

The CEFHALIC PRNG Package

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1 Overview

- The CEFHALIC PRNG Package is a set of high-performance Pseudo-Random Number Generators for FPGAs.
- The firmware is implemented in VHDL-2008 for maximum portability.
- The firmware has been tested in simulation using [MENTOR/SIEMENS ModelSim SE-64 2019.2](#) and tested for implementation in [Xilinx Vivado 2020.2](#).
- Software emulations of the firmware is provided, implemented in C++-11, and a Makefile is provided for compiling the software with GCC.
- The Makefile includes automated installation of the [TestU01](#), [PractRand](#) and [GJrand](#) random-number test-suites.
- The software includes executables for testing the software emulations with TestU01 and PractRand.
- In simulation, the firmware includes debugging output for testing with PractRand, or with TestU01 via the included executable.

2 Getting the code

The Cefhalic PRNG package is hosted on GitHub. To checkout anonymously via git, use

```
1 git clone git@github.com:Cefhalic/PRNG.git
```

To simply download a plain copy of the code, [a zip-file is also available](#).

3 Firmware interfaces

3.1 Xoshiro256**

The firmware implements the functional code as VHDL procedures for maximum code reuse, and which could be used directly within the user's processes. The primary interface for most user, however, will be through the VHDL entity:

```
1 ENTITY Xoshiro256starstar IS
2   GENERIC( Seed : tArray( 0 TO 3 ) := ( ... );
3           Debugging : BOOLEAN := FALSE );
4   PORT( Clk : IN STD_LOGIC ;
5         Data : OUT tData ;
6         Pull : IN BOOLEAN := TRUE;
7         Reset : IN BOOLEAN := FALSE;
8         ResetVal : IN tArray( 0 TO 3 ) := Seed
9         );
10 END Xoshiro256starstar;
```

Where the generics are

- **Seed** - The default value to which the state is reset if the 'ResetVal' port interface is not instantiated
- **Debugging** - Used in simulation to write the values to a file or pipe

It should be noted that both generics have default values and may be safely omitted if not required.

The ports are

- **Clk** - The algorithm clock
- **Data** - The pseudo-random number output
- **Pull** - Used to indicate that a new PRN should be emitted on the next clock-cycle
- **Reset** - Used to reset the state of the generator and scrambler
- **ResetVal** - The value to which the state should be reset

It should be noted that 'Pull', 'Reset' and 'ResetVal' have default values and may be safely omitted if not required.

The types ‘tData’ and ‘tArray’ are defined in the package ‘PkgPRNG’ and can be included using the VHDL

```
1 USE WORK.PkgPRNG64.ALL;
```

Example usage can be found in the file ‘Testbench.vhd’, an excerpt of which is shown here:

```
1 Instance0 : ENTITY WORK.Xoshiro256starstar
2 PORT MAP( Clk => Clk , Data => Data_With_Pull_And_Reset ,
3           Pull => PullInt , Reset => ResetInt );
4 Instance1 : ENTITY WORK.Xoshiro256starstar
5 PORT MAP( Clk => Clk , Data => Data_With_Pull_No_Reset ,
6           Pull => PullInt );
7 Instance2 : ENTITY WORK.Xoshiro256starstar
8 PORT MAP( Clk => Clk , Data => Data_No_Pull_With_Reset ,
9           Reset => ResetInt );
10 Instance3 : ENTITY WORK.Xoshiro256starstar
11 PORT MAP( Clk => Clk , Data => Data_No_Pull_No_Reset );
```

It should be noted that due to pipelining, the first three values emitted after a reset are 0. The behaviours of these four instances can be seen in figure 1.

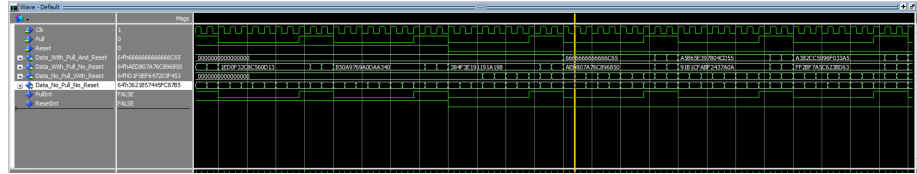


Figure 1: Waveform outputs from four example instantiations. From bottom to top: Data_No.Pull.No.Reset produces a new output on every clock; Data_No.Pull.With.Reset produces a new output on every clock, three clock-cycles after the reset line goes low; Data.With.Pull.No.Reset produces a new output on any clock-cycle after the ‘Pull’ input is high; and Data.With.Pull.And.Reset produces a new output on any clock-cycle after the ‘Pull’ input is high, three ‘Pulls’ after the reset line goes low.

