



Gisselquist  
Technology, LLC

## 1. Wires

Daniel E. Gisselquist, Ph.D.





# Lesson Overview



## ▷ Lesson Overview

First design  
Schematic  
Schematic  
Constraints  
PCF  
Build the design  
First Success!  
Simulation  
Verilator Driver  
Bus Signals  
Bit Select  
Internal Signals  
Schematic  
Circular Logic  
Dual Assignment  
Sim Result  
Examples  
Examples  
Exercise  
Conclusion

- What is a **wire**?
- What can I do with it?
- How do I build a design?

## Objectives

- To get an initial, basic familiarization with combinational logic
- To learn how to run the tools to build a design
- To get an initial design running on an FPGA board



# First design



Lesson Overview

▷ First design

Schematic

Schematic

Constraints

PCF

Build the design

First Success!

Simulation

Verilator Driver

Bus Signals

Bit Select

Internal Signals

Schematic

Circular Logic

Dual Assignment

Sim Result

Examples

Examples

Exercise

Conclusion

Let's build a simple Verilog design

```
module thruwire(i_sw, o_led);  
    input wire i_sw;  
    output wire o_led;  
  
    assign o_led = i_sw;  
endmodule
```



# First design



Let's build a simple Verilog design

```
module thruwire(i_sw, o_led);  
    input    wire    i_sw;  
    output   wire    o_led;  
  
    assign   o_led = i_sw;  
endmodule
```

- Verilog files contain modules
- This module is named thruwire
- While Verilog allows more than one module per file, I recommend only one module per file.

Lesson Overview

▷ First design

Schematic

Schematic

Constraints

PCF

Build the design

First Success!

Simulation

Verilator Driver

Bus Signals

Bit Select

Internal Signals

Schematic

Circular Logic

Dual Assignment

Sim Result

Examples

Examples

Exercise

Conclusion



# First design



Lesson Overview

▷ First design

Schematic

Schematic

Constraints

PCF

Build the design

First Success!

Simulation

Verilator Driver

Bus Signals

Bit Select

Internal Signals

Schematic

Circular Logic

Dual Assignment

Sim Result

Examples

Examples

Exercise

Conclusion

Let's build a simple Verilog design

```
module thruwire(i_sw, o_led);  
    input    wire    i_sw;  
    output   wire    o_led;  
  
    assign   o_led = i_sw;  
endmodule
```

- The **module** keyword marks the beginning
- **endmodule** marks the end of the module



# First design



Let's build a simple Verilog design

```
module thruwire(i_sw, o_led);  
    input wire i_sw;  
    output wire o_led;  
  
    assign o_led = i_sw;  
endmodule
```

- This module declare two ports, `i_sw` and `o_led`
- The first is declared to be an **input**
- The second an **output**
- Both are **wire**'s, but we'll get to that later

Lesson Overview

▷ First design

Schematic

Schematic

Constraints

PCF

Build the design

First Success!

Simulation

Verilator Driver

Bus Signals

Bit Select

Internal Signals

Schematic

Circular Logic

Dual Assignment

Sim Result

Examples

Examples

Exercise

Conclusion



# First design



Lesson Overview

▷ First design

Schematic

Schematic

Constraints

PCF

Build the design

First Success!

Simulation

Verilator Driver

Bus Signals

Bit Select

Internal Signals

Schematic

Circular Logic

Dual Assignment

Sim Result

Examples

Examples

Exercise

Conclusion

Let's build a simple Verilog design

```
module thruwire(i_sw, o_led);  
    input    wire    i_sw;  
    output   wire    o_led;  
  
    assign o_led = i_sw;  
  
endmodule
```

- Our one piece of logic sets o\_led to be the same as i\_sw



# First design



Lesson Overview

▷ First design

Schematic

Schematic

Constraints

PCF

Build the design

First Success!

Simulation

Verilator Driver

Bus Signals

Bit Select

Internal Signals

Schematic

Circular Logic

Dual Assignment

Sim Result

Examples

Examples

Exercise

Conclusion

Let's build a simple Verilog design

```
module thruwire(i_sw, o_led);  
    input    wire    i_sw;  
    output   wire    o_led;  
  
    assign   o_led = i_sw;  
endmodule
```

FPGA's are commonly used as:

- Traffic cops  
A programmable/adjustable wire fabric
- Voltage level shifters
- This logic would be appropriate for each  
... it generates a simple "wire" through the chip

