Introduction to FPGA Design using Quartus (Labsland)

Intel Programmable Solutions Group

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- Larry Landis – University Outreach Senior Manager, Intel Programmable Solutions Group
- 36 years in electronics industry – design, sales, marketing, training (Altera 2004)
- Adjunct Lecturer for Digital Electronics Course – Santa Clara University

CSUN
CALIFORNIA STATE UNIVERSITY NORTHRIDGE

BSEE

LMU | LA
Loyola Marymount University

MSEE

SANTA CLARA BRONCOS

Adjunct Lecturer

Best Practices for Teams/Virtual Training

- Mute your microphone unless you are speaking
- Join a breakout and someone can help you
- Watch the chat window for important information, and send a chat to all with an inquiry if relevant to all – you need to exit your lab breakout room
- Don’t be shy … Ask lots of questions!

Topics

- FPGAs at Intel
- Fundamentals of Digital Electronics
- Intel® Quartus® Prime Design Software
- FPGA Design Flow
- Today's Lab

Intel® FPGA Academic Ecosystem

- Train the next generation of FPGA Designers
- Increase Intel® FPGA presence in academia

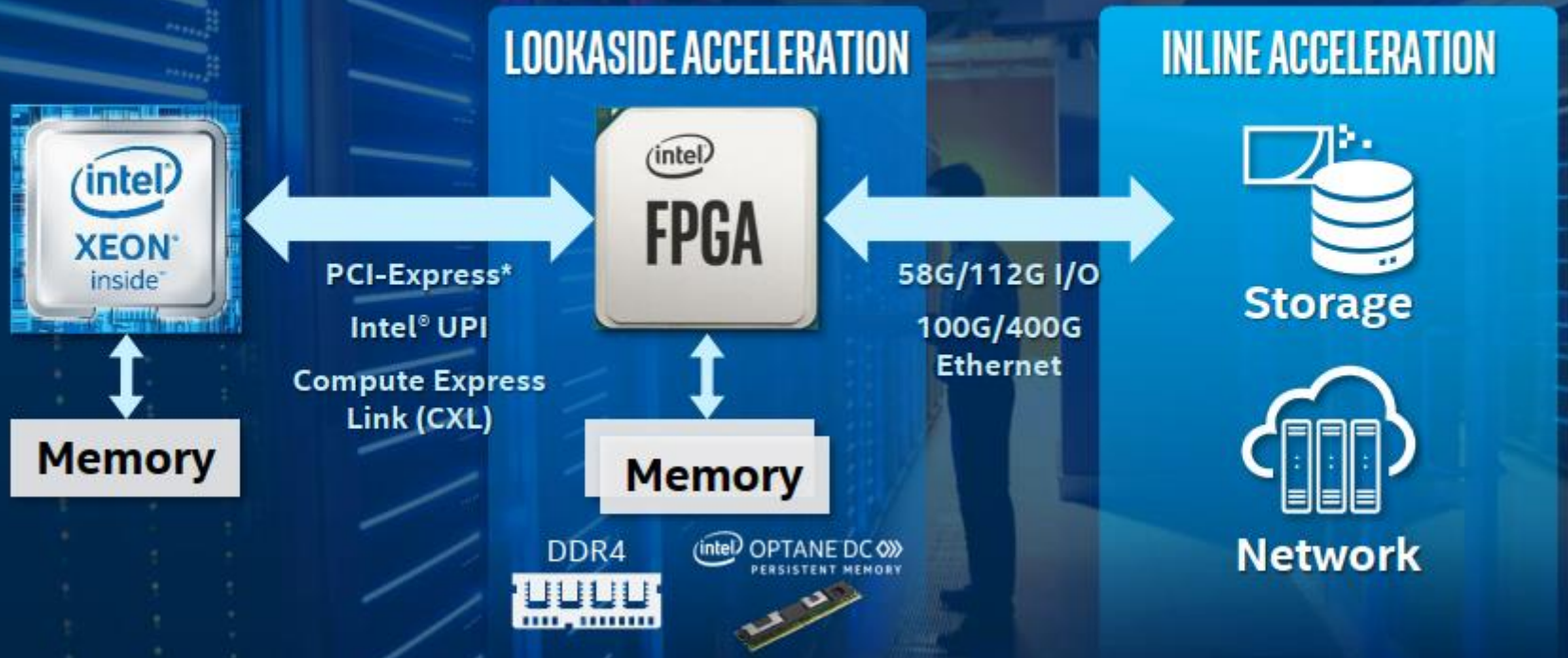
- Academic access to the latest generation of Intel FPGAs

- Nurture the talent pipeline for Intel and our customers
- Engage research on Intel FPGAs

INTEL® FPGA EE COURSEWORK OFFERINGS

- Undergraduate
  - Digital Logic
  - Digital Systems
  - Computer Organization
  - Embedded Systems

INTEL® FPGAS ACCELERATING THE CLOUD & ENTERPRISE



Website Access for the Intel® FPGA Devcloud

https://software.intel.com/en-us/devcloud/FPGA

Field Programmable Gate Array (FPGA)

- Flexible, multi-functional reprogrammable silicon
- Custom hardware functionality
- Bare-metal speed and reliability
- Truly parallel in nature

Benefits of FPGA Technology

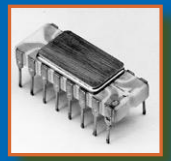
- Flexibility
- Time to market
- Performance
- Reliability
- Long-Term Maintenance – reprogram if features change or bugs found
- Many different applications – 5G, Data Center, Industrial, DSP
- Excellent prototyping vehicle

Rise of new markets

Intel's history with FPGAs

1968 — Intel is founded by Robert Noyce and Gordon Moore

1971 — World's first microprocessor

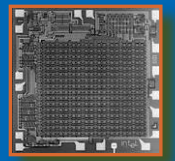


1983 — Founded

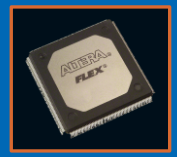
1984 — First PLD

1984 — Intel and Altera establish a joint marketing agreement

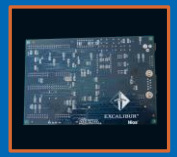
1994 — Altera purchases Intel's PLD business



