 | <f1> | NOT |
| 11 | <f2> | OR |
| 12 | <f2> | AND |

Table: The Production Table of Treatment BoolT5sgp3k of Experiment ExpE

Design of Experiment

Exploratory Analysis

A Summary

B Treatments

C xega

Treatment BoolT5sgp3k

# Treatment: BoolT5sgp3k

| | Treatment | Trials | Variable | min | mean | sd | max |
|---|---|---|---|---|---|---|---|
| 28 | BoolT5sgp3k | 80 | Evaluations | 200.00 | 200.00 | 0.00 | 200.00 |
| 25 | BoolT5sgp3k | 80 | Fitness | 0.00 | 0.00 | 0.00 | 0.00 |
| 27 | BoolT5sgp3k | 80 | Generations | 1.00 | 1.00 | 0.00 | 1.00 |
| 26 | BoolT5sgp3k | 80 | Seconds | 0.20 | 0.25 | 0.03 | 0.35 |

Table: Treatment: BoolT5sgp3k

Design of Experiment
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Exploratory Analysis
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A Summary
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B Treatments
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C xega
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Treatment BoolT5sgp3k
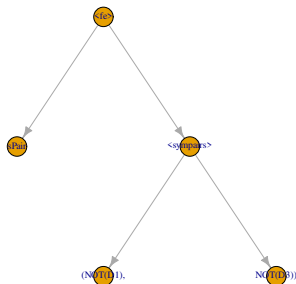
 The Solution Table of Treatment BoolT5sgp3k of Experiment ExpE. Fit: 0. Unique Shortest Solutions: 11.

|   | Solution |
|---|----------|
| 1 | sPair(D1, D3) |

Table: The Solution Table of Treatment BoolT5sgp3k of Experiment ExpE. Fit: 0. Unique Shortest Solutions: 11.

Design of Experiment
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Exploratory Analysis
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A Summary
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B Treatments
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C xega
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Treatment BoolT5sgp3k

# The Derivation Tree of a Solution of Treatment BoolT5sgp3k of Experiment ExpE

Design of Experiment
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Exploratory Analysis
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A Summary
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B Treatments
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C xega
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Treatment BoolT5sgp3k

# Plot of last xegaRun for Treatment BoolT5sgp3k of Experiment ExpE

Design of Experiment
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Exploratory Analysis
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A Summary
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B Treatments
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C xega
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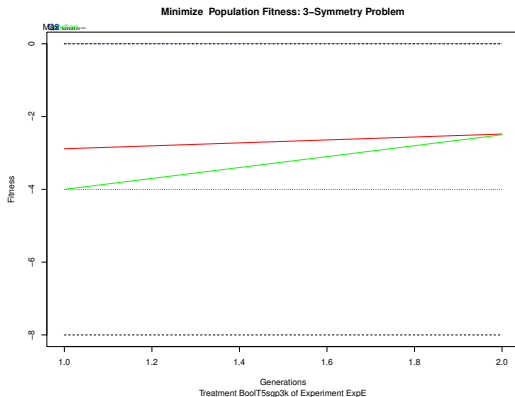
Treatment BoolT5sgp4k

## Parameters of treatment: BoolT5sgp4k

|  | Parameter Values |
|---:|---:|
| tRNG | L'Ecuyer-CMRG Inversion Rejection |
| tReplay | 0 |
| experimentName | EE |
| treatmentName | BoolT5sgp4k |
| trials | 20 |
| everyK | 10 |
| outpath | data |
| batchPath | . |
| tVerbose | 1 |

Table: Parameters of treatment: BoolT5sgp4k

Treatment BoolT5sgp4k

## Parameters of treatment BoolT5sgp4k passed to xegaRun

|  | Parameter Values |
|---|---|
| penv | 4-Symmetry Problem |
| grammar | /home/dj2333/dev/cran/kSymmetry/BNF/AndOrNotTuned5.txt |
| replay | 0 |
| algorithm | sgp |
| maxdepth | 7 |
| max | FALSE |
| worstFitness | -16 |
| popsize | 200 |
| generations | 500 |
| crossrate | 0.2 |
| mutrate | 0.4 |
| ivmutrate | Const |
| mutrate2 | 0.8 |
| ivcrossrate | Const |
| crossrate2 | 0.4 |

Table: Parameters of treatment BoolT5sgp4k passed to xegaRun (Part 1)

Treatment BoolT5sgp4k

## Parameters of treatment BoolT5sgp4k 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 | 160 |
| codonPrecision | LCM |
| terminationEps | -0.1 |
| terminationCondition | AbsoluteError |
| evalmethod | Deterministic |