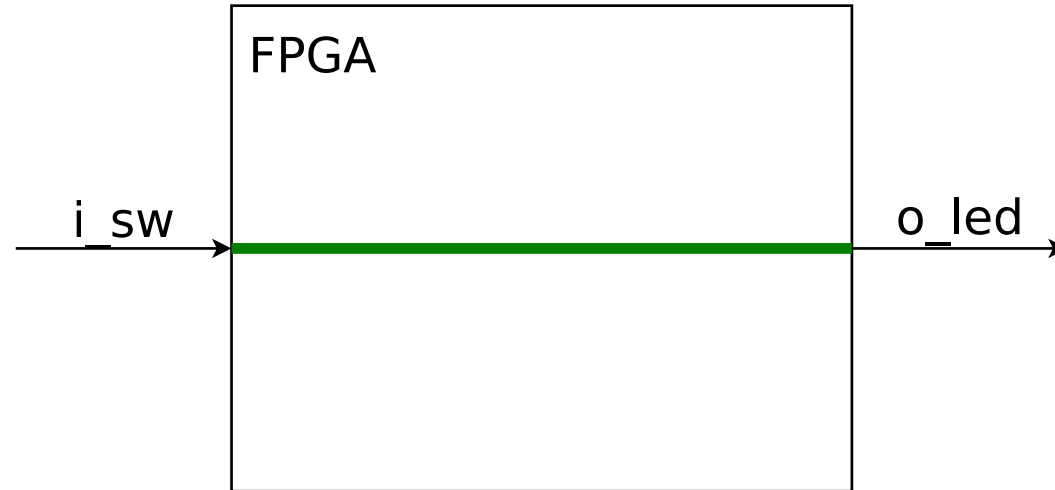




# Schematic



Here's what a schematic of this design would look like



All from this assign statement

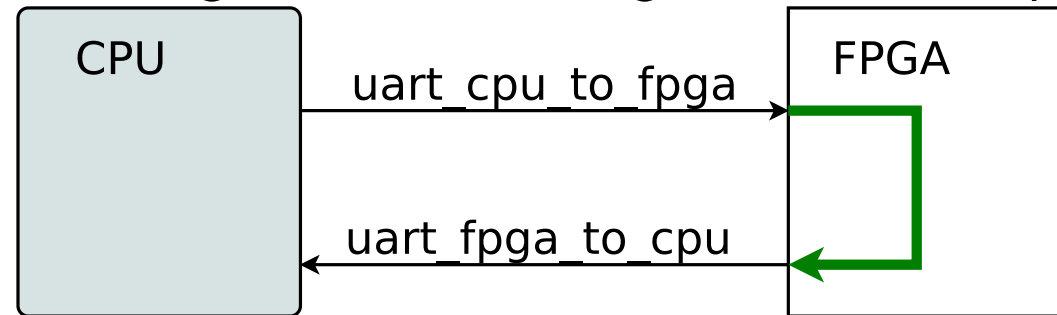
```
assign    o_led = i_sw;
```



# Schematic



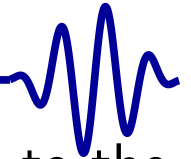
A very similar design would make a good first serial port test



- Your circuit board should pass this test before you try to implement your own serial port within it



# Constraints



Lesson Overview

First design

Schematic

Schematic

▷ Constraints

PCF

Build the design

First Success!

Simulation

Verilator Driver

Bus Signals

Bit Select

Internal Signals

Schematic

Circular Logic

Dual Assignment

Sim Result

Examples

Examples

Exercise

Conclusion

A fundamental part of any FPGA design maps your ports to the pins

- This is the purpose of a *Constraint File*
- Different vendors use different forms for their constraint files
  - PCF: Used by Arachne-PNR and NextPNR
  - UCF: Used by ISE for older Xilinx designs
  - XDC: Used by Vivado for newer Xilinx designs
  - QSF: Used by Quartus for ~~Altera~~ Intel chips
- Your board vendor should provide you with a master constraint file
- You'll still need to
  - Comment-out pins you aren't using
  - Rename pins to match your Verilog



# PCF File



Lesson Overview

First design

Schematic

Schematic

Constraints

▷ PCF

Build the design

First Success!

Simulation

Verilator Driver

Bus Signals

Bit Select

Internal Signals

Schematic

Circular Logic

Dual Assignment

Sim Result

Examples

Examples

Exercise

Conclusion

If you are using nextpnr, you'll need a PCF file

```
set_io    i_sw      P13
set_io    o_led     C8
```

- Maps top-level ports to pins
- You'll find P13 and C8 on the schematic
  - Find the FPGA pins connected to the switch  
... and the LED output
  - If your design has no switches, you can use buttons  
(for now)  
Buttons also bounce, but we'll get to that later



# UCF File



Lesson Overview

First design

Schematic

Schematic

Constraints

▷ PCF

Build the design

First Success!

Simulation

Verilator Driver

Bus Signals

Bit Select

Internal Signals

Schematic

Circular Logic

Dual Assignment

Sim Result

Examples

Examples

Exercise

Conclusion

If you are using ISE, you'll need a UCF file

```
NET "i_sw" LOC = "P9" | IOSTANDARD = LVCMOS33 ;  
NET "o_led" LOC = "N3" | IOSTANDARD = LVCMOS33 ;
```

- This would be for the older Xilinx FPGA's
  - Make sure you actually look up the correct pins
    - P13 for one board might be something else on another
- On this board, the switch is on pin P9
- Most development boards use the 3.3V LVCMOS standard
    - Pins are typically grouped in banks
    - All pins in a bank use the same voltage
    - This voltage is usually fixed
    - The master constraint file will help here



# XDC File



Lesson Overview

First design

Schematic

Schematic

Constraints

▷ PCF

Build the design

First Success!