1995 — First embedded RAM



2000 — First soft micro-processor



2002 — First embedded DSP

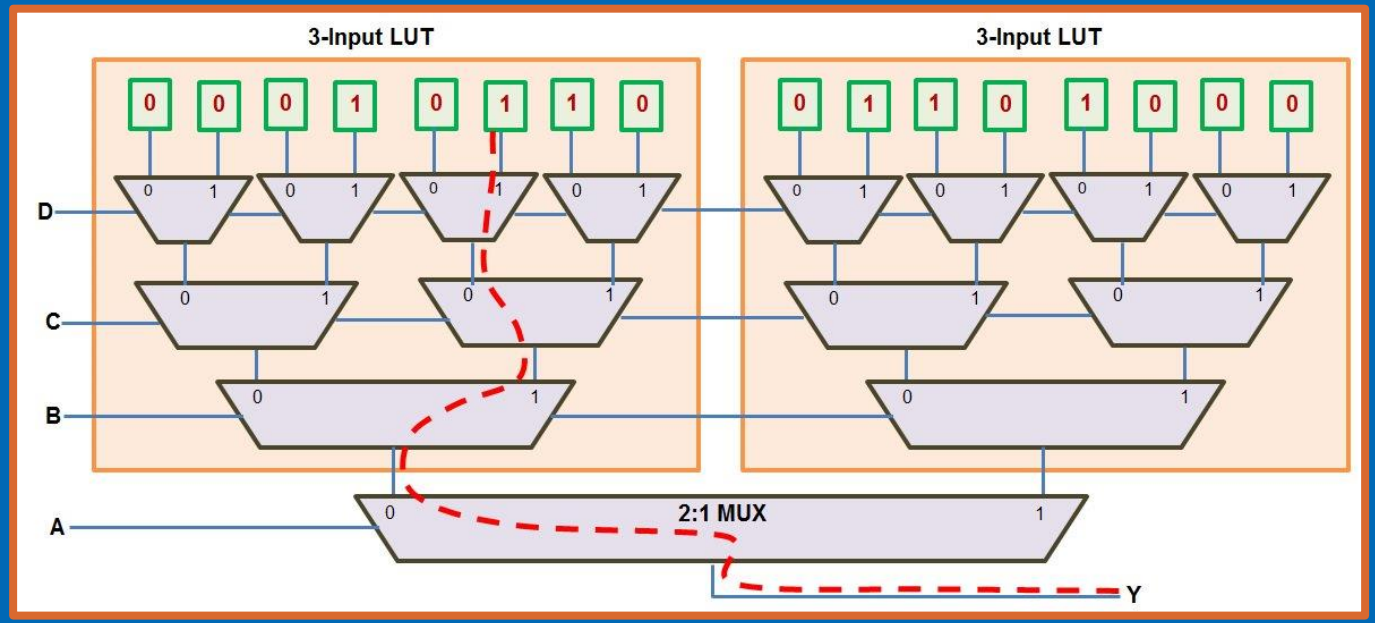
2012 — SoC FPGA

2013 — Intel and Altera start foundry relationship for 14nm FPGAs and SoCs

2015 — Intel acquires Altera

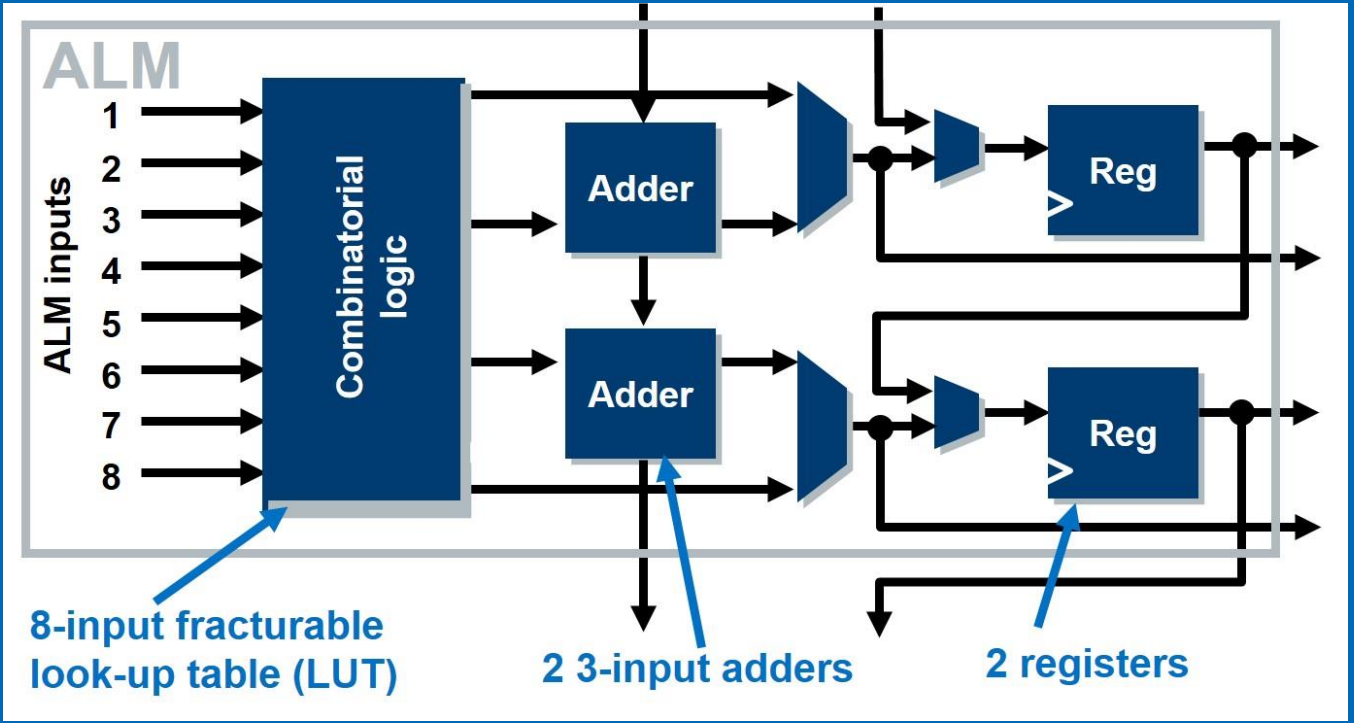
2016 — System-in-Package (SIP)

