Open-Source tools for FPGA development

Marek Vašut <marex@denx.de>

October 13, 2016

Marek Vasut

- Software engineer at DENX S.E. since 2011
  - Embedded and Real-Time Systems Services, Linux kernel and driver development, U-Boot development, consulting, training
- Versatile Linux kernel hacker
- Custodian at U-Boot bootloader
- oe-core contributor

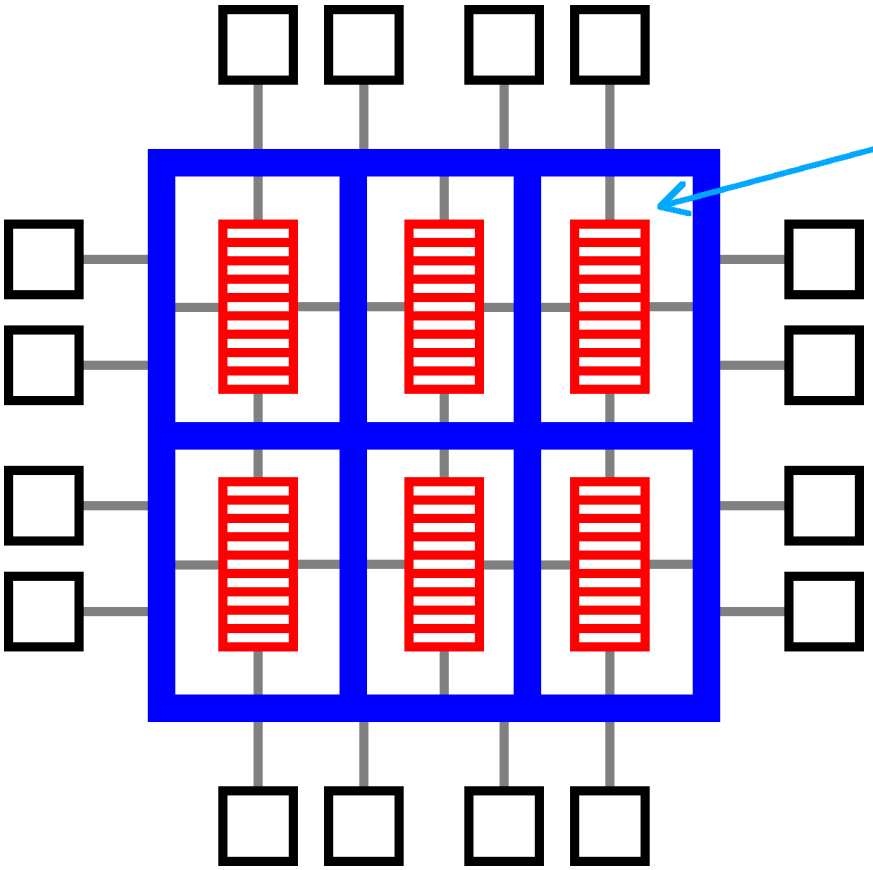
Structure of the talk

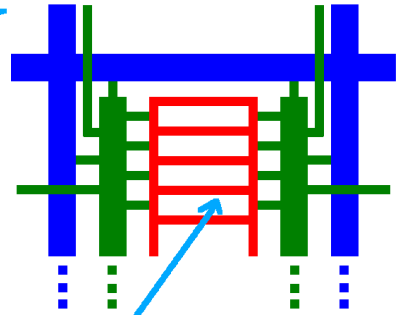
- Introduction to FPGA technology
- Compiling the FPGA content, from HDL to bitstream:
  - Analysis and Synthesis tools
  - Place and Route tools
  - Assembler tools
  - Simulation/Visualisation tools
- Demonstration
- Why are open-source FPGA tools hard?