Table: Parameters of treatment BoolT5sgp4k passed to xegaRun (Part 2)

Design of Experiment
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Exploratory Analysis
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A Summary
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B Treatments
ooooooo

C xega
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Treatment BoolT5sgp4k

# Parameters of treatment BoolT5sgp4k passed to xegaRun

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

Table: Parameters of treatment BoolT5sgp4k passed to xegaRun (Part 3)

Design of Experiment
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Exploratory Analysis
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A Summary
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B Treatments
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C xega
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Treatment BoolT5sgp4k

## The Production Table of Treatment BoolT5sgp4k of Experiment ExpE

|     | LHS | RHS |
| --- | --- | --- |
| 1 | <fe> | <f0> |
| 2 | <fe> | <f1>(<fe>) |
| 3 | <fe> | <f2>(<fe>,<fe>) |
| 4 | <f0> | D1 |
| 5 | <f0> | D2 |
| 6 | <f0> | D3 |
| 7 | <f0> | D4 |
| 8 | <fe> | sPair<sympairs> |
| 9 | <sympairs> | (D1,D4) |
| 10 | <sympairs> | (NOT(D1),NOT(D4)) |
| 11 | <sympairs> | (D2,D3) |
| 12 | <sympairs> | (NOT(D2),NOT(D3)) |
| 13 | <f1> | NOT |
| 14 | <f2> | OR |
| 15 | <f2> | AND |

Table: The Production Table of Treatment BoolT5sgp4k of Experiment ExpE

Design of Experiment
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Exploratory Analysis
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A Summary
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B Treatments
ooooooo

C xega
oooooo

Treatment BoolT5sgp4k

# Treatment: BoolT5sgp4k

| | Treatment | Trials | Variable | min | mean | sd | max |
|---|---|---|---|---|---|---|---|
| 32 | BoolT5sgp4k | 80 | Evaluations | 200.00 | 245.00 | 110.12 | 800.00 |
| 29 | BoolT5sgp4k | 80 | Fitness | 0.00 | 0.00 | 0.00 | 0.00 |
| 31 | BoolT5sgp4k | 80 | Generations | 1.00 | 1.23 | 0.55 | 4.00 |
| 30 | BoolT5sgp4k | 80 | Seconds | 0.20 | 0.31 | 0.11 | 0.91 |

Table: Treatment: BoolT5sgp4k

Design of Experiment
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Exploratory Analysis
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A Summary
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B Treatments
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C xega
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Treatment BoolT5sgp4k

The Solution Table of Treatment BoolT5sgp4k of Experiment ExpE. Fit: 0. Unique Shortest Solutions: 39.

|   | Solution |
|---|----------|
| 1 | AND(sPair(D2, D3), sPair(D1, D4)) |

Table: The Solution Table of Treatment BoolT5sgp4k of Experiment ExpE. Fit: 0. Unique Shortest Solutions: 39.

Design of Experiment
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Exploratory Analysis
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A Summary
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B Treatments
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C xega
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Treatment BoolT5sgp4k

# The Derivation Tree of a Solution of Treatment BoolT5sgp4k of Experiment ExpE

Design of Experiment
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Exploratory Analysis
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A Summary
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B Treatments
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C xega
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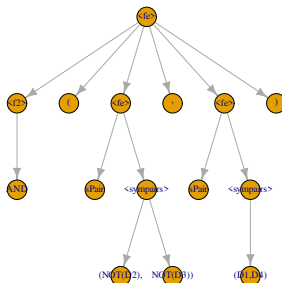
Treatment BoolT5sgp4k

# Plot of last xegaRun for Treatment BoolT5sgp4k of Experiment ExpE



Minimize Population Fitness: 4–Symmetry Problem

Generations
Treatment BoolT5sgp4k of Experiment ExpE
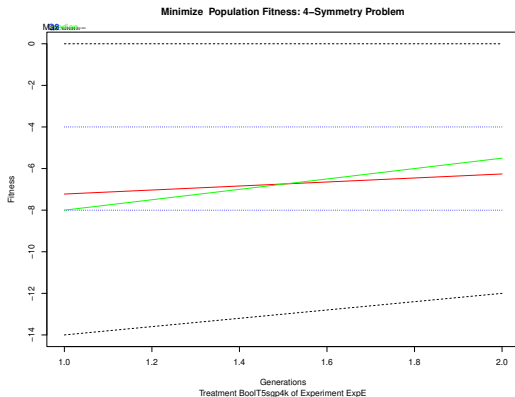
## Parameters of treatment: BoolT5sgp5k

|  | Parameter Values |
|---:|---:|
| tRNG | L'Ecuyer-CMRG Inversion Rejection |
| tReplay | 0 |
| experimentName | EE |
| treatmentName | BoolT5sgp5k |
| trials | 20 |
| everyK | 10 |
| outpath | data |
| batchPath | . |
| tVerbose | 1 |

