Embedded system Characteristics

- Need increase in performance and more functions often.
- Need Integration of more devices and chips
- Decrease in Power consumption
- Decrease in cost
- Decrease in size
- Decreased time to market

Implement using?

Microprocessor/ Microcontroller --
more commonly used.

ASIC-- for large volume products

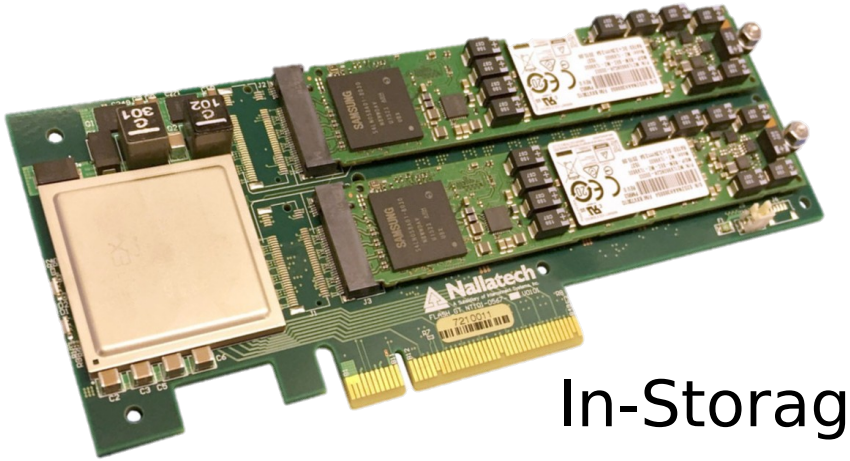
FPGA-- How easy or How fast ?

What Are FPGAs

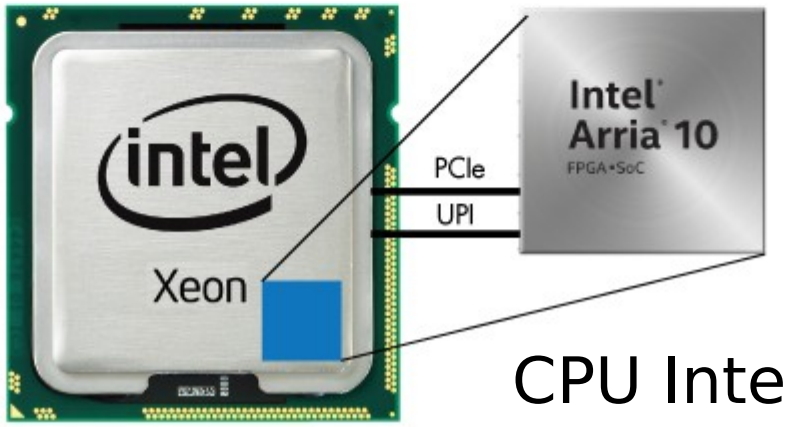
- ***Field-Programmable*** Gate Array
- Can be configured to act like any circuit – More later!
- Can do many things, but we focus on computation acceleration