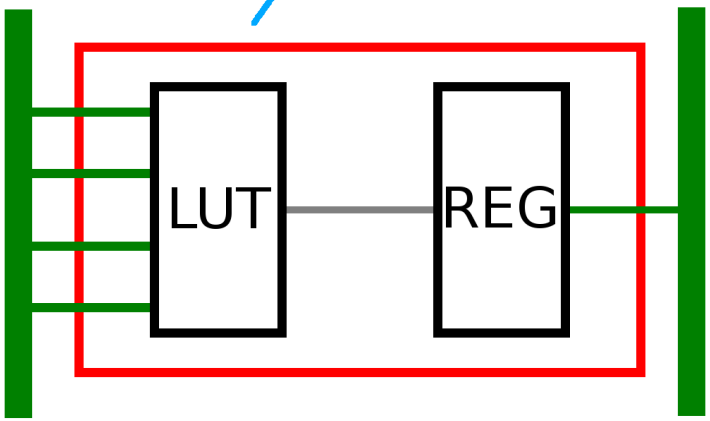
FPGA

- Field Programmable Gate Array
- High-Speed Programmable logic
- Plenty of I/O options
- Extremely parallel architecture
- Usually used for:
  - Digital Signal Processing (DSP)
  - Parallel data processing
  - Custom hardware interfaces
  - ASIC prototyping
  - ...
- Common vendors – Xilinx, Altera, Lattice, Microsemi...

Internal structure







BLUE Global interconnect

GREEN Local interconnect

RED Logic element

Programming the FPGA

- Each vendor has his own set of tools:
  Altera Quartus, Xilinx Vivado/ISE, Lattice Diamond, ...
- Tools are generally closed source
- Flow is very similar between tools:

Analysis and Synthesis	HDL $\rightarrow$ Netlist
Pack, Place and Route	Netlist $\rightarrow$ Technology
Assembler	Technology $\rightarrow$ Bitstream
Timing Analysis	Analyze design timing Check timing constraints
Simulation and Visualisation	Simulate and analyze the design on the host

Analysis and Synthesis

- HDL $\rightarrow$ Netlist
- Behavioral model $\rightarrow$ Circuit schematic
- Analysis – Parsing of HDLs, validation, ...
- Synthesis – Parsed HDL to Netlist
- Tools:
  - Icarus Verilog
  - Odin II
  - Yosys

Icarus Verilog

- HDL simulation/translation/synthesis tool
- GPL license (with plugin exception)
- Plugin support
- Input:
  - Verilog 2005
    - Mostly supported
    - Widely used
    - Active development
  - System Verilog – Similar level of support as Verilog 2005
  - VHDL – Limited support
- Output:
  - VVP – Intermediate language used for simulation
  - Verilog – Minimization/Simplification
  - VHDL – Translation
  - Gate-level netlist – dropped in 0.9.1
- Website: `http://iverilog.icarus.com/`

Odin II

- HDL synthesis framework with visualisation support
- MIT license
- Input:
  - Verilog
  - BLIF netlist – from downstream stages
- Output: BLIF Netlist
  - Works directly with VPR
  - Usable for both FPGA and ASIC synthesis
- Links:
  - Website: `https://code.google.com/archive/p/odin-ii/`
  - Git: `https://github.com/verilog-to-routing/vtr-verilog-to-routing/tree/master/ODIN_II`

Berkeley abc

- Logic optimization/minimization
- Often coupled with synthesis tool
- Input: BLIF netlist
- Output: BLIF netlist

Yosys

- HDL synthesis suite
- ISC license
- Input:
  - Verilog 2005
  - BLIF netlist
- Output:
  - Simplified Verilog
  - BLIF/EDIF/... netlist
- Built-in logic optimization/minimization using abc
- Supports mapping (overlaps with PnR):
  - ASIC cell libraries
  - Xilinx 7-series FPGAs
  - Lattice iCE40 FPGAs
- Website: `http://www.clifford.at/yosys/`

Place and Route

- Netlist $\rightarrow$ Technology-mapped netlist
- Consists of multiple sub-steps:
  - Pack – Clump netlist elements into larger blocks
  - Place – Place the blocks in the FPGA
  - Route – Route the interconnect between blocks
- Tools:
  - Arachne PnR
  - VPR

Arachne PnR

- Place and Route tool specific to iCE40 FPGA
- Works specifically with Yosys
- Input:
  - Technology mapped netlist from Yosys
- Output:
  - Textual representation of bitstream
- Website: `https://github.com/cseed/arachne-pnr`

VPR

- Versatile Placement and Routing
- Pack, Place, Route tool
- Now part of VtR (Verilog to Routing)
- Extremely flexible
- Works with any reasonable FPGA technology
- Used extensively in FPGA research
- Also works well with commercial FPGA tools
- Website:
  `http://www.eecg.toronto.edu/~vaughn/vpr/vpr.html`

Assembler

- Placed/Routed netlist $\rightarrow$ Bitstream
- Technology is often undocumented "family gold"
- This step has the least amount of tools
- Tools:
  - IcePack