Simulation

Verilator Driver

Bus Signals

Bit Select

Internal Signals

Schematic

Circular Logic

Dual Assignment

Sim Result

Examples

Examples

Exercise

Conclusion

If you are using Vivado, you'll need a XDC file

```
set_property -dict {PACKAGE_PIN E22
                    IOSTANDARD LVCMOS12} [get_ports {i_sw}]
set_property -dict {PACKAGE_PIN T14
                    IOSTANDARD LVCMOS25} [get_ports {o_led}]
```

- This would be for the newer Xilinx FPGA's
- Usually, the vendor will provide a "master XDC" file
- From there, you should be able to
  - Rename the appropriate ports to `i_sw` and `o_led`
  - Comment out every other I/O port



# Build the design



Lesson Overview

First design

Schematic

Schematic

Constraints

PCF

▷ Build the design

First Success!

Simulation

Verilator Driver

Bus Signals

Bit Select

Internal Signals

Schematic

Circular Logic

Dual Assignment

Sim Result

Examples

Examples

Exercise

Conclusion

For an iCE40 design, this will look like:

```
% yosys -p 'synth_ice40 -json thruwire.json' \  
    thruwire.v  
% nextpnr-ice40 --hx8k --package ct256 \  
    --pcf thruwire.pcf --json thruwire.json  
% icepack thruwire.asc thruwire.bin
```

You'll need to do this for every project—get used to this flow.

- A makefile can drastically simplify this process

You should now have a file `thruwire.bin` that you can load onto your board.

- If you aren't using an iCE40, follow your chip vendor's instructions



# First Success!



- Lesson Overview
- First design
- Schematic
- Schematic
- Constraints
- PCF
- Build the design
- ▷ First Success!
- Simulation
- Verilator Driver
- Bus Signals
- Bit Select
- Internal Signals
- Schematic
- Circular Logic
- Dual Assignment
- Sim Result
- Examples
- Examples
- Exercise
- Conclusion

Follow your board vendor's instructions for loading this file onto your board.

Notice now that every time you flip the switch, the LED responds





# First Success!



- Lesson Overview
- First design
- Schematic
- Schematic
- Constraints
- PCF
- Build the design
  - ▷ First Success!
- Simulation
- Verilator Driver
- Bus Signals
- Bit Select
- Internal Signals
- Schematic
- Circular Logic
- Dual Assignment
- Sim Result
- Examples
- Examples
- Exercise
- Conclusion

Follow your board vendor's instructions for loading this file onto your board.

Notice now that every time you flip the switch, the LED responds Yaaaayyyyyy!!! Your first FPGA design.



# Simulation



Lesson Overview

First design

Schematic

Schematic

Constraints

PCF

Build the design

First Success!

▷ Simulation

Verilator Driver

Bus Signals

Bit Select

Internal Signals

Schematic

Circular Logic

Dual Assignment

Sim Result

Examples

Examples

Exercise

Conclusion

Simulation is an important part of design

Simulation	Hardware
Can trace all signals	Can only see some signals
Extended tests cost GB	Extended tests are simple
Easy to debug	<i>Very hard</i> to debug

Because hardware is so hard to debug, simulation is vital

- A successful complex project  
... *requires simulation!*



# Simulation



Lesson Overview

First design

Schematic

Schematic

Constraints

PCF

Build the design

First Success!

▷ Simulation

Verilator Driver

Bus Signals

Bit Select

Internal Signals

Schematic

Circular Logic

Dual Assignment

Sim Result

Examples

Examples

Exercise

Conclusion

Simulation is an important part of design

Simulation	Hardware
Can trace all signals	Can only see some signals
Extended tests cost GB	Extended tests are simple
Easy to debug	<i>Very hard</i> to debug

Because hardware is so hard to debug, simulation is vital

- A successful complex project  
... *requires simulation!*

Do it the easy way:



# Simulation



Lesson Overview

First design

Schematic

Schematic

Constraints

PCF

Build the design

First Success!

▷ Simulation

Verilator Driver

Bus Signals

Bit Select

Internal Signals

Schematic

Circular Logic

Dual Assignment

Sim Result

Examples

Examples

Exercise

Conclusion

Simulation is an important part of design

Simulation	Hardware
Can trace all signals	Can only see some signals
Extended tests cost GB	Extended tests are simple
Easy to debug	<i>Very hard</i> to debug

Because hardware is so hard to debug, simulation is vital

- A successful complex project  
... *requires simulation!*

Do it the easy way: *use the simulator!*



# Verilator



Lesson Overview

First design

Schematic

Schematic

Constraints

PCF

Build the design

First Success!

▷ Simulation

Verilator Driver

Bus Signals

Bit Select

Internal Signals

Schematic

Circular Logic

Dual Assignment

Sim Result

Examples

Examples

Exercise

Conclusion

Let's now build our design using Verilator

```
% verilator -Wall -cc thruwire.v
% cd obj_dir/
% make -f Vthruwire.mk
```

- Verilator compiles Verilog into C++ placed into obj\_dir/
- The make command then builds this converted C++ file into a shared object file we can now use



# Verilator Driver



You'll need a main simulation driver too.

```
#include <stdio.h>
#include <stdlib.h>
#include "Vthruwire.h"
#include "verilated.h"

int main(int argc, char **argv) {
    // Your logic here
}
```

Lesson Overview

First design

Schematic

Schematic

Constraints

PCF

Build the design

First Success!