Table: Parameters of treatment: BoolT5sgp5k

Treatment BoolT5sgp5k

## Parameters of treatment BoolT5sgp5k passed to xegaRun

| | Parameter Values |
|---|---|
| penv | 5-Symmetry Problem |
| grammar | /home/dj2333/dev/cran/kSymmetry/BNF/AndOrNotTuned5.txt |
| replay | 0 |
| algorithm | sgp |
| maxdepth | 7 |
| max | FALSE |
| worstFitness | -32 |
| popsize | 200 |
| generations | 500 |
| crossrate | 0.2 |
| mutrate | 0.4 |
| ivmutrate | Const |
| mutrate2 | 0.8 |
| ivcrossrate | Const |
| crossrate2 | 0.4 |

Table: Parameters of treatment BoolT5sgp5k passed to xegaRun (Part 1)

Design of Experiment  Exploratory Analysis  A Summary  B Treatments  C xega
ooooooo                ooo                   ooo        B Treatments  oooooo
                       ooooooo
                       oooo

Treatment BoolT5sgp5k

## Parameters of treatment BoolT5sgp5k 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 | 200 |
| codonPrecision | LCM |
| terminationEps | -0.1 |
| terminationCondition | AbsoluteError |
| evalmethod | Deterministic |

Table: Parameters of treatment BoolT5sgp5k passed to xegaRun (Part 2)

Design of Experiment · ○○○○○○○
Exploratory Analysis · ○○○ ○○○○○○○○ ○○○○
A Summary · ○○○
B Treatments · ○○○○○○
C xega · ○○○○○○

Treatment BoolT5sgp5k

## Parameters of treatment BoolT5sgp5k passed to xegaRun

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

Table: Parameters of treatment BoolT5sgp5k passed to xegaRun (Part 3)

## The Production Table of Treatment BoolT5sgp5k of Experiment ExpE

| | LHS | RHS |
|---|---|---|
| 1 | <fe> | <f0> |
| 2 | <fe> | <f1>(<fe>) |
| 3 | <fe> | <f2>(<fe>,<fe>) |
| 4 | <f0> | D1 |
| 5 | <f0> | D2 |
| 6 | <f0> | D3 |
| 7 | <f0> | D4 |
| 8 | <f0> | D5 |
| 9 | <fe> | sPair<sympairs> |
| 10 | <sympairs> | (D1,D5) |
| 11 | <sympairs> | (NOT(D1),NOT(D5)) |
| 12 | <sympairs> | (D2,D4) |
| 13 | <sympairs> | (NOT(D2),NOT(D4)) |
| 14 | <f1> | NOT |
| 15 | <f2> | OR |

Table: The Production Table of Treatment BoolT5sgp5k of Experiment
ExpE (Part 1)

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Treatment BoolT5sgp5k

## The Production Table of Treatment BoolT5sgp5k of Experiment ExpE

|    | LHS    | RHS  |
|----|--------|------|
| 16 | <f2>   | AND  |

Table: The Production Table of Treatment BoolT5sgp5k of Experiment ExpE (Part 2)

## Treatment: BoolT5sgp5k

|    | Treatment  | Trials | Variable    | min    | mean   | sd     | max    |
|----|------------|--------|-------------|--------|--------|--------|--------|
| 36 | BoolT5sgp5k | 80    | Evaluations | 200.00 | 240.00 | 112.06 | 800.00 |
| 33 | BoolT5sgp5k | 80    | Fitness     | 0.00   | 0.00   | 0.00   | 0.00   |
| 35 | BoolT5sgp5k | 80    | Generations | 1.00   | 1.20   | 0.56   | 4.00   |
| 34 | BoolT5sgp5k | 80    | Seconds     | 0.25   | 0.34   | 0.09   | 0.74   |

Table: Treatment: BoolT5sgp5k

The Solution Table of Treatment BoolT5sgp5k of Experiment ExpE. Fit: 0. Unique Shortest Solutions: 33.

|   | Solution |
|---|----------|
| 1 | AND(sPair(D1, D5), sPair(D2, D4)) |

Table: The Solution Table of Treatment BoolT5sgp5k of Experiment ExpE. Fit: 0. Unique Shortest Solutions: 33.