IcePack

- Open-Source assembler for iCE40 FPGA
- Part of the IceStorm project
- Textual representation of bitstream → binary bitstream
- Website: `http://www.clifford.at/icestorm/`

Whole design flows

- Aforementioned tools can be assembled into complete flows
- Flows which take HDL and produce bitstream:
  - IceStorm

IceStorm

- Verilog to Bitstream flow
- Specific to Lattice iCE40 FPGA
- Tools:
  - Yosys – Analysis and Synthesis
  - Arachne PnR – Place and Route
  - IcePack – Bitstream generation
- Additional tools:
  - IceProg – Programming of the FPGA
  - IceTime – Timing analysis
- Website: `http://www.clifford.at/icestorm/`

IceStorm demo part 1

Example of using IceStorm, Gray counter, Top module

```
1  module top (
2          input hwclk,
3          output led1,
4          output led2,
5          output led3,
6          output led4,
7          output led5,
8          output led6,
9          output led7,
10         output led8
11 );
```

Example of using IceStorm, Gray counter, Top module

```
1  /* Counter register */
2  reg [7:0] count = 8'b0;
3  /* Grey counter implementation */
4  assign led1 = count[0] ^ count[1];
5  assign led2 = count[1] ^ count[2];
6  assign led3 = count[2] ^ count[3];
7  assign led4 = count[3] ^ count[4];
8  assign led5 = count[4] ^ count[5];
9  assign led6 = count[5] ^ count[6];
10 assign led7 = count[6] ^ count[7];
11 assign led8 = count[7];
12 /* Increment counter */
13 always @(posedge hwclk)
14     count <= count + 1;
15 endmodule
```

Example of using IceStorm, Gray counter, Pin map

```
1 set_io --warn-no-port led1 B5
2 set_io --warn-no-port led2 B4
3 set_io --warn-no-port led3 A2
4 set_io --warn-no-port led4 A1
5 set_io --warn-no-port led5 C5
6 set_io --warn-no-port led6 C4
7 set_io --warn-no-port led7 B3
8 set_io --warn-no-port led8 C3
9 set_io --warn-no-port hwclk J3
```

IceStorm demo part 4

Example of using IceStorm, Building and Programming

```
$ yosys -p "synth_ice40 -top top -blif top.blif" top.v
$ arachne-pnr -d 8k -P ct256 \
              -o top.txt -p pinmap.pcf top.blif
$ icepack top.txt top.bin
$ iceprog top.bin
```

Simulation and Visualisation

- HDL is simulated on the development host
- Allows applying triggers and constraints
- Tools:
  - gHDL
  - Icarus Verilog
  - Verilator

gHDL

- VHDL simulator
- Compiles VHDL into native code
- Uses GCC/LLVM/built-in backend for code generation
- Faster than interpreted simulator
- Output:
  - VCD (Value Change Dump) – Verilog oriented
  - gHDL waveform – Native format fit for VHDL
- Website: `http://ghdl.free.fr/`

Verilator

- Synthesis from Verilog to C++
- Verilator does perform optimization during synthesis
- Supported input:
  - Verilog
  - Verilog 2005 – Subset is supported
  - System Verilog – Subset is supported
- Website: `http://www.veripool.org/wiki/verilator`

Icarus Verilog

- Primarily a simulator/translator
- HDL is compiled to intermediate VVP code
- The `vvp` tool is used as VVP interpreter
- Extremely useful for writing testbenches
- Visualisation output: GTKWave
- Website: `http://iverilog.icarus.com/`

Icarus Verilog Demo part 1

Example of using iVerilog, Gray counter, Testbench

```
1  module top_tb ();
2
3  reg clk;
4  wire led1;
5  wire led2;
6  wire led3;
7  wire led4;
8  wire led5;
9  wire led6;
10 wire led7;
11 wire led8;
```