Simulation

▷ Verilator Driver

Bus Signals

Bit Select

Internal Signals

Schematic

Circular Logic

Dual Assignment

Sim Result

Examples

Examples

Exercise

Conclusion



# Verilator Driver



You'll need a main simulation driver too.

```
// ...  
int main(int argc , char **argv) {  
    // Call commandArgs first!  
    Verilated::commandArgs(argc , argv);  
  
    // Instantiate our design  
    Vthruwire *tb = new Vthruwire;  
  
    // ...  
}
```

- Lesson Overview
- First design
- Schematic
- Schematic
- Constraints
- PCF
- Build the design
- First Success!
- Simulation
  - ▷ Verilator Driver
- Bus Signals
- Bit Select
- Internal Signals
- Schematic
- Circular Logic
- Dual Assignment
- Sim Result
- Examples
- Examples
- Exercise
- Conclusion



# Verilator Driver



You'll need a main simulation driver too.

```
int main(int argc, char **argv) {  
    // ...  
  
    // Now run the design thru 20 timesteps  
    for(int k=0; k<20; k++) {  
        // We'll set the switch input  
        // to the LSB of our step  
        tb->i_sw = k&1;  
  
        tb->eval();  
  
        // ...  
    }  
}
```





# Verilator Driver



You'll need a main simulation driver too.

```
int main(int argc, char **argv) {  
    // ...  
    for(int k=0; k<20; k++) {  
        // We'll set the switch input  
        // to the LSB of our counter  
        tb->i_sw = k&1;  
  
        tb->eval();  
  
        // Now let's print our results  
        printf("k_=%2d, ", k);  
        printf("sw_=%d, ", tb->i_sw);  
        printf("led_=%d\n", tb->o_led);  
    }  
}
```

Lesson Overview

First design

Schematic

Schematic

Constraints

PCF

Build the design

First Success!

Simulation

▷ Verilator Driver

Bus Signals

Bit Select

Internal Signals

Schematic

Circular Logic

Dual Assignment

Sim Result

Examples

Examples

Exercise

Conclusion



# Building it all



Lesson Overview

First design

Schematic

Schematic

Constraints

PCF

Build the design

First Success!

Simulation

▷ Verilator Driver

Bus Signals

Bit Select

Internal Signals

Schematic

Circular Logic

Dual Assignment

Sim Result

Examples

Examples

Exercise

Conclusion

Last step, let's put it all together:

```
% g++ -I /usr/share/verilator/include \
    -I obj_dir/ \
    /usr/share/verilator/include/verilated.cpp \
    thruwire.cpp obj_dir/Vthruwire__ALL.a \
    -o thruwire
```

(Double check the location of Verilator in your own installation, it might be located in another directory.)

Wow, that's pretty complicated.

You should have a Makefile in your ex-01-thruwire directory with both the code and the build instructions.

```
% cd ex-01-thruwire/
% make
# (Make output skipped for brevity)
%
```



# Simulation



Lesson Overview

First design

Schematic

Schematic

Constraints

PCF

Build the design

First Success!

Simulation

▷ Verilator Driver

Bus Signals

Bit Select

Internal Signals

Schematic

Circular Logic

Dual Assignment

Sim Result

Examples

Examples

Exercise

Conclusion

We can now run our simulator!

```
% thruwire
k = 0, sw = 0, led = 0
k = 1, sw = 1, led = 1
k = 2, sw = 0, led = 0
k = 3, sw = 1, led = 1
k = 4, sw = 0, led = 0
k = 5, sw = 1, led = 1
k = 6, sw = 0, led = 0
k = 7, sw = 1, led = 1
k = 8, sw = 0, led = 0
k = 9, sw = 1, led = 1
# .... (Lines skipped for brevity)
%
```



# Good habits



Lesson Overview

First design

Schematic

Schematic

Constraints

PCF

Build the design

First Success!

Simulation

▷ Verilator Driver

Bus Signals

Bit Select

Internal Signals

Schematic

Circular Logic

Dual Assignment

Sim Result

Examples

Examples

Exercise

Conclusion

Many Verilog problems can be avoided by some simple steps

1. Make **'default\_nettype** none the first line of your Verilog file
  - Before your **module** declaration
  - Otherwise mis-spelled identifiers will be quietly turned into wires

```
module thruwire(i_sw, o_led);  
        input    wire    i_sw;  
        output   wire    o_led;  
  
        assign   o_led = sw;  
endmodule
```

Without **'default\_nettype** none, this design would pass without error



# Good habits



Lesson Overview

First design

Schematic

Schematic

Constraints

PCF

Build the design

First Success!