FPGAs Come In Many Forms

PCIe-Attached



In-Storage



CPU Integrated

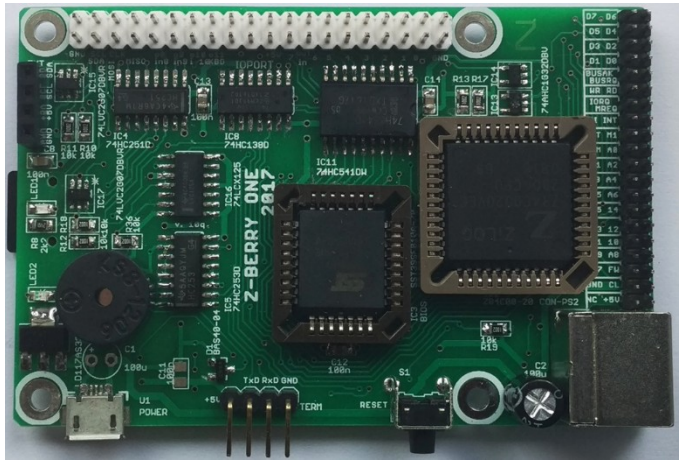
In-Network

How Is It Different From CPU/GPUs

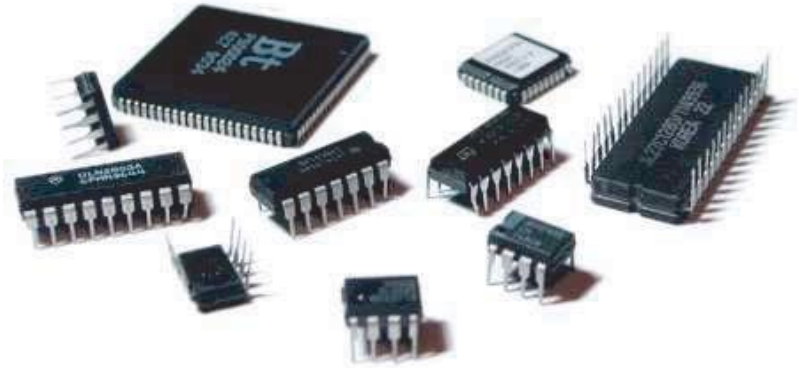
- GPU – The other major accelerator
- CPU/GPU hardware is fixed
  - “General purpose”
  - we write programs (sequence of instructions) for them
- FPGA hardware is not fixed
  - “Special purpose”
  - Hardware can be whatever we want
  - Will our hardware require/support software? Maybe!
- Optimized hardware is very efficient
  - GPU-level performance**
  - 10x power efficiency (300 W vs 30 W)

Analogy

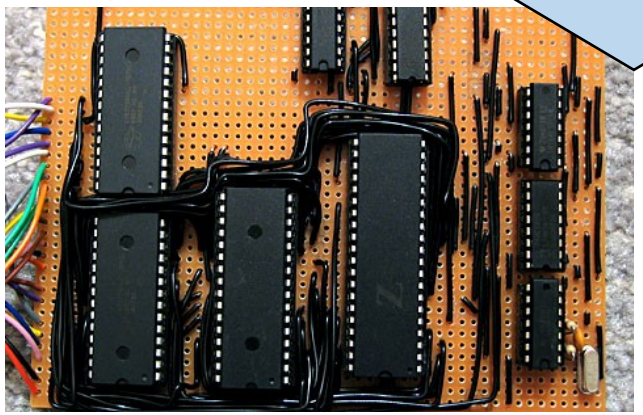
CPU/GPU comes with fixed circuits