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Treatment BoolT5sgp5k

# The Derivation Tree of a Solution of Treatment BoolT5sgp5k of Experiment ExpE

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C xega
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Treatment BoolT5sgp5k

# Plot of last xegaRun for Treatment BoolT5sgp5k of Experiment ExpE



**Minimize Population Fitness: 5–Symmetry Problem**

Generations
Treatment BoolT5sgp5k of Experiment ExpE
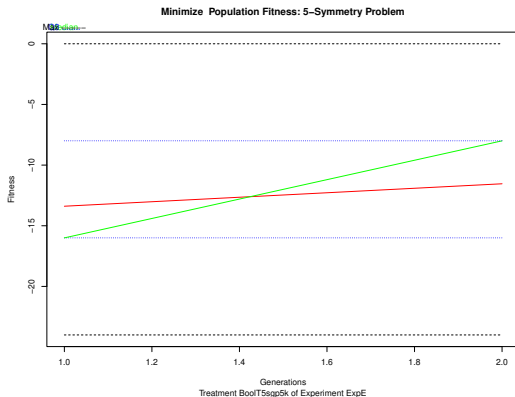
## Parameters of treatment: BoolT5sgp6k

|  | Parameter Values |
|---|---|
| tRNG | L'Ecuyer-CMRG Inversion Rejection |
| tReplay | 0 |
| experimentName | EE |
| treatmentName | BoolT5sgp6k |
| trials | 20 |
| everyK | 10 |
| outpath | data |
| batchPath | . |
| tVerbose | 1 |

Table: Parameters of treatment: BoolT5sgp6k

## Parameters of treatment BoolT5sgp6k passed to xegaRun

|  | Parameter Values |
| --- | --- |
| penv | 6-Symmetry Problem |
| grammar | /home/dj2333/dev/cran/kSymmetry/BNF/AndOrNotTuned5.txt |
| replay | 0 |
| algorithm | sgp |
| maxdepth | 7 |
| max | FALSE |
| worstFitness | -64 |
| popsize | 200 |
| generations | 500 |
| crossrate | 0.2 |
| mutrate | 0.4 |
| ivmutrate | Const |
| mutrate2 | 0.8 |
| ivcrossrate | Const |
| crossrate2 | 0.4 |

Table: Parameters of treatment BoolT5sgp6k passed to xegaRun (Part 1)

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Treatment BoolT5sgp6k

## Parameters of treatment BoolT5sgp6k 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 | 240 |
| codonPrecision | LCM |
| terminationEps | -0.1 |
| terminationCondition | AbsoluteError |
| evalmethod | Deterministic |

Table: Parameters of treatment BoolT5sgp6k passed to xegaRun (Part 2)

Design of Experiment
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Exploratory Analysis
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Treatment BoolT5sgp6k

# Parameters of treatment BoolT5sgp6k passed to xegaRun

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

Table: Parameters of treatment BoolT5sgp6k passed to xegaRun (Part 3)

## The Production Table of Treatment BoolT5sgp6k of Experiment ExpE

|    | LHS | RHS |
|----|-----|-----|
| 1  | <fe> | <f0> |
| 2  | <fe> | <f1>(<fe>) |
| 3  | <fe> | <f2>(<fe>,<fe>) |
| 4  | <f0> | D1 |
| 5  | <f0> | D2 |
| 6  | <f0> | D3 |
| 7  | <f0> | D4 |
| 8  | <f0> | D5 |
| 9  | <f0> | D6 |
| 10 | <fe> | sPair<sympairs> |
| 11 | <sympairs> | (D1,D6) |
| 12 | <sympairs> | (NOT(D1),NOT(D6)) |
| 13 | <sympairs> | (D2,D5) |
| 14 | <sympairs> | (NOT(D2),NOT(D5)) |
| 15 | <sympairs> | (D3,D4) |

Table: The Production Table of Treatment BoolT5sgp6k of Experiment ExpE (Part 1)

# The Production Table of Treatment BoolT5sgp6k of Experiment ExpE

|    | LHS | RHS |
|----|-----|-----|
| 16 | \<sympairs\> | (NOT(D3),NOT(D4)) |
| 17 | \<f1\> | NOT |
| 18 | \<f2\> | OR |
| 19 | \<f2\> | AND |