Simulation

▷ Verilator Driver

Bus Signals

Bit Select

Internal Signals

Schematic

Circular Logic

Dual Assignment

Sim Result

Examples

Examples

Exercise

Conclusion

Many Verilog problems can be avoided by some simple steps

1. Make **'default\_nettype** none the first line of your Verilog file
2. Fix any errors when you verilator -Wall your design
3. Run your design in a simulator
  - Attempt to recreate any hardware bugs ... *in the simulator*

These three rules will save you a lot of heartache!  
... *Get in the habit of using them!*



# Bus Signals



That was one single wire. We can also declare values consisting of many bits.

```
input  wire [8:0] i_sw;  
output wire [8:0] o_led;
```

This defines

- `i_sw` to be 9-input wires, and
- `o_led` to be 9-output wires



# Bit Select



Lesson Overview

First design

Schematic

Schematic

Constraints

PCF

Build the design

First Success!

Simulation

Verilator Driver

Bus Signals

▷ Bit Select

Internal Signals

Schematic

Circular Logic

Dual Assignment

Sim Result

Examples

Examples

Exercise

Conclusion

- Select bits of interest from a bus

```
assign    o_led[7] = i_led[0];  
assign    o_led[6:5] = i_led[5:4];
```

- Bit 7 of o\_led is set to bit 0 of i\_led
- Bits 4 through 6 of o\_led is set to bits 3 through 5 of i\_led

- Concatenate bits together

```
assign    o_led[4:0] = {i_led[7:6], i_led[2:0]};
```

- The {.,.} operator composes a new bit vector from other vectors



# Internal Signals



Lesson Overview

First design

Schematic

Schematic

Constraints

PCF

Build the design

First Success!

Simulation

Verilator Driver

Bus Signals

Bit Select

▷ Internal Signals

Schematic

Circular Logic

Dual Assignment

Sim Result

Examples

Examples

Exercise

Conclusion

You can also declare and work with internal wires

```
wire      [8:0]    w_internal;
```

- Internal wires are neither **input** nor **output**
- These wires can now be used in logic

```
assign    w_internal = 9'h87;  
assign    o_led = i_sw ^ w_internal;
```





# Literals



Lesson Overview

First design

Schematic

Schematic

Constraints

PCF

Build the design

First Success!

Simulation

Verilator Driver

Bus Signals

Bit Select

▷ Internal Signals

Schematic

Circular Logic

Dual Assignment

Sim Result

Examples

Examples

Exercise

Conclusion

A Verilog literal is defined as

- A width
- An apostrophe
- An optional sign indication, s

Defaults to unsigned

- A numeric type: h (hex), d (decimal), o (octal), b (binary), sd (signed decimal)
- The value: a series of digits, possibly containing underscores  
Underscores can be *very* useful for longer numbers

Examples include:

1'b0   1'b1   2'b01   4'b0101   4'h5   -7'sd124  
32'hdead\_beef   32'd100\_000\_000

Place a '-' in front of the width for negative numbers



# Sign Extension



Lesson Overview

First design

Schematic

Schematic

Constraints

PCF

Build the design

First Success!

Simulation

Verilator Driver

Bus Signals

Bit Select

▷ Internal Signals

Schematic

Circular Logic

Dual Assignment

Sim Result

Examples

Examples

Exercise

Conclusion

If the literal is smaller than the context ...

- If there is no 's', the number is unsigned and it is zero extended
- Any literal with an 's' is sign extended
- ... to fit the width

If the literal is too big for the context ...

- It is truncated to fit the context

Many tools will create a warning for width mismatches



# Operators



## Lesson Overview

First design  
Schematic  
Schematic  
Constraints  
PCF  
Build the design  
First Success!  
Simulation  
Verilator Driver  
Bus Signals  
Bit Select  
▷ Internal Signals  
Schematic  
Circular Logic  
Dual Assignment  
Sim Result  
Examples  
Examples  
Exercise  
Conclusion

The Verilog language supports the following operators

+	Addition	—	Subtraction
<<	Left Shift	>>	Right shift
—	Unary negation	?:	Tertiary operator
~	Bit-wise negation	^	Bit-wise XOR
	Bitwise OR	&	Bitwise AND
	Logical OR	&&	Logical and
!	Logical negation	>>>	Arithmetic right shift
==	Equality	!=	Inequality
<, <=	Less than (Equal)	>, >=	Greater than (Equal)
Limited, use with care		Avoid within logic	
*	Multiplication	/	Division
		%	Remainder

- Some FPGA's support native multiplication
- None support a single clock divide or remainder



# Schematic



Lesson Overview

First design

Schematic

Schematic

Constraints

PCF

Build the design

First Success!