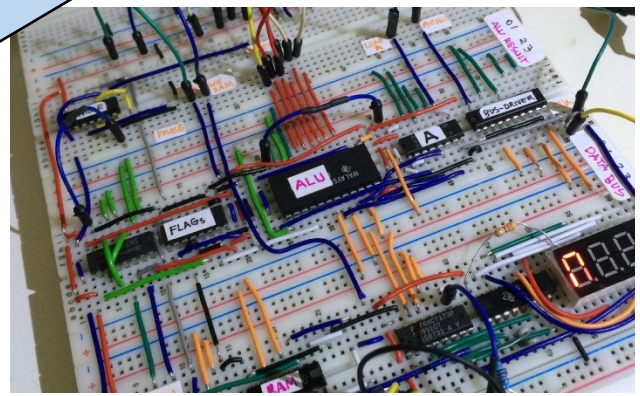
FPGA gives you a big bag of components



To build whatever



Could be a CPU/GPU



How Is It Different From ASICs

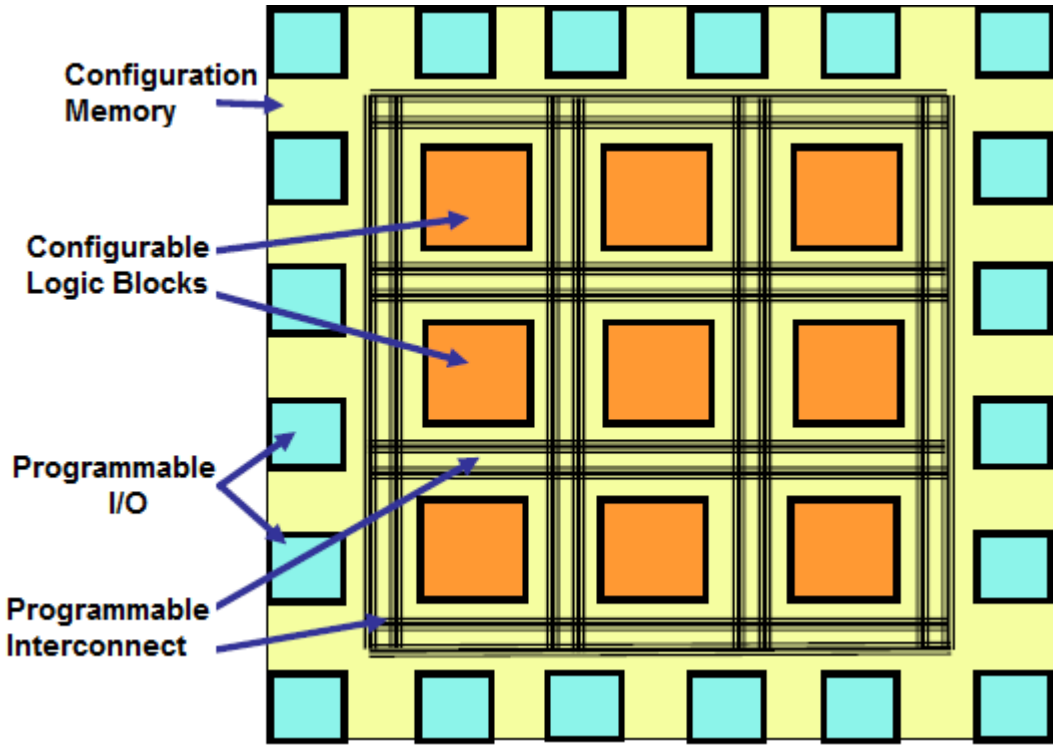
- ASIC (Application-Specific Integrated Circuit)
  - Special chip purpose-built for an application
  - E.g., ASIC bitcoin miner, Intel neural network accelerator
  - Function cannot be changed once expensively built
- \+ FPGAs can be ***field-programmed***
  - Function can be changed completely whenever
  - FPGA fabric ***emulates*** custom circuits
- \- Emulated circuits are not as efficient as bare-met
  - ~10x performance (larger circuits, faster clock)
  - ~10x power efficiency

