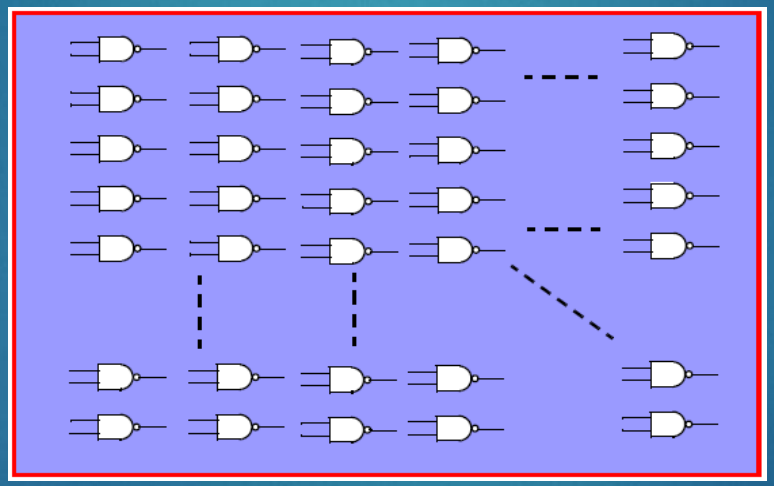
Introduction to FPGAs

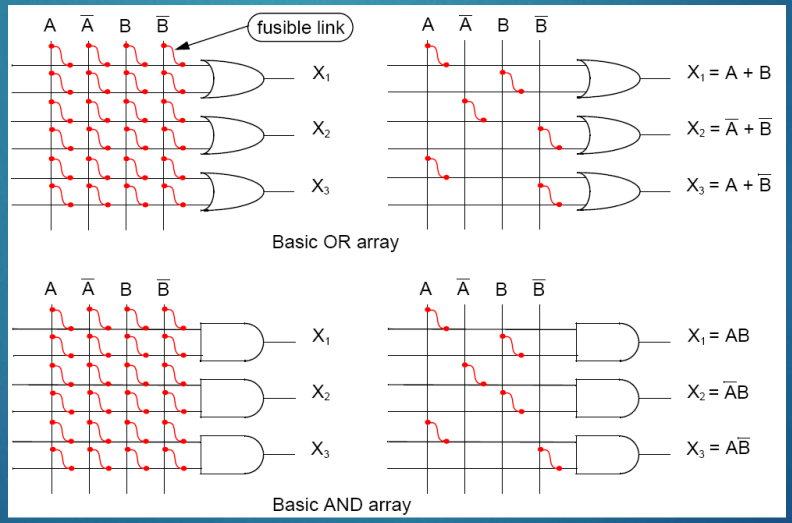
Historical Introduction

- In the beginning, digital design was done with the '74 series of chips.
- Some people would design their own chips based on Gate Arrays, which were nothing else than an array of NAND gates:



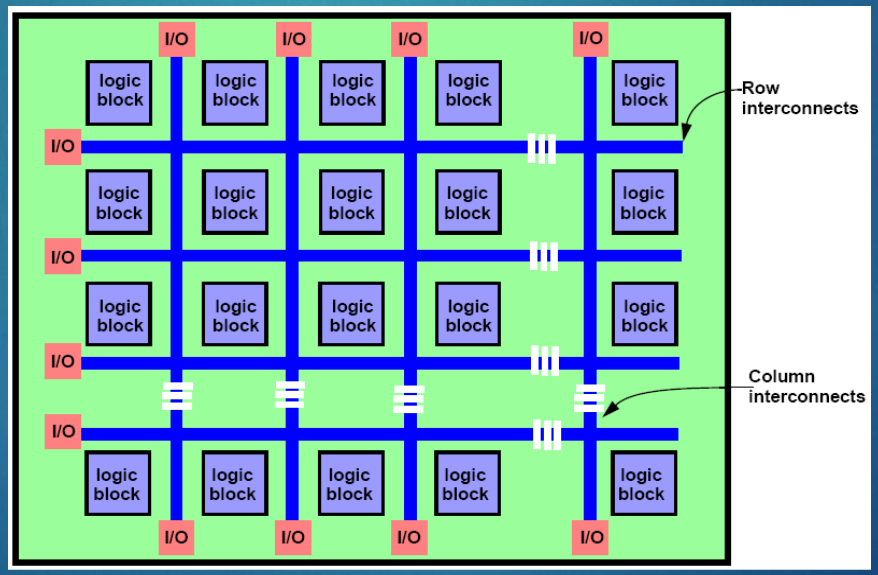
Historical Introduction

- The first programmable chips were PLAs (Programmable Logic Arrays): two level structures of AND and OR gates with user programmable connections.
- Programmable Array Logic devices were an improvement in structure and cost over PLAs. Today such devices are generically called Programmable Logic Devices (PLDs).



Historical introduction

- A complex PLD (CPLD) is nothing else than a collection of multiple PLDs and an interconnection structure.
- Compared to a CPLD, a Field Programmable Gate Array (FPGA) contains a much larger number of smaller individual blocks + large interconnection structure that dominates the entire chip.