Simulation

Verilator Driver

Bus Signals

Bit Select

Internal Signals

▷ Schematic

Circular Logic

Dual Assignment

Sim Result

Examples

Examples

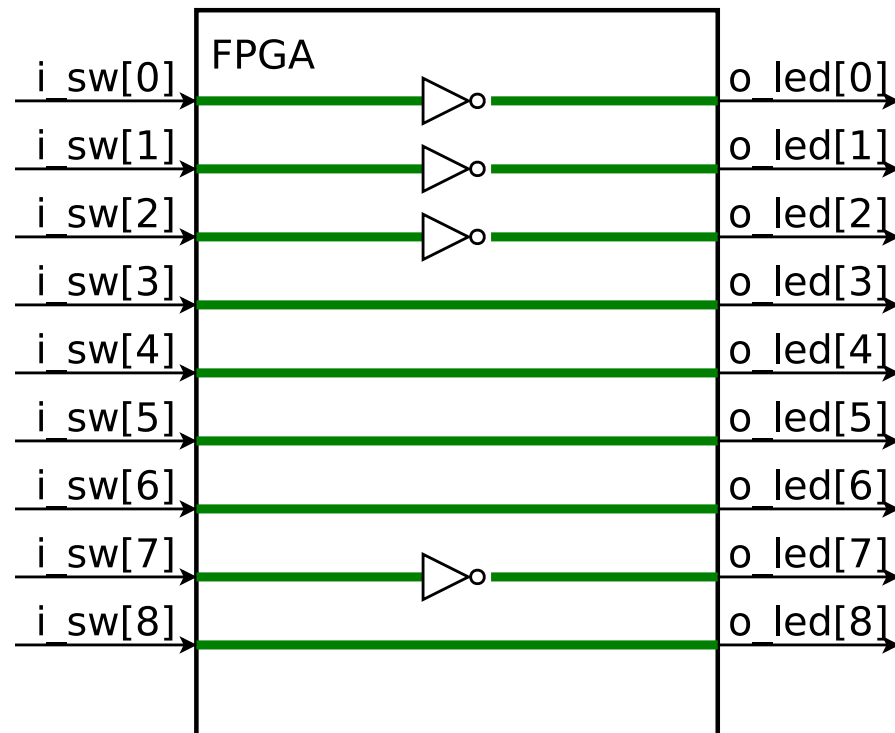
Exercise

Conclusion

From this code:

```
assign    w_internal = 9'h87;  
assign    o_led = i_sw ^ w_internal;
```

Get this internal structure:

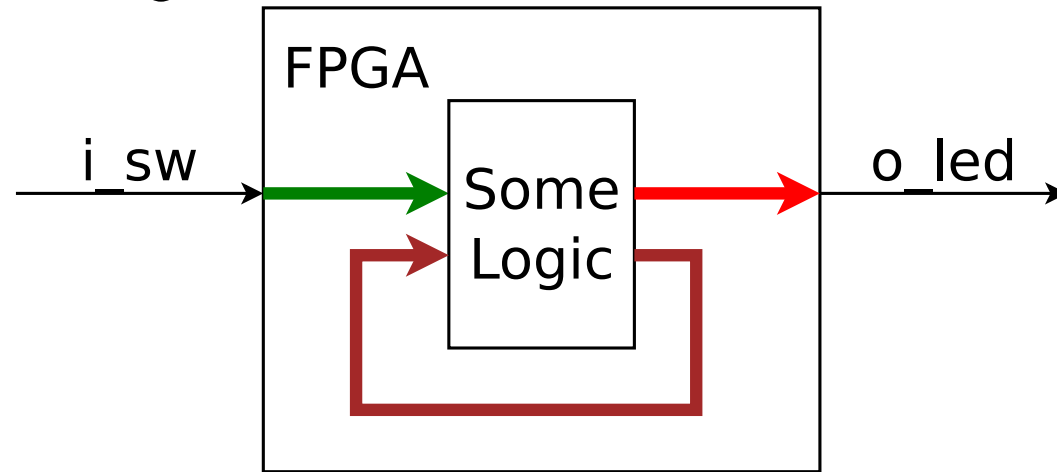




# Circular Logic



Avoid circular logic!



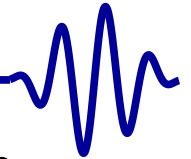
Example:

```
assign    o_led = i_sw + o_led;
```

- This doesn't work in hardware like it might in software
  - This is roughly equivalent to creating a short circuit
  - Most tools will fail to build such designs
- This include Verilator



# Dual Assignment



Lesson Overview

First design

Schematic

Schematic

Constraints

PCF

Build the design

First Success!

Simulation

Verilator Driver

Bus Signals

Bit Select

Internal Signals

Schematic

Circular Logic

Dual  
▷ Assignment

Sim Result

Examples

Examples

Exercise

Conclusion

You are designing hardware: A value can only be set once  
This is an error:

```
assign o_led = i_sw + o_led;  
assign o_led = i_sw + 1;
```



# Let's build it



Lesson Overview

First design

Schematic

Schematic

Constraints

PCF

Build the design

First Success!