FPGA Principles

- A Field-Programmable Gate Array (FPGA) is an integrated circuit that can be configured by the user to emulate any digital circuit as long as there are enough resources

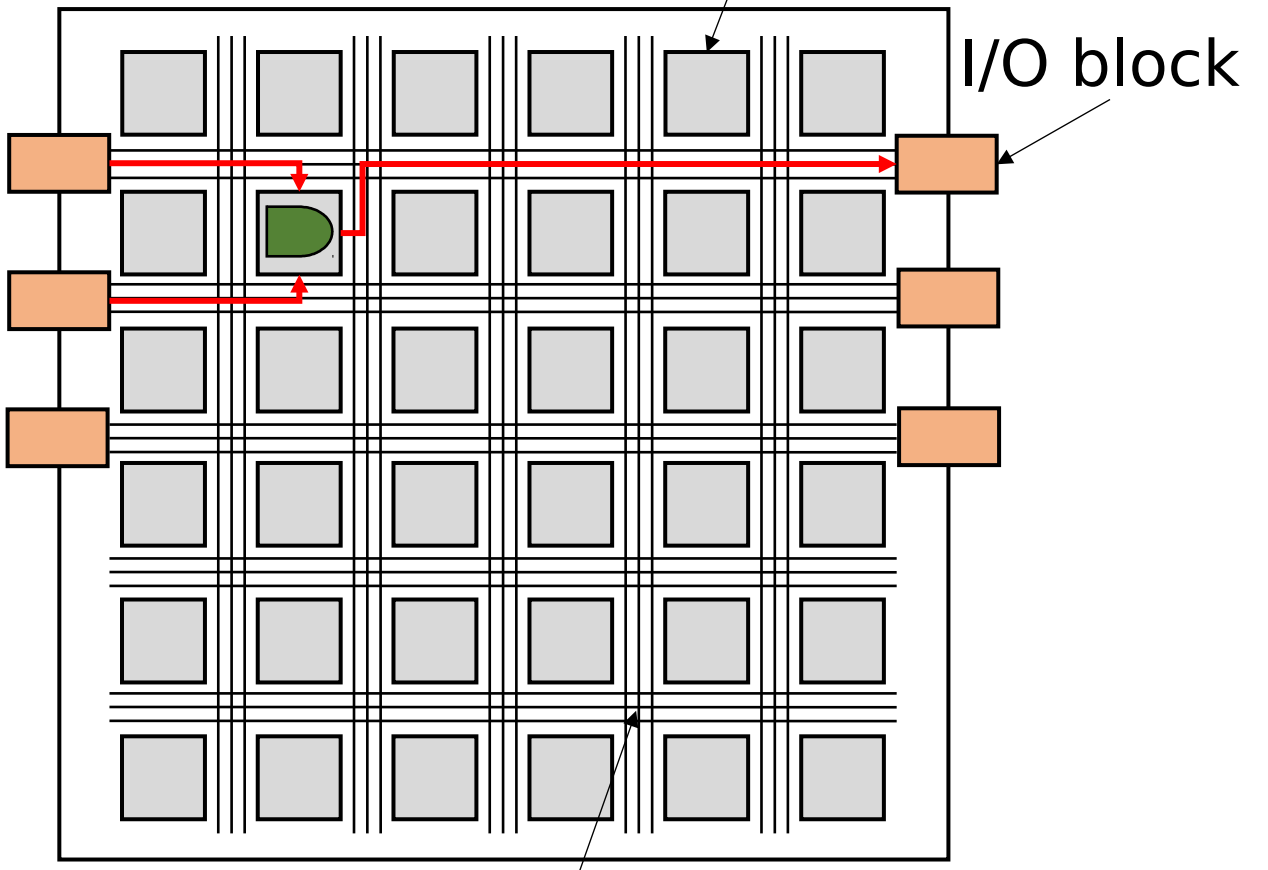
- An FPGA can be seen as an array of Configurable Logic Blocks (CLBs) connected through programmable interconnect (Switch Boxes)