Look-Up Table (LUT): the foundation



Y=A’B’CD+AB’CD’+A’BCD’+AB’C’D+A’BC’D+A’BCD

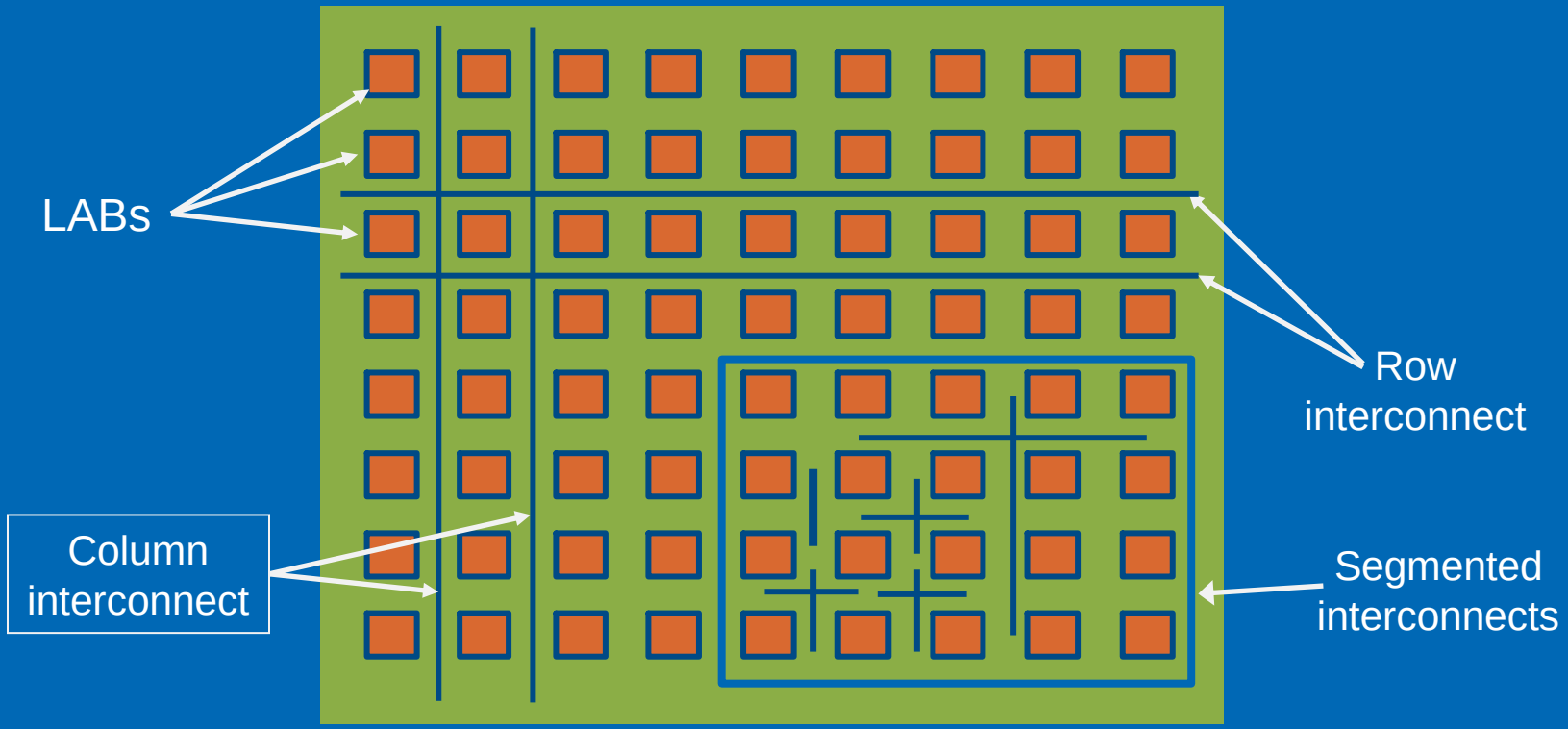
Logic Array Blocks



x 10

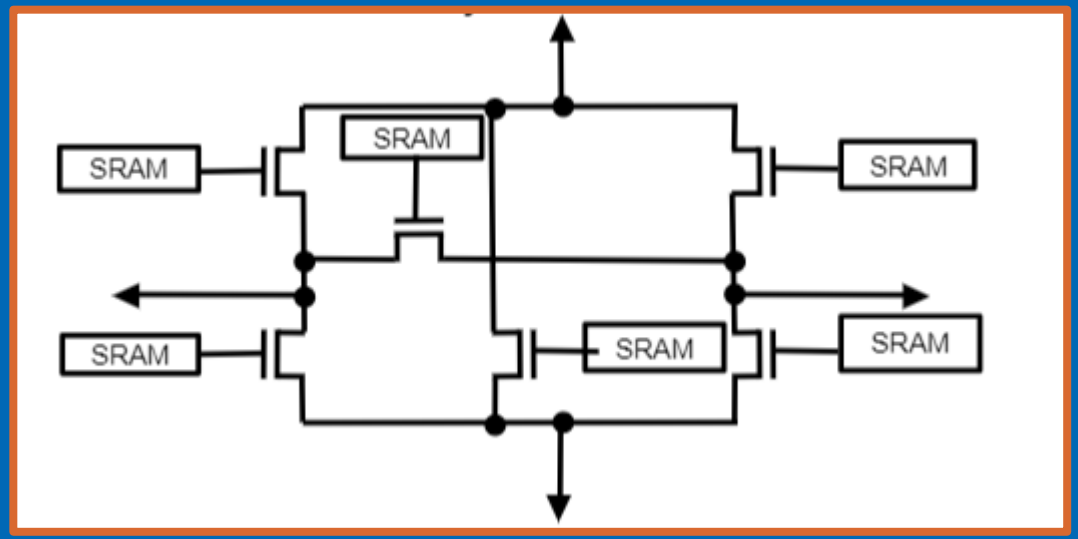
*Number of inputs and ALMs per LAB vary by product family

Building the Array



How switching fabric is programmed

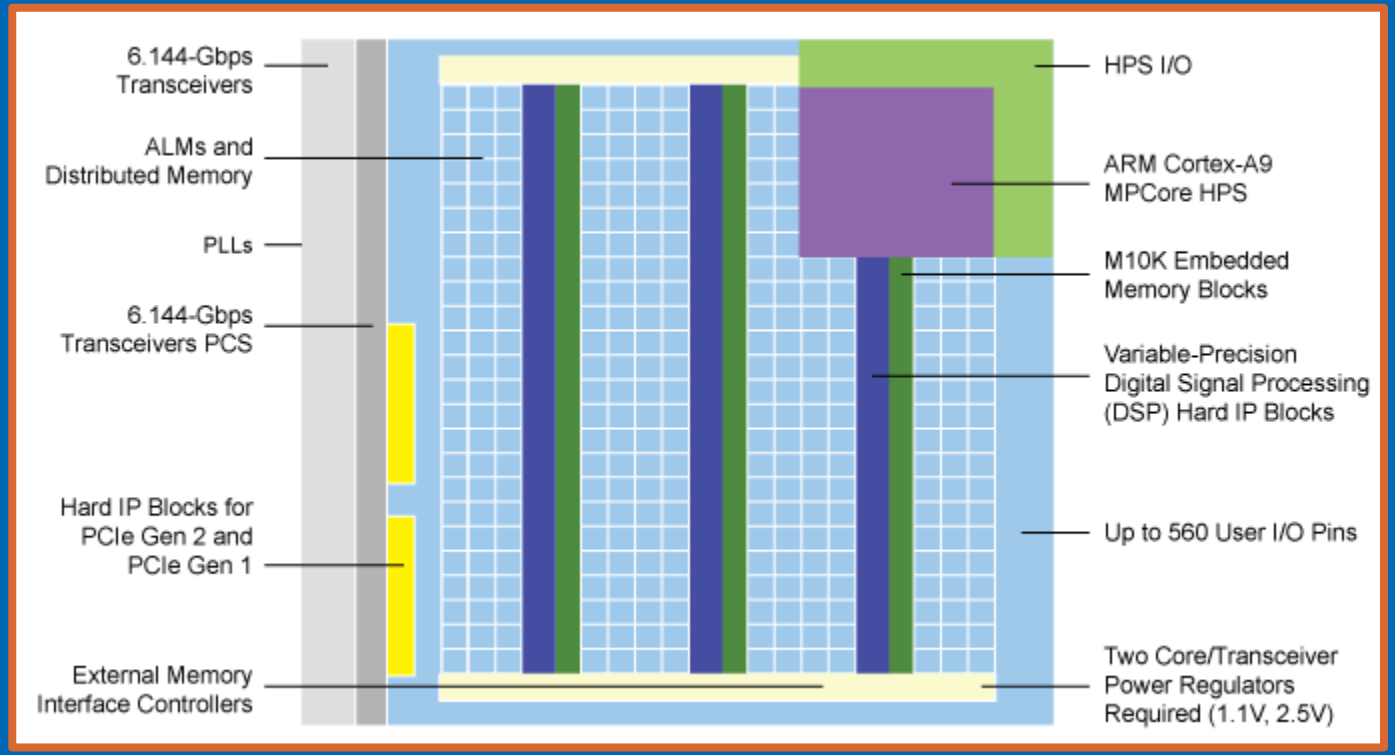
Row/Column Interconnect Junction



Programming info stored in a external non-volatile device

- Active: programmed automatically at power-on
- Passive: Intelligent host (CPU) controls programming