Example of using iVerilog, Gray counter, Testbench

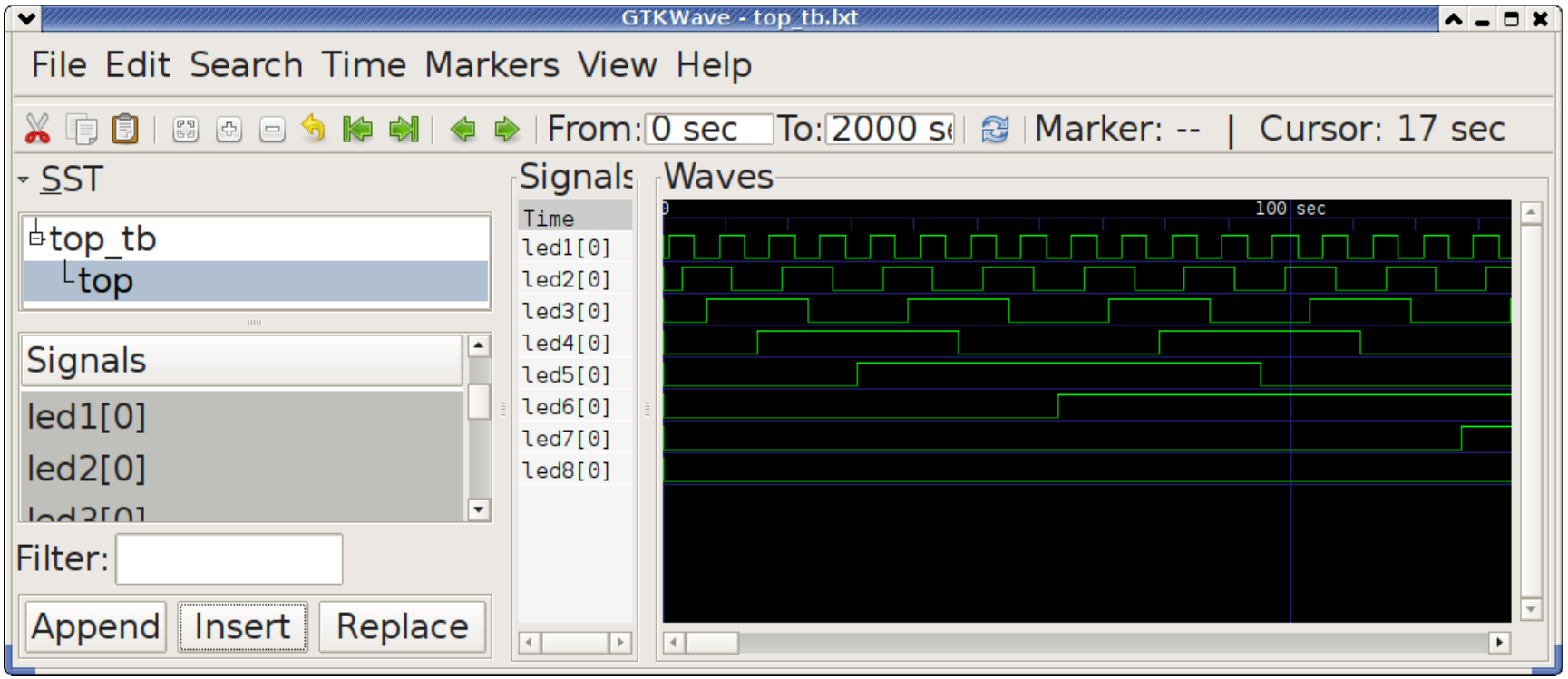
```
1  top top (
2          .hwclk(clk),
3          .led1(led1),
4          .led2(led2),
5          .led3(led3),
6          .led4(led4),
7          .led5(led5),
8          .led6(led6),
9          .led7(led7),
10         .led8(led8)
11 );
```

Example of using iVerilog, Gray counter, Testbench

```
1  initial begin
2          $dumpfile("top_tb.lxt");
3          $dumpvars(0, top);
4          clk = 1'b0;
5          repeat(1000) begin
6                  #1 clk = ~clk;
7                  #1 clk = ~clk;
8          end
9  end
10
11 endmodule
```

Example of using iVerilog, Gray counter, Performing the test:

```
1 iverilog -o top.vvp top_tb.v top.v
2 vvp top.vvp -lxt2
3 gtkwave top_tb.lxt
```



GTKWave

- Visualisation tool
- Supports many formats – VCD, LXT, FST, ...
- Works well with gHDL, Icarus Verilog ...
- Website: `http://gtkwave.sourceforge.net/`

Why are open-source FPGA tools hard?

- Lack of documentation
- Fear of releasing proprietary algorithms
- Pushback from IP vendors

DeBit

- Attempt to document Altera and Xilinx FPGAs
- Appears inactive
- Textual documentation mostly missing
- Lots of cryptic C code
- Supports only old FPGAs
- Allows dumping bitstream of specific parts

Thank you for your attention!

Contact: Marek Vasut <marex@denx.de>