Basic FPGA Architecture



•More recent FPGA architectures have small block RAM arrays (usually placed in center column), multipliers, processor cores, DSP cores w/ multipliers, and I/O cells along columns for BGAs.

Basic FPGA Architecture



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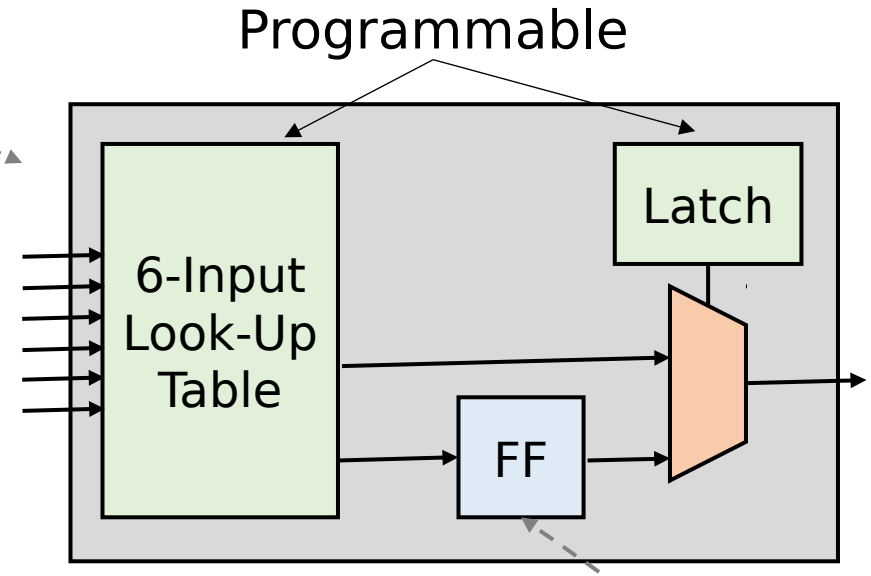
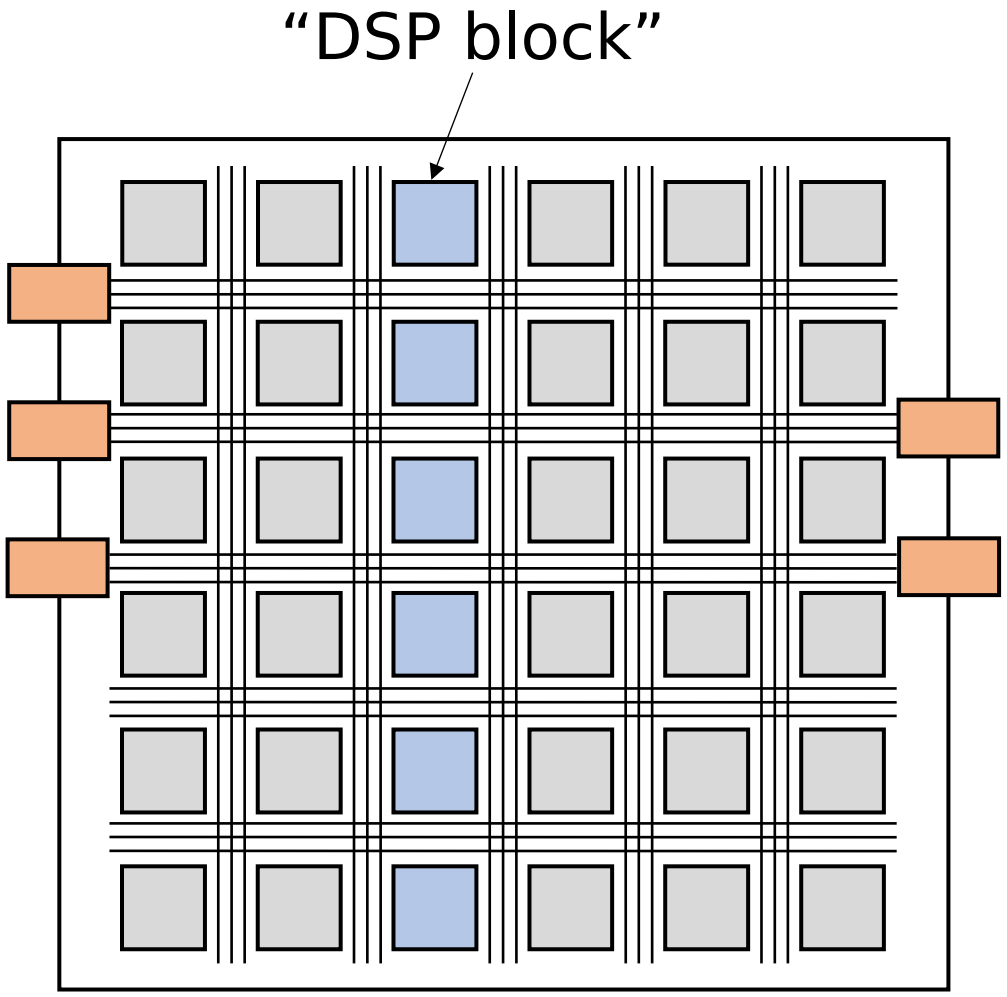