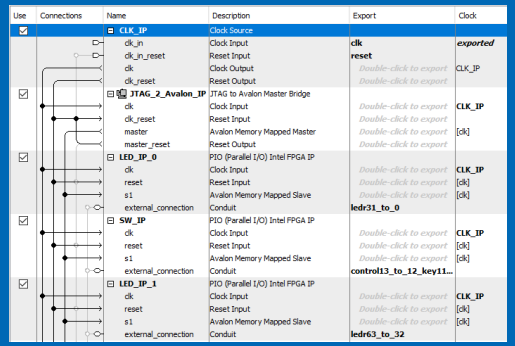
FPGAs “Hardened” features (Cyclone V)

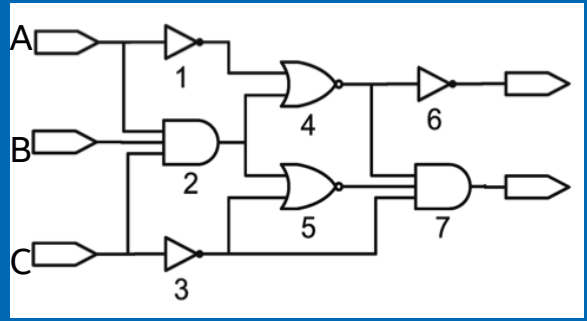


Describing FPGAs

- Schematics
- System Integration Tools – predefined blocks
- Hardware Description Languages (HDLs)
  - Verilog, VHDL are most popular
- High level languages
  - “HLS”
  - OpenCL
  - Data Parallel C++

```
try {

    sycl::queue q(sycl::default_selector{});

    const float A(aval);

    sycl::buffer<float,1> d_X { h_X.data(), sycl::range<1>(h_X.size()) };
    sycl::buffer<float,1> d_Y { h_Y.data(), sycl::range<1>(h_Y.size()) };
    sycl::buffer<float,1> d_Z { h_Z.data(), sycl::range<1>(h_Z.size()) };

    q.submit([&](sycl::handler& h) {

        auto X = d_X.template get_access<sycl::access::mode::read>(h);
        auto Y = d_Y.template get_access<sycl::access::mode::read>(h);
        auto Z = d_Z.template get_access<sycl::access::mode::read_write>(h);

        h.parallel_for<class nstream>( sycl::range<1>{length}, [=] (sycl::id<1> it) {
            const int i = it[0];
            Z[i] += A * X[i] + Y[i];
        });
      });
      q.wait();
}
```



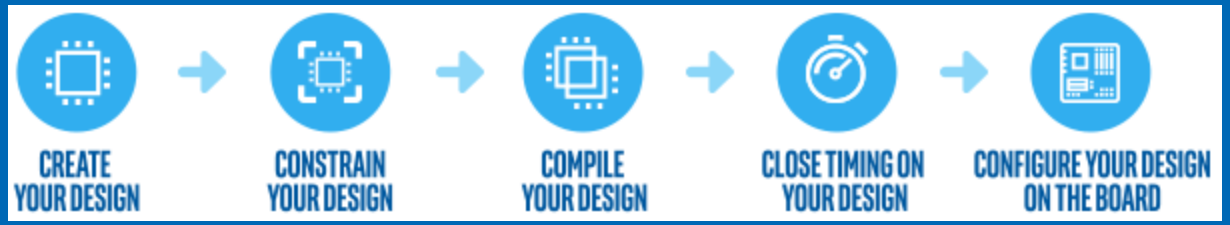


What is IP (Intellectual Property)

- Complex functions that Intel designs for our customers so they don’t have to design it themselves
  - Sometimes IP is free
  - The more complex stuff costs since its expensive to develop and make sure it works
- Examples: Ethernet Controller, PCIe Controller, soft processor, multiplier functions, etc.

Basics of Quartus

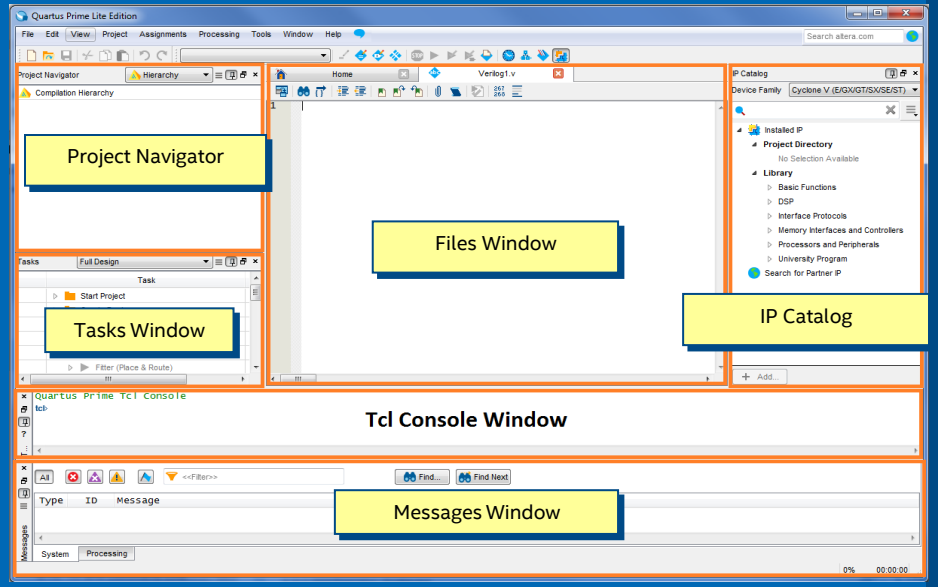
- Intel® Quartus® Prime Design Software is a tool for FPGA, SOC and CPLD design
- Includes synthesis, debug, optimization, verification and simulation
- Takes a description of an FPGA (schematic or HDL) and determines how the lookup tables are programmed



