

# CGP++ User Guide

## 1 Introduction

The user guide serves to give some specific details that can support the usage of **CGP++**. It therefore represent as supplementary and supporting element to the corresponding paper that introduces **GGP++** which is currently under peer-review.

Our repository on GitHub serves as the main resource for **CGP++**:  
<https://github.com/RomanKalkreuth/cgp-plusplus>

## 2 Requirements

Since **CGP++** uses modern techniques of **C++**, it has to be compiled with a version of **GCC** that supports the **C++17** standard.

We recommend compiling **CGP++** by using the **G++** compiler with the following command:  
`g++ -std=c++17 -O3`

## 3 Build

For Linux, a classical Unix **makefile** is provided in the build folder. The command **make all** can be used to create the executable.

For building **CGP++** on Windows, we recommend, considering popular choices such as **Mingw-w64**<sup>1</sup>, **MSVC**<sup>2</sup> or **VSCode**<sup>3</sup>.

On MacOS, the use of **clang**<sup>4</sup> in combination with **VSCode**<sup>5</sup> can be considered as an alternative to using **G++**.

## 4 Configuration

The compiled executable can be used with the parameter file in the **data/parfile** folder and the following command line options. The files are located in the **data/** folder. The data

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<sup>1</sup><https://www.mingw-w64.org/>

<sup>2</sup><https://visualstudio.microsoft.com/vs/features/cplusplus/>

<sup>3</sup><https://code.visualstudio.com/docs/languages/cpp>

<sup>4</sup><https://clang.llvm.org/>

<sup>5</sup><https://code.visualstudio.com/docs/setup/mac>

and parameter file are passed to CGP via command line. Optionally, a checkpoint file can be passed to CGP this way. The CGP and run-specific options can be the passed to CGP via the command line and parameter file configuration. Listing 1 shows the command line configuration and Listing 7 in the appendix gives an overview over the parameterization via parameter file.

```
usage: DATAFILE PARFILE CHECKPOINTFILE <options>

-a - search algorithm: 0 = one-plus-lambda; 1 = mu-plus-lambda
-n - number of function nodes
-v - number of variables
-z - number of constants
-i - number of inputs
-o - number of outputs
-f - number of functions
-r - maximum arity
-p - mutation rate
-c - crossover rate
-m - number of parents (mu)
-l - number of offspring (lambda)
-e - maximal number of fitness evaluations
-g - goal (ideal) fitness
-j - number of jobs
-s - global seed
-l - duplication rate
-2 - max duplication depth
-3 - inversion rate
-4 - max inversion depth
```

Listing 1: Parameters that can be configured via the command line

## 5 Datafiles

Datafiles that describe the input-output matching are used to represent training and test datasets for experiments with black-box problems. Currently CGP++ supports `.plu` and `.dat` files. For problems in the logic synthesis domain, truth tables are compressed format and stored in `.plu` files that have been commonly used in the past for this purpose. For symbolic regression benchmarks, we provide `.dat` files that describe the input-output matching of the training or test data. An example of a `.dat` file that represent the objective function of the Koza1 benchmark is shown in 2.

```
.i 1
.o 1
.p 20
0.571965 1.19325
0.198192 0.2468
0.332413 0.491852
-0.630832 -0.325559
-0.89878 -0.164464
0.970743 3.71587
0.894716 3.05229
0.147635 0.173123
-0.445633 -0.296104
-0.664529 -0.321376
-0.425338 -0.288645
0.522597 1.01302
0.442076 0.762097
-0.659558 -0.32222
0.0462336 0.0484745
-0.0465327 -0.0444635
-0.172244 -0.146806
-0.781772 -0.274873
0.151308 0.178191
0.393863 0.634155
.e
```

Listing 2: Example of a checkpoint file.

## 6 Constants

CGP++ supports the generation and usage of ephemeral random constants (ERC). The number of constants can be specified via the `num_constants` parameter and the type of the ERC can be configured via the `constant_type` setting.

## 7 Concurrency

CGP++ supports evaluation concurrency that can be enabled by defining the `num_eval_threads` setting in the parameter file. Breeding concurrency is a planned feature.

## 8 Checkpointing

The generation of checkpoints can be enabled/disabled via the `checkpointing` setting. The checkpoint interval is defined with the `checkpoint_modulo` parameter. The checkpoints are stored in the `data_checkpoints` folder. A new folder with a unique (timestamp) name will be created for the experiment. An example of an checkpoint is provided in Listing 3.

```
generation_number 50
global_seed 1706766371186480657
genome 1,0,1,2,0,2,2,3,1,0,4,3,2,1,2,0,5,2,1,0,0,0,8,4,0,7,1,0,7,3,3
genome 1,0,1,2,0,2,2,3,1,2,4,3,2,1,2,0,5,2,1,0,5,0,8,4,0,7,1,0,7,3,3
genome 1,0,1,2,0,2,2,3,1,0,4,3,2,2,1,0,1,2,1,0,0,0,8,4,0,7,1,0,7,3,3
genome 1,0,1,2,0,2,2,0,1,0,4,3,2,2,1,0,1,2,1,0,0,0,8,4,0,7,1,0,7,1,3
genome 1,0,1,2,0,2,2,3,1,0,4,3,2,2,3,0,1,2,1,0,0,0,8,4,0,7,1,0,7,3,3
constant -0.74118
```

Listing 3: Example of a checkpoint file.