3.2 Xoshiro256float

...

4 Testing

4.1 Testing software emulators

To compile the software, in the software directory, from the commandline execute

```
1 make
```

To test the emulated xoshiro256** generator with TestU01, run

```
1 ./test_bits.exe --suite 0 --bits 0
```

Where the arguments are

- **suite** - The test-suite to use: 0=SmallCrush, 1=Crush, 2=BigCrush
- **bits** - The bits to test with TestU01: 0=Low-32, 1=High-32, 2=Low-32 reversed, 3=High-32 reversed

To test the emulated xoshiro256** generator with PractRand, run

```
1 ./test_bits.exe --suite 3 | ./PractRand/RNG_test.exe stdin64
```

PractRand runs indefinitely until the user halts execution.

4.2 Testing all software emulators on a batch-system

A bash-script is included for launching all permutations of the TestU01 suite and PractRand suite on a batch-system via the Sun grid engine, that is a batch system using 'qsub'. This is experimental code and meant as illustrative only, as local queue limits and policies may affect the behaviour on your system. From the software directory, simply execute

```
1 ./run_tests.sh
```

4.3 Testing firmware with Modelsim GUI

To run the Xoshiro256** testbench in Modelsim with the GUI, use the following invocation from the Linux or Microsoft Windows commandline within the firmware directory:

```
1 vsim -i -nolog -do modelsim-gui.tcl
```

This invocation was used to produce the output seen in figure 1.

4.4 Testing firmware with Modelsim and either PractRand or TestU01

To test the Xoshiro256** firmware implementation using either TestU01 or PractRand, the firmware includes 'debugging' output which opens and appends the binary data to an operating-system 'file' called 'NamedPipe' located in the firmware directory. On operating systems which do not support FIFO files, 'NamedPipe' is simply a binary file. On other operating systems, 'NamedPipe' should be created as a FIFO, so that Modelsim dumps data into one end of the Fifo, and the output of the FIFO be streamed into PractRand or the TestU01 test-executable.

To create a fifo, in a BASH environment, in the firmware directory:

```
1 mkfifo NamedPipe
```

A modelsim tcl script is provided to run the Xoshiro256** indefinitely, dumping PRNs in binary format to 'file', without visual wave output. This can, in

principle, be run in batch mode, but newer versions of Modelsim appear to suffer from a malloc issues when run without the GUI, so we run vsim interactively:

```
1 vsim -i -nolog -do modelsim.tcl &
```

If ‘NamedPipe’ exists and is a FIFO, rather than a regular file, Modelsim will pause until a consumer is bound to the FIFO.

If you want to validate that Modelsim is running and writing to the FIFO, it can be convenient to use hexdump:

```
1 hexdump < ./NamedPipe
```

To test the firmware with TestU01, from the software directory run

```
1 ./test_stdin.exe --suite 0 --bits 0 < ../firmware/NamedPipe
```

where the commandline options are the same as those for testing the C++ emulation.

To test the firmware with PractRand, from the software directory run

```
1 ./PractRand/RNG_test.exe stdin64 < ../firmware/NamedPipe
```

PractRand runs indefinitely until the user halts execution.

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```
<one line to give the program's name and a brief idea of what it does.>
Copyright (C) <textyear> <name of author>
This program is free software: you can redistribute it and/or modify it
under the terms of the GNU General Public License as published by the
Free Software Foundation, either version 3 of the License, or
(at your option) any later version.
This program is distributed in the hope that it will be useful, but
WITHOUT ANY WARRANTY; without even the implied warranty of MERCHANTABILITY
or FITNESS FOR A PARTICULAR PURPOSE.
See the GNU General Public License for more details.
You should have received a copy of the GNU General Public License
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```

Also add information on how to contact you by electronic and paper mail. If the program does terminal interaction, make it output a short notice like this when it starts in an interactive mode:

```
<program> Copyright (C) <year> <name of author>
This program comes with ABSOLUTELY NO WARRANTY; for details type 'show w'.
This is free software, and you are welcome to redistribute it under certain conditions;
type 'show c' for details.
```

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