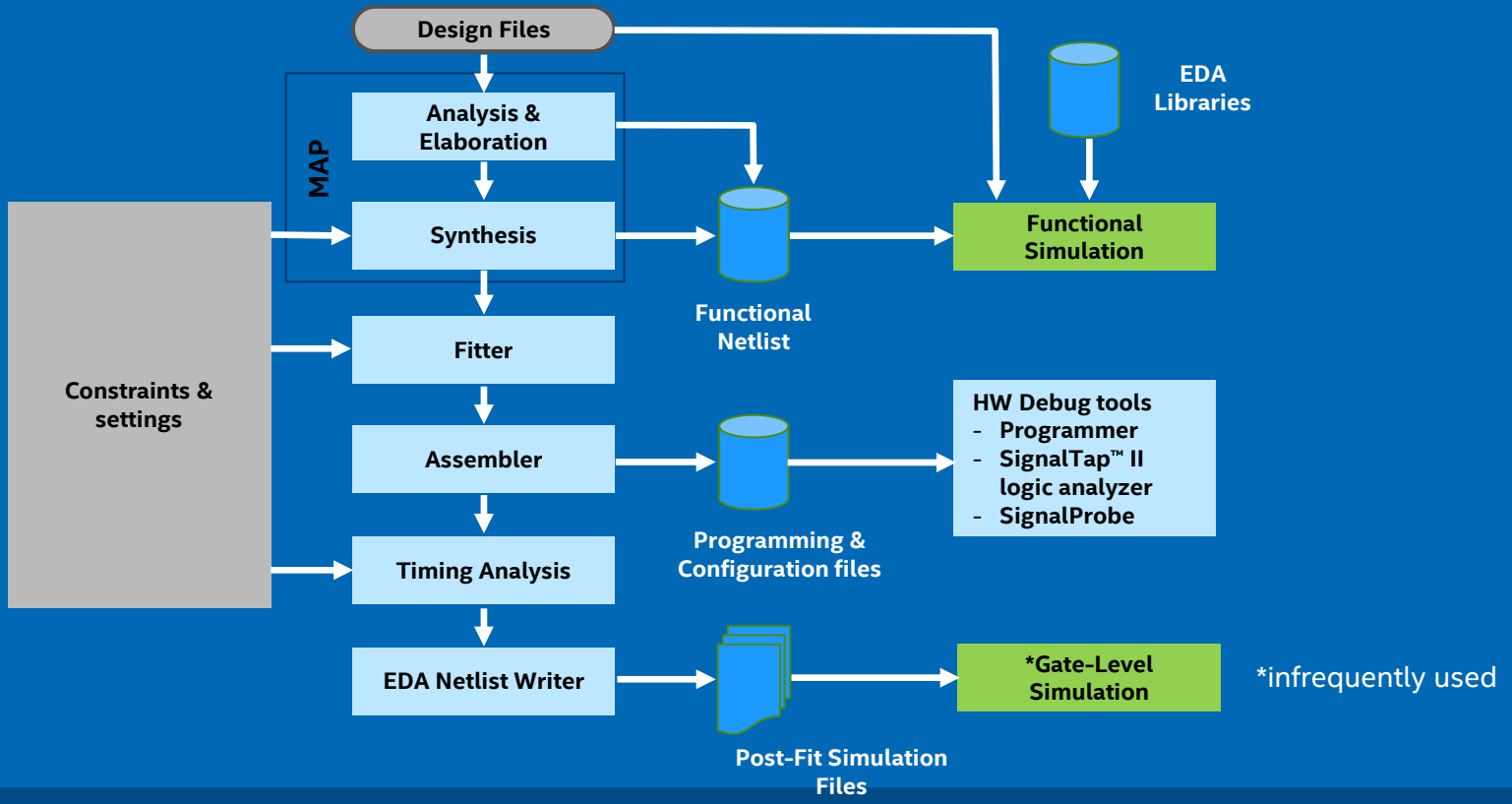
- Many formats to program an FPGA
  - In this class we will use a ".sof" file (SRAM object file)
  - The .sof file is "volatile" and needs to be reprogrammed every time the board is restarted

Quartus User Interface

- Quartus Prime Software Main Window
  - *Project Navigator* shows your project hierarchy, source files, design units, IP and design revisions in your project.
  - *Tasks* window shows the status of the design and can be used to run or re-run parts of the design flow
  - *Messages* window outputs messages from each process of the run.
  - *Files* window has tabs for the report browser, open design files and any other file opened by the user.
  - *IP Catalog* window is open by default and is used to generate IP functions that are to be used in your design.



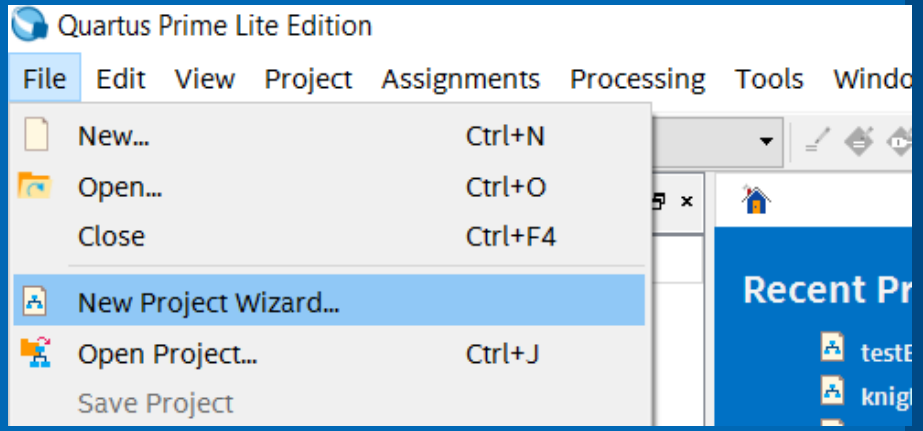
Tools Flow



*infrequently used

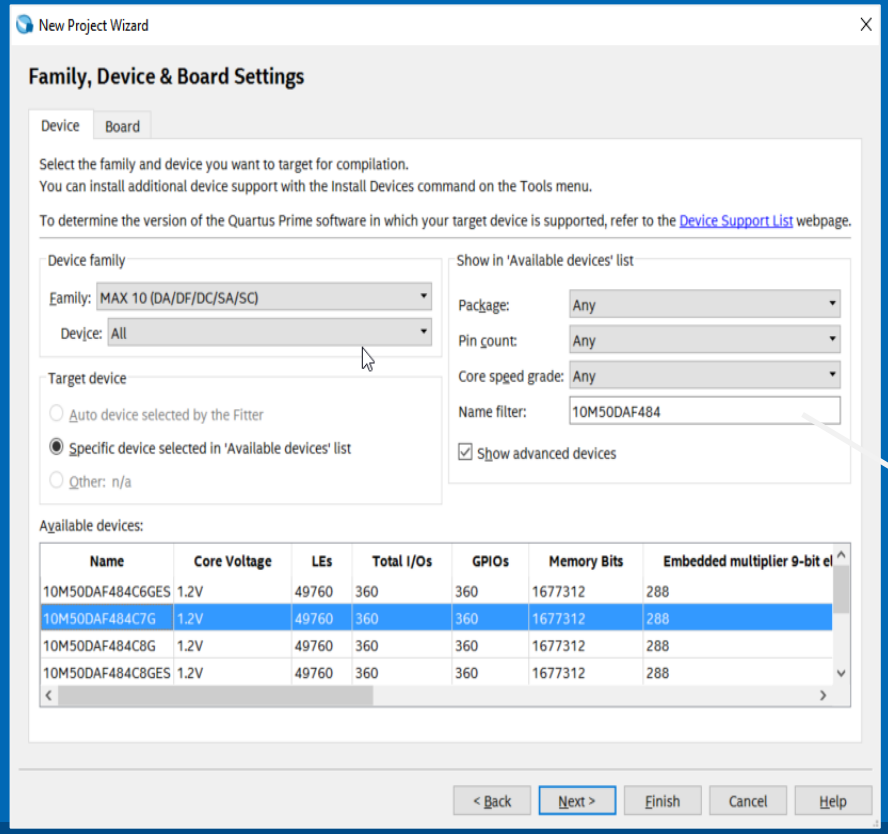
New Project Wizard

1. Name project
2. Set Working Directory & Top-Level Entity
3. Add source files
4. Select Device
5. EDA tool settings



All settings can be modified later. Some steps can be skipped.
The top level entity must match the top level module in your design exactly (case sensitive) in order to avoid a compile error.