Ex) 2-LUT for “AND”

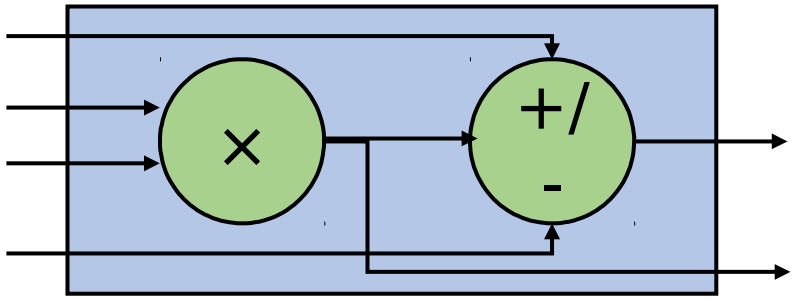
Input 1	Input 2	Output
0	0	0
0	1	0
1	0	0
1	1	1

Sequential circui
construction

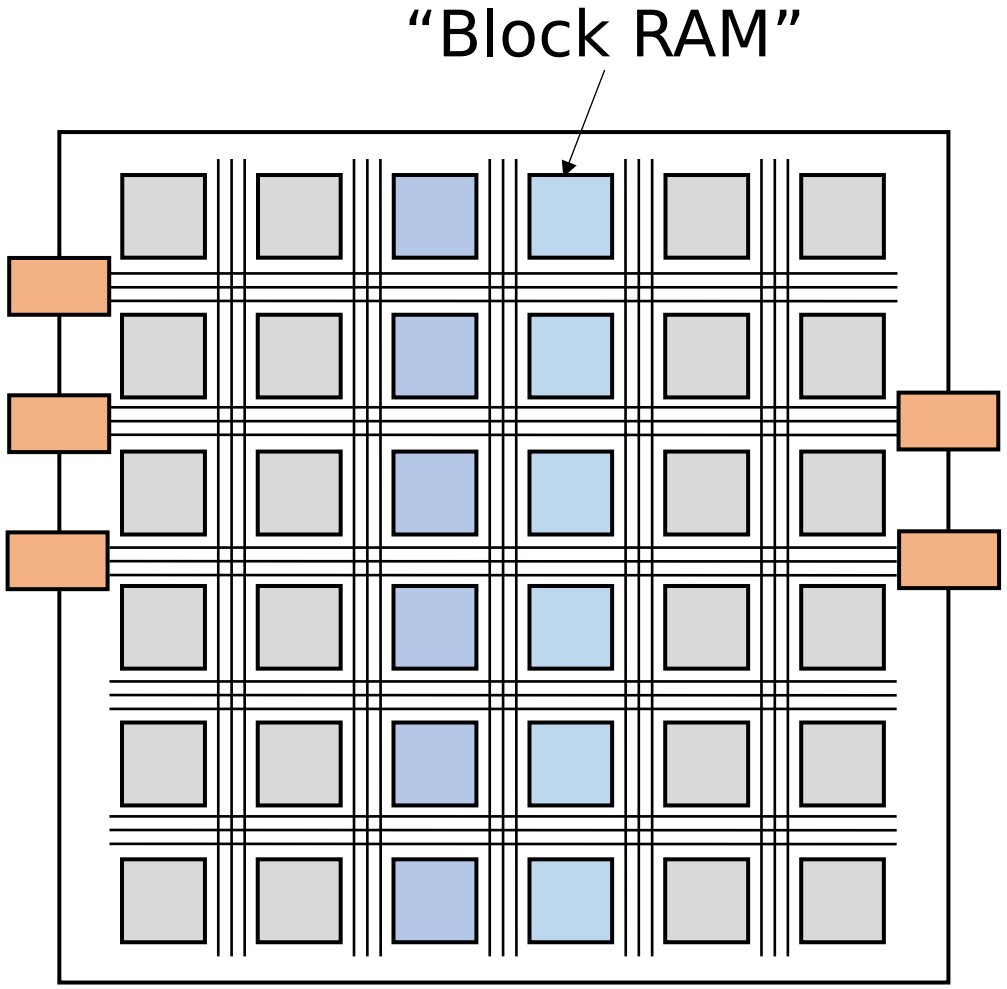
Basic FPGA Architecture – DSP Blocks



- CLBs act as gates – Many needed to implement high-level logic
- Arithmetic operation provided as efficient ALU blocks
  - “Digital Signal Processing (DSP) blocks”
  - Each block provides an adder + multiplier

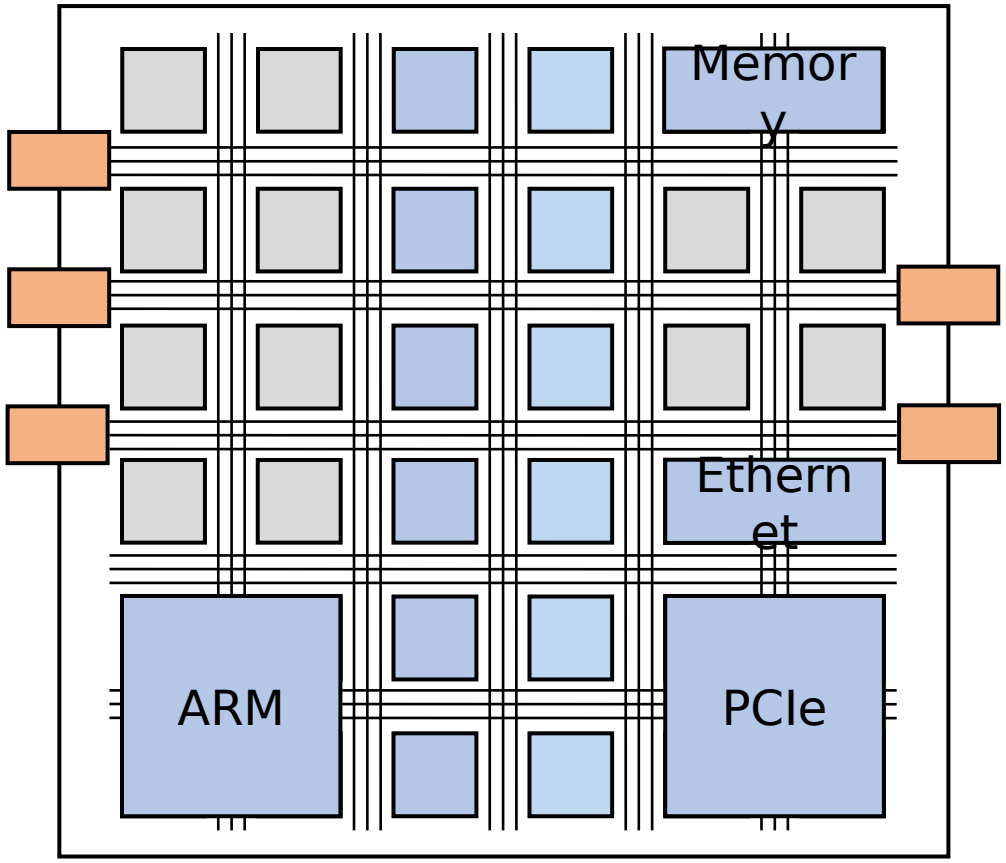


Basic FPGA Architecture – Block RAM



- CLB can act as flip-flops
  - (~1 bit/block) – tiny!
- Some on-chip SRAM provided as blocks
  - ~18/36 Kbit/block, MBs per chip
  - Massively parallel access to data → multi-TB/s bandwidth