Simulation

Verilator Driver

Bus Signals

Bit Select

Internal Signals

Schematic

Circular Logic

    Dual  
▷ Assignment

Sim Result

Examples

Examples

Exercise

Conclusion

Let's build this design:

```
'default_nettype          none

module maskbus(i_sw, o_led);
    input      [8:0]    i_sw;
    output     [8:0]    o_led;

    wire       [8:0]    w_internal;

    assign     w_internal = 9'h87;
    assign     o_led = i_sw ^ w_internal;
endmodule
```

... using Verilator



# Updated Driver



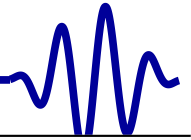
Let's update our driver for this wire bus design

```
int main(int argc, char **argv) {  
    // ...  
    for(int k=0; k<20; k++) {  
        // ...  
        // Bottom 9 bits of counter  
        tb->i_sw = k & 0x1ff;  
  
        tb->eval();  
  
        // Now let's print our results  
        printf("k_=%2d, ", k);  
        printf("sw_=%3x, ", tb->i_sw);  
        printf("led_=%3x\n", tb->o_led);  
    }  
}
```





# Sim Result



- Lesson Overview
- First design
- Schematic
- Schematic
- Constraints
- PCF
- Build the design
- First Success!
- Simulation
- Verilator Driver
- Bus Signals
- Bit Select
- Internal Signals
- Schematic
- Circular Logic
- Dual Assignment
- ▷ Sim Result
- Examples
- Examples
- Exercise
- Conclusion

```
% ./maskbus
k = 0, sw = 0, led = 87
k = 1, sw = 1, led = 86
k = 2, sw = 2, led = 85
k = 3, sw = 3, led = 84
k = 4, sw = 4, led = 83
k = 5, sw = 5, led = 82
k = 6, sw = 6, led = 81
k = 7, sw = 7, led = 80
k = 8, sw = 8, led = 8f
k = 9, sw = 9, led = 8e
# .... (Lines skipped for brevity)
%
```



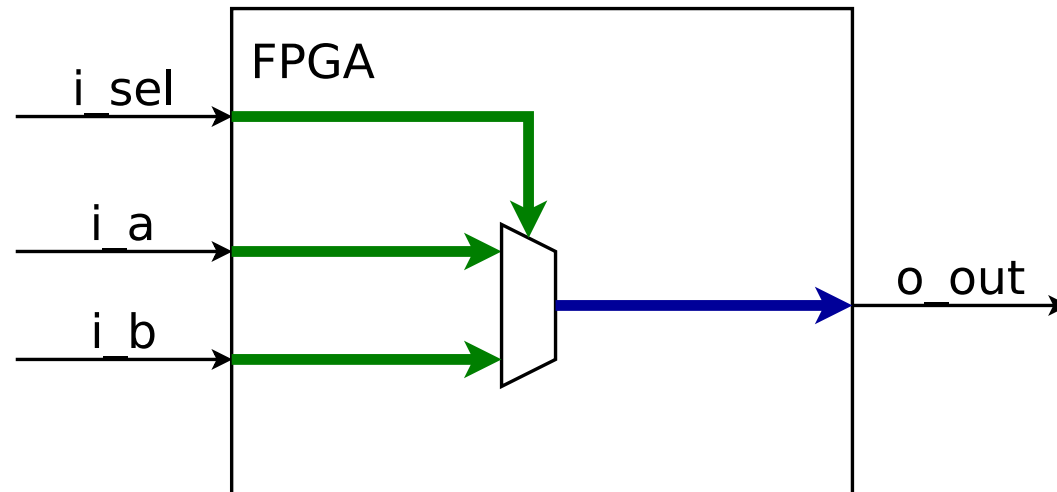
# Examples



What can you do with wires and wire logic?

Example: Multiplexer

```
input    wire    i_a, i_b, i_sel;  
output   wire    o_out;  
  
assign   o_out = (i_sel) ? i_a : i_b;
```





# Examples



Lesson Overview

First design

Schematic

Schematic

Constraints

PCF

Build the design

First Success!

Simulation

Verilator Driver

Bus Signals

Bit Select

Internal Signals

Schematic

Circular Logic

Dual Assignment

Sim Result

Examples

▷ Examples

Exercise

Conclusion

What can you do with wires and wire logic?

Example: Multiplexer

```
input      wire      i_a, i_b, i_sel;  
output     wire      o_out;  
  
assign     o_out = (i_sel) ? i_a : i_b;
```

- This is a good example of the tertiary operator
- Interested in making a connection to one of two serial ports?
- How about connecting one of two bus masters to an interconnect?

We'll get to these examples later.