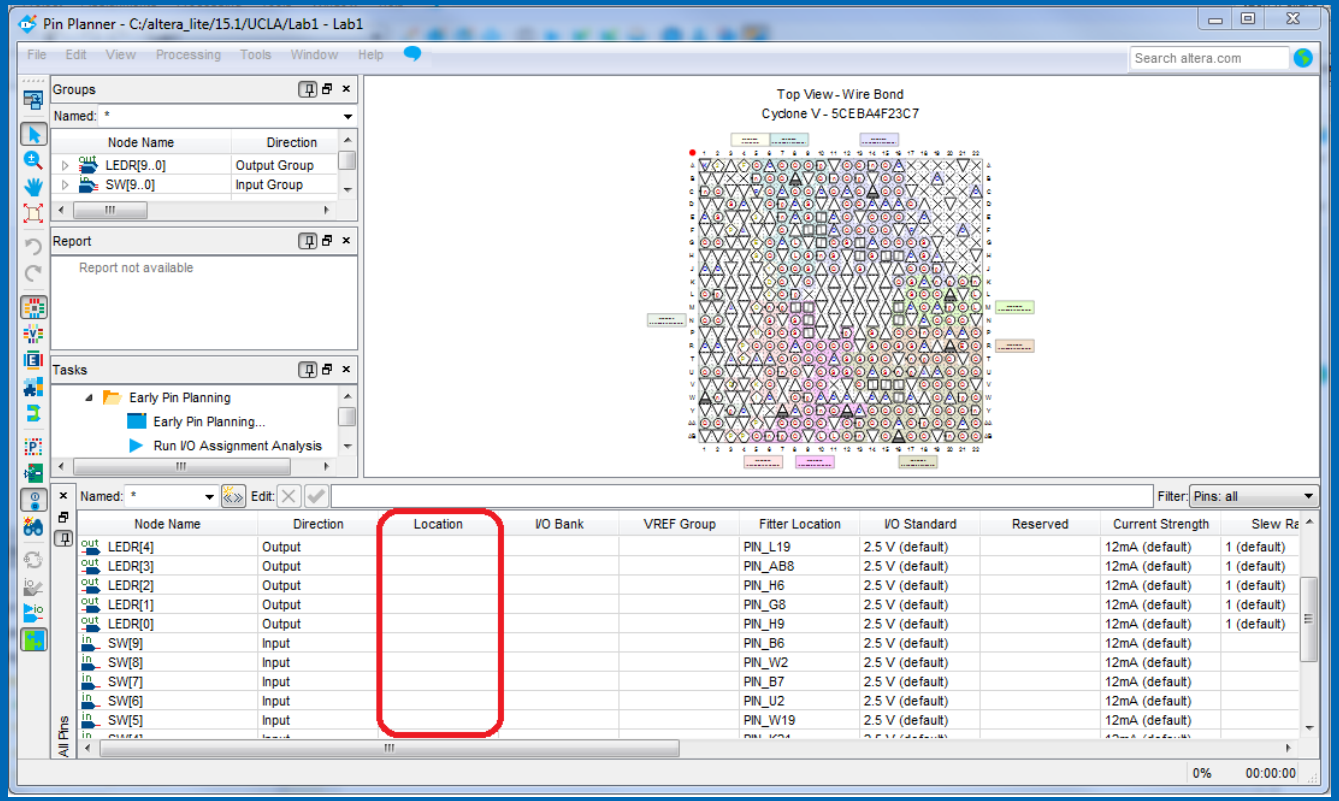
Family & Device Settings



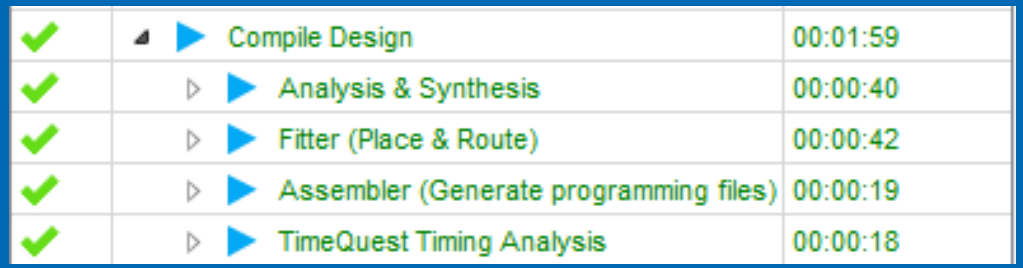
Expand the window so you can see all the fields

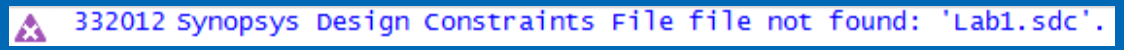
Get the part number for your specific device by looking on the chip on your board or the side of the box.

Pin Planner


Pin Planner - C:/altera_lite/15.1/UCLA/Lab1 - Lab1
File Edit View Processing Tools Window Help
Search altera.com
Groups
Named: *
Node Name Direction
LEDR[9..0] Output Group
SW[9..0] Input Group
Report
Report not available
Tasks
Early Pin Planning
Early Pin Planning...
Run I/O Assignment Analysis
Top View - Wire Bond
Cyclone V - 5CEBA4F23C7
Named: * Edit: Filter: Pins: all
Node Name Direction Location I/O Bank VREF Group Fitter Location I/O Standard Reserved Current Strength Slew Ra
LEDR[4] Output PIN_L19 2.5 V (default) 12mA (default) 1 (default)
LEDR[3] Output PIN_AB8 2.5 V (default) 12mA (default) 1 (default)
LEDR[2] Output PIN_H6 2.5 V (default) 12mA (default) 1 (default)
LEDR[1] Output PIN_G8 2.5 V (default) 12mA (default) 1 (default)
LEDR[0] Output PIN_H9 2.5 V (default) 12mA (default) 1 (default)
SW[9] Input PIN_B6 2.5 V (default) 12mA (default)
SW[8] Input PIN_W2 2.5 V (default) 12mA (default)
SW[7] Input PIN_B7 2.5 V (default) 12mA (default)
SW[6] Input PIN_U2 2.5 V (default) 12mA (default)
SW[5] Input PIN_W19 2.5 V (default) 12mA (default)
All Pins
0% 00:00:00