Table: The Production Table of Treatment BoolT5sgp6k of Experiment ExpE (Part 2)

Design of Experiment
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Treatment BoolT5sgp6k

## Treatment: BoolT5sgp6k

| | Treatment | Trials | Variable | min | mean | sd | max |
|---|---|---|---|---|---|---|---|
| 40 | BoolT5sgp6k | 80 | Evaluations | 200.00 | 1445.00 | 853.27 | 4600.00 |
| 37 | BoolT5sgp6k | 80 | Fitness | 0.00 | 0.00 | 0.00 | 0.00 |
| 39 | BoolT5sgp6k | 80 | Generations | 1.00 | 7.22 | 4.27 | 23.00 |
| 38 | BoolT5sgp6k | 80 | Seconds | 0.38 | 1.93 | 1.38 | 9.60 |

Table: Treatment: BoolT5sgp6k

Treatment BoolT5sgp6k

The Solution Table of Treatment BoolT5sgp6k of Experiment ExpE. Fit: 0. Unique Shortest Solutions: 75.

|   | Solution |
|---|----------|
| 1 | AND(sPair(D2, D5), AND(sPair(D1, D6), sPair(D3, D4))) |

Table: The Solution Table of Treatment BoolT5sgp6k of Experiment ExpE. Fit: 0. Unique Shortest Solutions: 75.

Design of Experiment
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Treatment BoolT5sgp6k

# The Derivation Tree of a Solution of Treatment BoolT5sgp6k of Experiment ExpE

Design of Experiment
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A Summary
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C xega
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Treatment BoolT5sgp6k

# Plot of last xegaRun for Treatment BoolT5sgp6k of Experiment ExpE
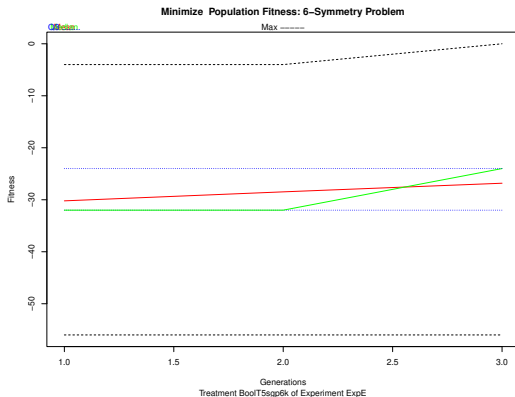


Minimize Population Fitness: 6–Symmetry Problem

Design of Experiment
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Exploratory Analysis
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A Summary
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B Treatments

C xega
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# All parameters of xegaRun of treatment BoolT4sgp2k

| | Parameter Values |
|---|---|
| penv | 2-Symmetry Problem |
| grammar | /home/dj2333/dev/cran/kSymmetry/BNF/AndOrNotTuned4.txt |
| max | FALSE |
| algorithm | sgp |
| popsize | 200 |
| generations | 500 |
| crossrate | 0.2 |
| mutrate | 0.4 |
| elitist | TRUE |
| replay | 0 |
| maxdepth | 7 |
| maxtrials | 5 |
| codons | 80 |
| codonBits | 0 |
| codonPrecision | LCM |

Table: All parameters of xegaRun of treatment BoolT4sgp2k (Part 1)

Design of Experiment
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Exploratory Analysis
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A Summary
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B Treatments

C xega
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## All parameters of xegaRun of treatment BoolT4sgp2k

|  | Parameter Values |
|---|---|
| maxPBias | 0.01 |
| evalmethod | Deterministic |
| evalrep | 1 |
| reportEvalErrors | TRUE |
| genemap | Bin2Dec |
| 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 BoolT4sgp2k (Part 2)

Design of Experiment
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Exploratory Analysis
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A Summary
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B Treatments

C xega
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## All parameters of xegaRun of treatment BoolT4sgp2k

| | 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 BoolT4sgp2k (Part 3)

## All parameters of xegaRun of treatment BoolT4sgp2k

| | 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 BoolT4sgp2k (Part 4)

Design of Experiment
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Exploratory Analysis
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A Summary
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B Treatments

C xega
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## All parameters of xegaRun of treatment BoolT4sgp2k

| | 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 | -4 |

Table: All parameters of xegaRun of treatment BoolT4sgp2k (Part 5)

Design of Experiment
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Exploratory Analysis
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A Summary
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B Treatments

C xega
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## All parameters of xegaRun of treatment BoolT4sgp2k

|  | 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 BoolT4sgp2k (Part 6)