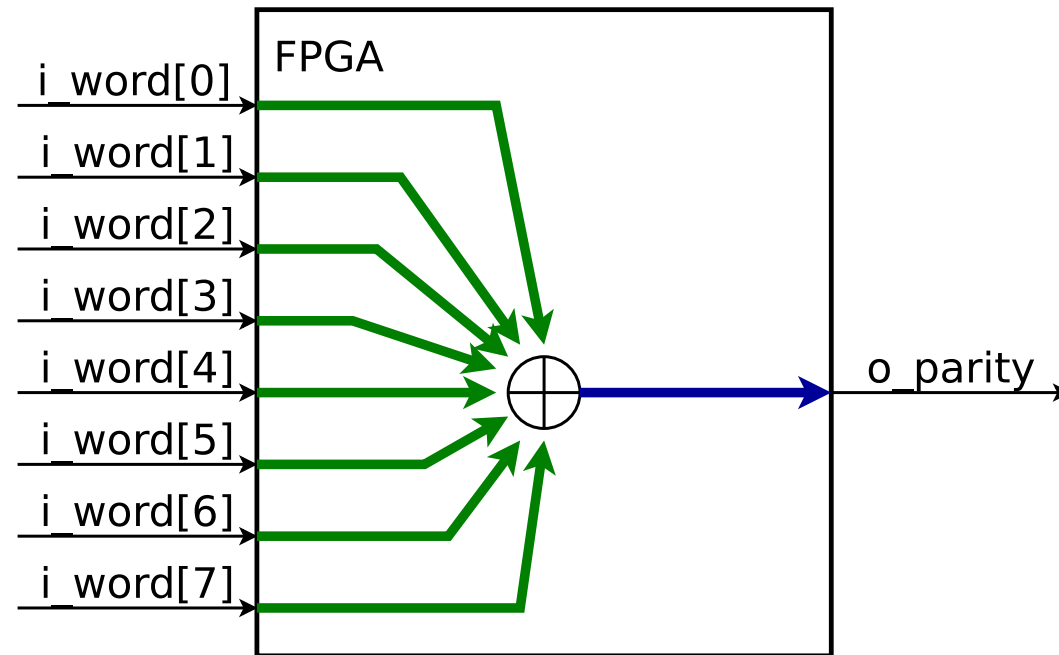
# Examples



What can you do with wires and wire logic?

Example: Parity check

```
input    wire    [7:0]    i_word;  
output   wire    o_parity;  
  
assign   o_parity = ^i_word;
```





# Examples



Lesson Overview

First design

Schematic

Schematic

Constraints

PCF

Build the design

First Success!

Simulation

Verilator Driver

Bus Signals

Bit Select

Internal Signals

Schematic

Circular Logic

Dual Assignment

Sim Result

Examples

▷ Examples

Exercise

Conclusion

What can you do with wires and wire logic?

Example: Parity check

```
input  wire [7:0] i_word;  
output wire      o_parity;  
  
assign o_parity = ^i_word;
```

This form of XOR is a *reduction operator*

- It XORs all the word's bits together
- Other reduction operators include | and &

Error Correction Code (ECC) creation logic is very similar



# Examples



Lesson Overview

First design

Schematic

Schematic

Constraints

PCF

Build the design

First Success!

Simulation

Verilator Driver

Bus Signals

Bit Select

Internal Signals

Schematic

Circular Logic

Dual Assignment

Sim Result

Examples

▷ Examples

Exercise

Conclusion

What can you do with wires and wire logic?

Example: Interrupt detector

```
input    wire    [7:0]    i_irq_source;  
output   wire    o_irq;  
  
assign   o_irq = | i_irq_source;
```

- i\_irq\_source contains eight interrupt sources
- o\_irq is true if any interrupt source is true



# Examples



Lesson Overview

First design

Schematic

Schematic

Constraints

PCF

Build the design

First Success!

Simulation

Verilator Driver

Bus Signals

Bit Select

Internal Signals

Schematic

Circular Logic

Dual Assignment

Sim Result

Examples

▷ Examples

Exercise

Conclusion

What can you do with wires and wire logic?

Example: CPU stall determination

```
assign    dcd_stall = (dcd_valid)&&(op_stall);
```

From the ZipCPU, the decode stage must stall if

- It has produced a valid result, and
  - The next stage, read operands, is stalled for some reason
- These stalls can back up through the CPU
- Ex. Read operands might be stalled if the ALU is stalled



# Examples



Lesson Overview

First design

Schematic

Schematic

Constraints

PCF

Build the design

First Success!

Simulation

Verilator Driver

Bus Signals

Bit Select

Internal Signals

Schematic

Circular Logic

Dual Assignment

Sim Result

Examples

▷ Examples

Exercise

Conclusion

What can you do with wires and wire logic?

Example: Determining if there's a phase error in a phase lock loop

```
assign phase_err = (output_phase != input_phase);
```

In this case, the loop will adjust if there are any errors





# Exercise



Lesson Overview

First design

Schematic

Schematic

Constraints

PCF

Build the design

First Success!

Simulation

Verilator Driver

Bus Signals

Bit Select

Internal Signals

Schematic

Circular Logic

Dual Assignment

Sim Result

Examples

Examples

▷ Exercise

Conclusion

This section has two exercises:

1. Build and try the thruwire demo.
  - Toggle the switch.
  - Verify that toggling your switch will toggle the LED
  - Build and run the Verilator simulation
2. Create a test of your serial port connection
  - Connecting the input serial port wire to the output  
Beware: These wires are often marked “TX” and “RX”, but not always from the perspective of the FPGA
  - Turn off any ‘local echo’
  - Turn off any hardware flow control
  - Verify that characters typed into your terminal program show up on the screen



# Conclusion



Lesson Overview

First design

Schematic

Schematic

Constraints

PCF

Build the design

First Success!

Simulation

Verilator Driver

Bus Signals

Bit Select

Internal Signals

Schematic

Circular Logic

Dual Assignment

Sim Result

Examples

Examples

Exercise

▷ Conclusion

- Wires represent connections within the design
- Wires can also represent the outputs of combinatorial logic
- Wires have no memory, circular logic or feedback is illegal
- You know how to create constraints for your project!

You can now build and load a design onto an FPGA!