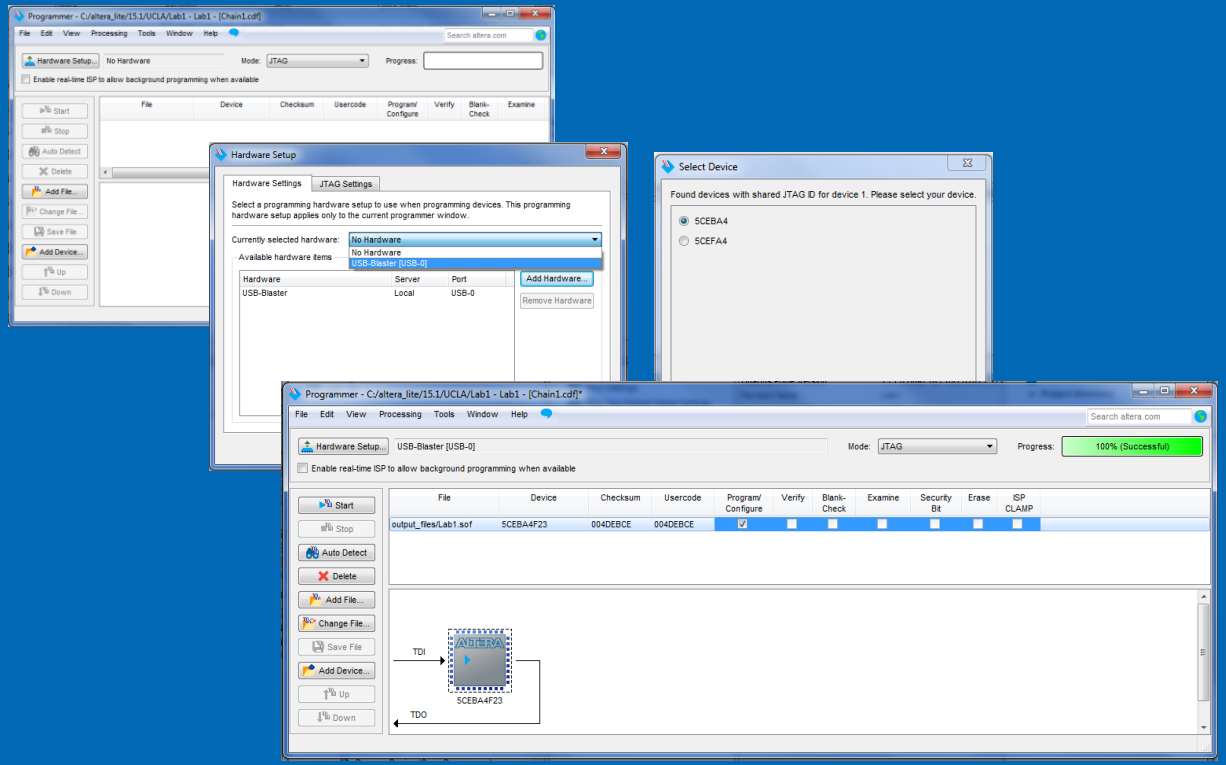
Compile your design



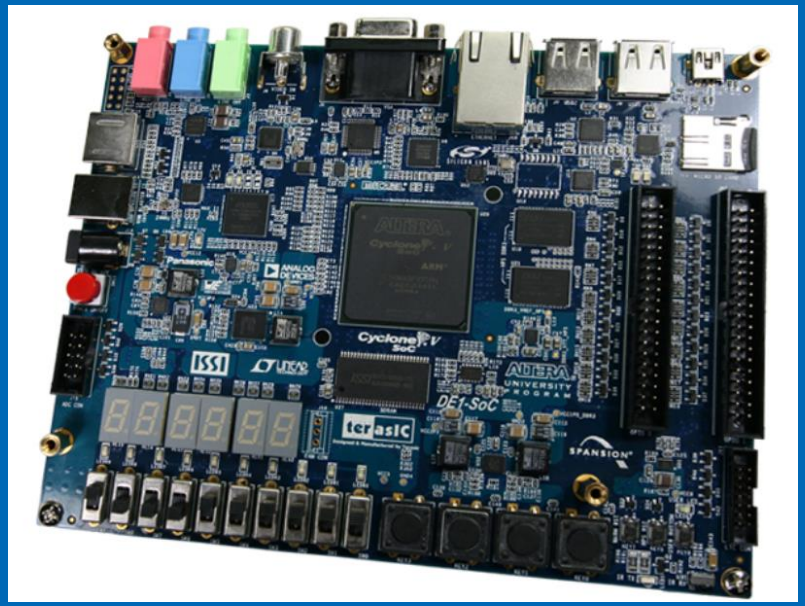


Warnings shown in blue won't prevent your design from compiling or being programmed, but they could indicate possible bugs. This lab does not have any design constraints, so the .sdc file is not needed. You will learn how to create one in the timing analysis workshop.

Program your FPGA



Test your design



Live Hardware

Labsland

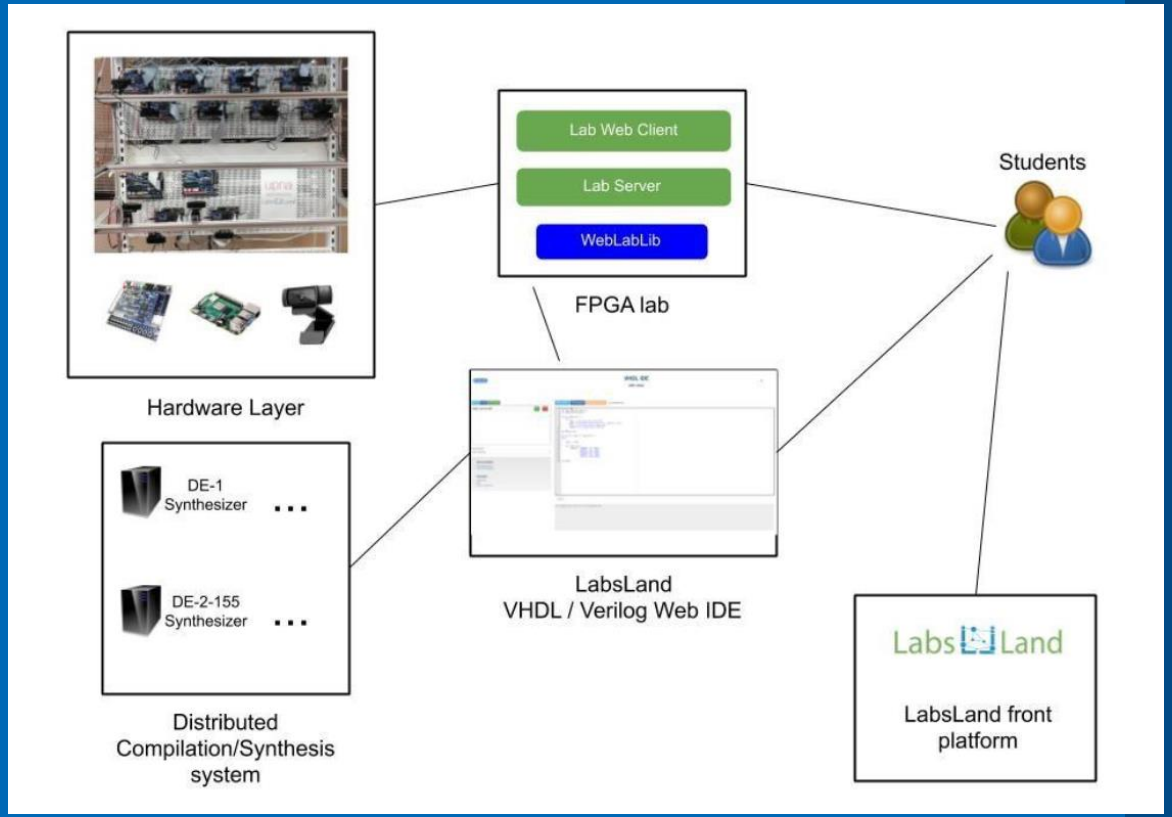
Covid-19: New challenges for remote learners