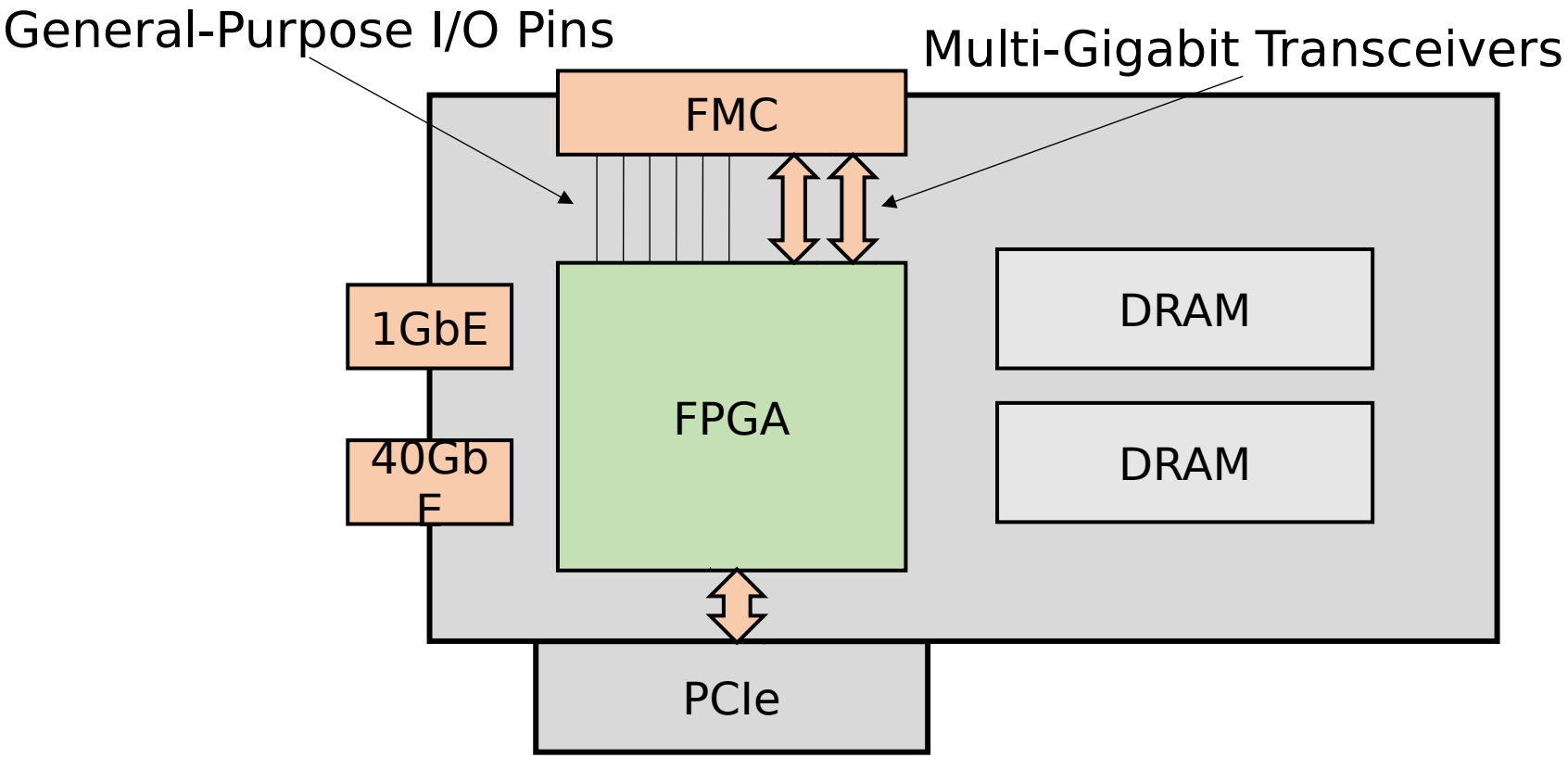
Basic FPGA Architecture – Hard Cores



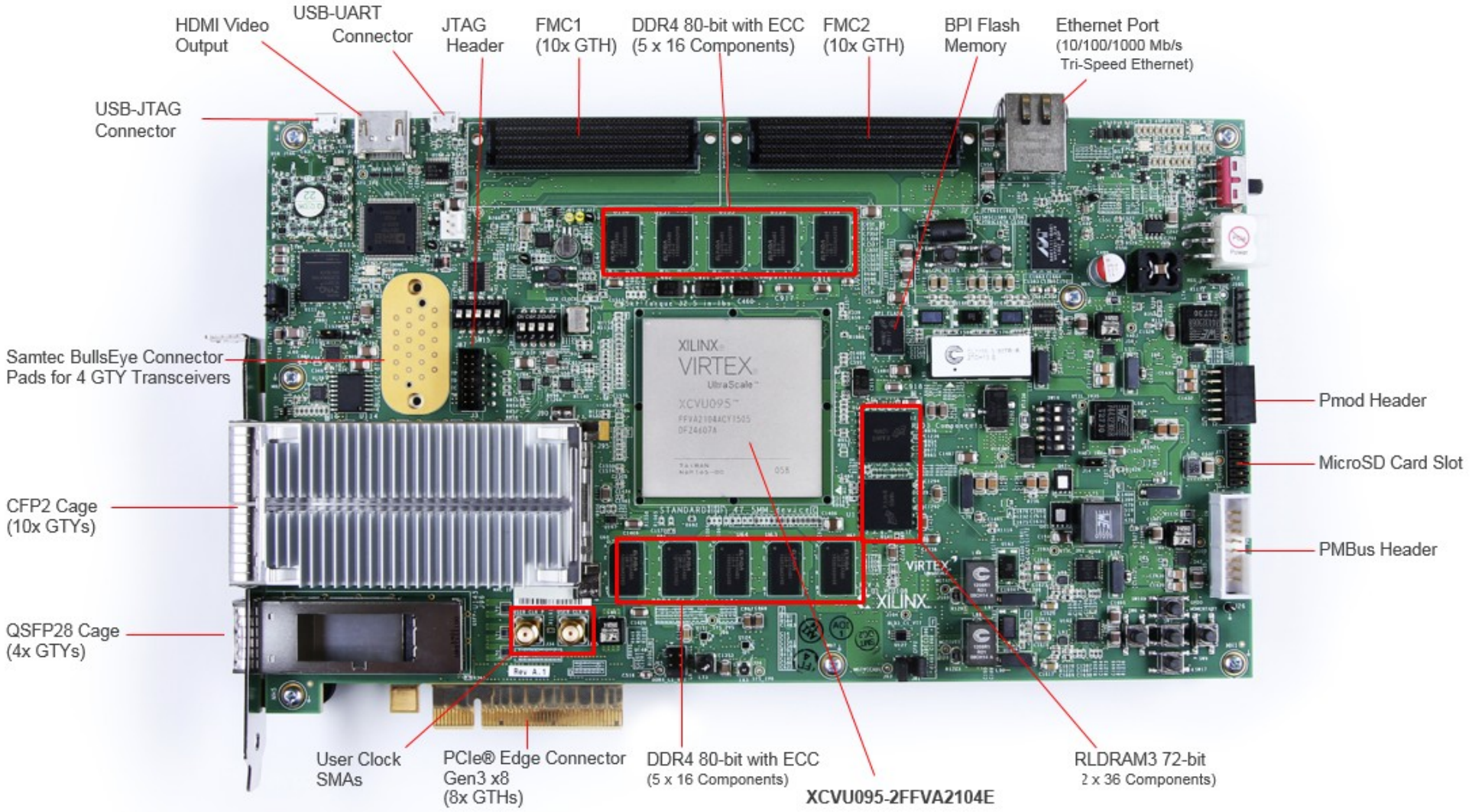
- Some functions are provided as efficient, non-configurable “hard cores”
  - Multi-core ARM cores (“Zynq” series)
  - Multi-Gigabit Transceivers
  - PCIe/Ethernet PHY
  - Memory controllers
  - …

Example Accelerator Card Architecture

- “FPGA Mezzanine Card” Expansion
  - Network Ports, Memory, Storage, PCIe, …



Example Accelerator Card (VCU108)



Advantages of Micros

- Flexible to program and change
- Available off the shelf as processor, board, or with interface chips
- You can choose from 100s of types of Micros to suit the application
- Easy to bring out a product in a short time
- Power consumption is medium
- Custom board can be designed after developing the product using generic boards.

Micros-- Disadvantages

- If you change the requirement or processor, new board is needed.
- Micro may contain more features than needed or may not have needed features.
- Cost depends on the volume.
- To increase performance, you need to increase the memory or change the processor etc.

ASIC--- Advantage

- Lowest per unit cost for high volume
- Can optimize power consumption, speed, performance, size, etc
- Initial development cost prevents others entering this market.

ASIC– Disadvantage

- Initial Cost is high and increases every year
- High Labor cost to design, test, modify etc
- Development is challenging
- Complex
- Becomes obsolete soon since technology or requirement changes.

FPGA Advantages

- **Designing with FPGA: Faster, Cheaper**
- **Ideal for customized designs**
  - Product differentiation in a fast-changing market
- **Offer the advantages of high integration**
  - High complexity, density, reliability
  - Low cost, power consumption, small physical size
- **Avoid the problems of ASICs**
  - high NRE cost, long delay in design and testing
  - increasingly demanding electrical issues

FPGA Advantages

- **Very fast custom logic**
  - massively parallel operation
- **Faster than microcontrollers and microprocessors**
  - much faster than DSP engines
- **More flexible than dedicated chipsets**
  - allows unlimited product differentiation
- **More affordable and less risky than ASICs**
  - no NRE, minimum order size, or inventory risk
- **Reprogrammable at any time**
  - in design, in manufacturing, after installation