## 9 Example Runs

### 9.1 Logic Synthesis

The following call to CGP++ triggers a run with a simple 1-Bit adder benchmark by using a 1+1-ES as search algorithm and a simple CGP with 10 function nodes and point mutation:

```
./cgp data/plufiles/add1c.plu data/parfiles/cgp.params -a 0 -b 10 -n 10 -v 1 -z 0 -o 1 -f 4 -r
2 -m 1 -l 1 -p 0.1 -c 0.0 -e 1000000 -j 10 -g 0
```

### 9.2 Symbolic Regression

The following call triggers a run with the simple Koza1 benchmark (quartic polynomial) by using a 4+16-ES as search algorithm and discrete recombination:

```
./cgp data/datfiles/koza1.dat data/parfiles/cgp.params -a 1 -b 10 -n 10 -v 1 -z 0 -o 1 -f 4 -r
2 -m 4 -l 16 -p 0.1 -c 0.5 -e 10000000 -j 10 -g 0.01
```

## 10 Program Output

The overview of the configuration of the parameters can be printed by enabling the `print_configuration` in the parameter file. Generational output inside of a run can be activated/deactivated by

setting `report_during_job`. The report interval can be configured via the `report_interval` setting. Metrics of the respective instances such as number of fitness evaluations, best fitness and runtime can be printed by activating the `report_during_job` setting. Listing 4 shows the output of the CGP++ configuration, Listing 5 the generational output inside of a job and Listing 6 the output of metrics for respective jobs.

```

CGP++ CONFIGURATION
-----
Number of function nodes: 10
Levels back: 10

Number of functions: 4
Maximum arity: 2

Number of variables: 1
Number of constants: 1

Number of inputs: 2
Number of outputs: 1

Crossover rate: 0.5
Mutation rate: 0.1

Number of parents (mu): 4
Number of offspring (lambda): 8

Ideal fitness value: 0.01

Number of jobs: 100
Maximum number of fitness evaluations: 1000000000
Maximum number of generations: 125000000

Global seed: 1707214445176910306

Functions: [1] ADD [2] SUB [3] MUL [4] DIV
Constants: [1] -0.416173

Recombination: Discrete Crossover
Mutation: [1] Probabilistic Point [2] Inversion
[3] Duplication

Algorithm: mu-plus-lambda
-----

```

Listing 4: Output of the CGP++ configuration

```

Generation # 10 :: Best Fitness: 11.2734
Generation # 20 :: Best Fitness: 11.2734
Generation # 30 :: Best Fitness: 11.2734
Generation # 40 :: Best Fitness: 4.51127
Generation # 50 :: Best Fitness: 4.51127
Generation # 60 :: Best Fitness: 4.51127
Generation # 70 :: Best Fitness: 4.34047
Generation # 80 :: Best Fitness: 3.42921
Generation # 90 :: Best Fitness: 2.56594
Ideal fitness has been reached in generation # 94

```

Listing 5: Generational output inside of a run.

```

Job # 1 :: Evaluations: 1980264 :: Best Fitness: 2.08206e-05 :: Runtime (s): 40.5062
Job # 2 :: Evaluations: 167528 :: Best Fitness: 2.11298e-05 :: Runtime (s): 2.47478
Job # 3 :: Evaluations: 113000 :: Best Fitness: 2.10702e-05 :: Runtime (s): 2.098
Job # 4 :: Evaluations: 49800 :: Best Fitness: 2.11298e-05 :: Runtime (s): 0.590241
Job # 5 :: Evaluations: 8832 :: Best Fitness: 2.08057e-05 :: Runtime (s): 0.128364

```

Listing 6: Output of metrics for respective jobs.

## 11 Python Binding

A this time, we do not provide bindings for python. However, a gentle tutorial to create own Python bindings can be found here: <https://nwcpp.org/Aug-2021.html>

## A Appendix

algorithm	- 0 = one-plus-lambda, 1 = mu-plus-lambda
levels_back	- type: integer
num_jobs	- type: integer
num_function_nodes	- type: integer
num_variables	- type: integer
num_constants	- type: integer
constant_type	- 0 = Koza
num_outputs	- type: integer
num_functions	- type: integer
max_arity	- type: integer
num_parents	- type: integer
num_offspring	- type: integer
max_fitness_evaluations	- type: integer
ideal_fitness	- type: generic
minimizing_fitness	- 0 = false, 1 = true
crossover_type	- 0 = block, 1 = discrete
crossover_rate	- type: float, range: [0.0, 1.0]
probabilistic_point_mutation	- 0 = deactivated, 1 = activated
single_active_gene_mutation	- 0 = deactivated, 1 = activated
inversion_mutation	- 0 = deactivated, 1 = activated
duplication_mutation	- 0 = deactivated, 1 = activated
point_mutation_rate	- type: float, range: [0.0, 1.0]
duplication_rate	- type: float, range: [0.0, 1.0]
inversion_rate	- type: float, range: [0.0, 1.0]
max_duplication_depth	- type: integer
max_inversion_depth	- type: integer
neutral_genetic_drift	- 0 = deactivated, 1 = activated
simple_report_type	- 0 = deactivated, 1 = activated
print_configuration	- 0 = deactivated, 1 = activated
evaluate_expression	- 0 = deactivated, 1 = activated
num_eval_threads	- type: integer
generate_random_seed	- 0 = deactivated, 1 = activated
global_seed	- type: long long
report_during_job	- 0 = deactivated, 1 = activated
report_after_job	- 0 = deactivated, 1 = activated
report_simple	- 0 = deactivated, 1 = activated
report_interval	- 0 = deactivated, 1 = activated
checkpointing	- 0 = deactivated, 1 = activated
checkpoint_modulo	- type: integer
write_statfile	- 0 = deactivated, 1 = activated

Listing 7: Parameters that can be configured in the paramter file