- In June 2020, we launched initiatives to help remote learners
- Addresses situation where student does not have a physical board in their possession
- Simulation based only requires Modelsim
  - Quick compiles
  - More setup with IP
  - Slower clock speed
- Hardware based requires Intel Quartus Prime-Lite
  - Longer compiles, but hardware accurate
  - Two methods Remote Console and Labsland *we are using Labsland for this lab
  - More complex networking, adds a level of hierarchy in the design

Labs Land

Real laboratories, on the Internet

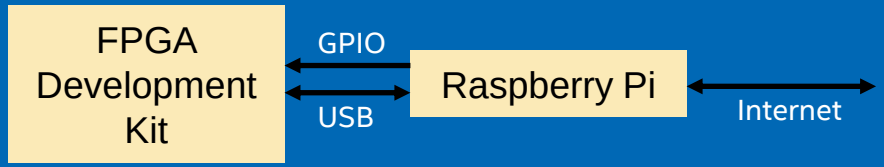
- LabsLand connects schools and universities with **real laboratories** available somewhere else on the Internet. A real laboratory can be a small Arduino powered robot in Spain, a kinematics setup in Brazil or a radioactivity testing lab in Australia. They are real laboratories, not simulations: the laboratories are physically there, and students from these schools and universities access them.
- Fee based model to access labs (no charge today!)
- Note – there is a special link to register for labsland access, registration from the labsland home page will not work



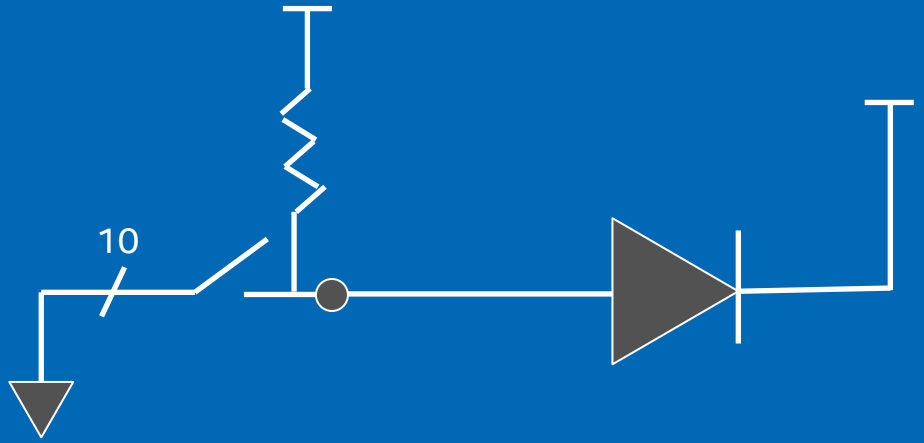
Labs Land

Real laboratories, on the Internet

- Two modes:
- IDE mode is an overlay on Quartus. No software or hardware install required by the user. Compiles are on the cloud. Some limitations on IP usage and debug capabilities
- No-IDE mode requires local software installation and utilizes Labsland remote FPGA hardware installation – this is what you will use in today's lab

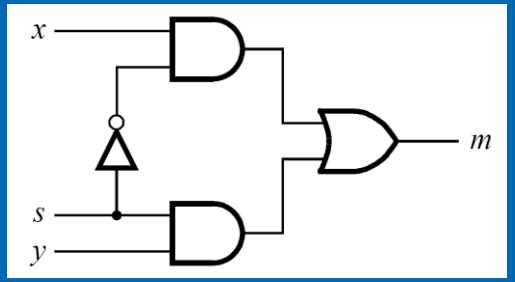


First Lab: Switch to LED



assign LED = SW;

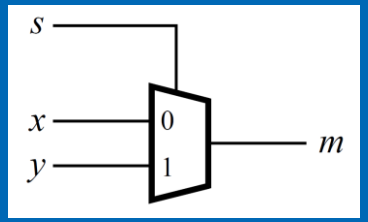
Next lab: Multiplexer



Circuit

s	m
0	x
1	y

Truth table

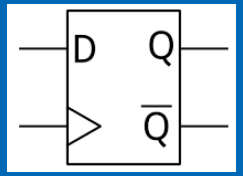


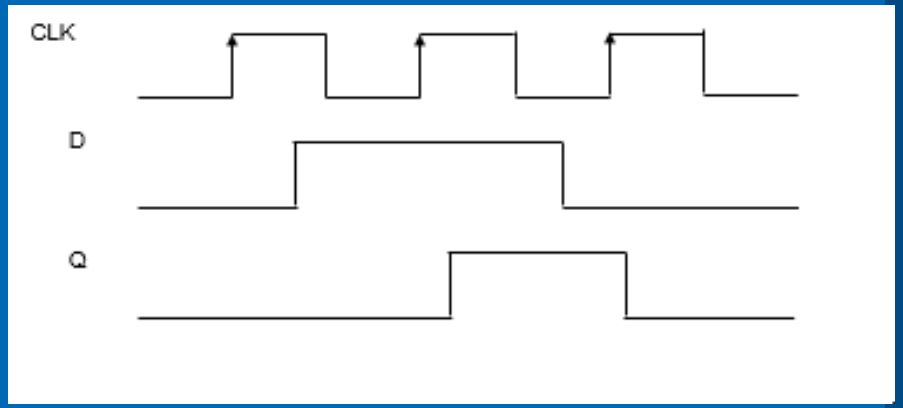
Symbol

The multiplexer can be described by the following Verilog statement:

```
assign m = (~s & x) | (s & y);
```

Knight Rider





Quartus and Design Tips

- When Quartus Prime Lite first starts for the very first time it might ask you about purchasing a license, select Run Quartus, all licenses are free for this lab.
- If things fail to compile, check your top Level Entity Setting → Setting → Top Level Entity and make sure that the module <design> matches your top level entity, including case.
- Check the LEDR[0] and LEDR[9] pins carefully in the Knight Rider lab and see if they sequence properly. If not, study the code carefully!
- Sometimes copy and paste from files into Quartus has carriage return formatting errors. Open the github URL in the breakout room and you can also download the files directly.

Learning more

- DE10-Lite development kit - $65 from Terasic with student discount
- http://fpgauniversity.intel.com – lots of helpful labs and tutorials
- Customer training site (google Intel FPGA training)
  - In catalog, search on university
- Practice makes perfect!
- Thanks for attending!