Programmable logic

- An integrated circuit that can be programmed/reprogrammed with a digital logic of a curtain level.
- Started at late 70s and constantly growing
- Now available of up to approximately 700K Flip-Flops in a single chip.

What are FPGAs

Field-Programmable Gate Array

Keywords

Field-Programmable-
Programmable on Site

Gate Arrays- Array like structure

What are the advantages?

- **Can be configured to act like any circuit**

  Rapid Prototyping

- **Reconfigurable**

  Can be programmed many times

- **Saves Product to Market Time**

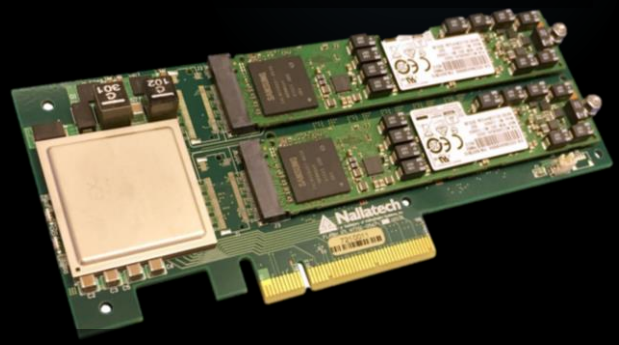
  - Short Development time
  - Flexible to changes
  - No need for ASIC expensive design and production
  - Fast time to market
  - Of the shelf solutions are available

FPGAs Come In Many Forms

PCIe-Attached

CPU Integrated

In-Network



In-Storage

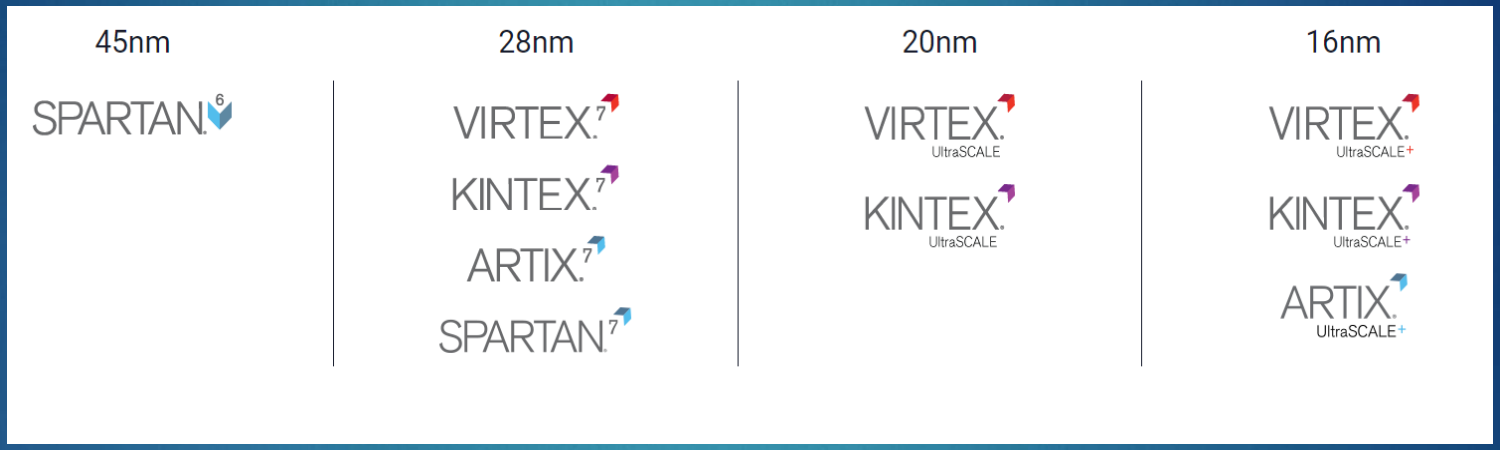
Image Source: https://itpeernetwork.intel.com/intel-processors-fpga-better-together/

https://www.compsource.com/buy/AU50P00GPQG/Xilinx-6217

Manufacturers

- Xilinx
- Altera
- Lattice
- Actel

XILINX FPGAs



https://www.xilinx.com/products/silicon-devices/fpga.html

Xilinx FPGAs

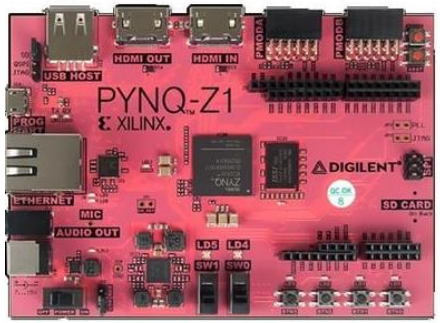
https://www.xilinx.com/products/silicon-devices/soc.html

FPGAs in Lab

Zynq Ultrascale

Artix 7

Zynq/Xilinx Zynq-7000



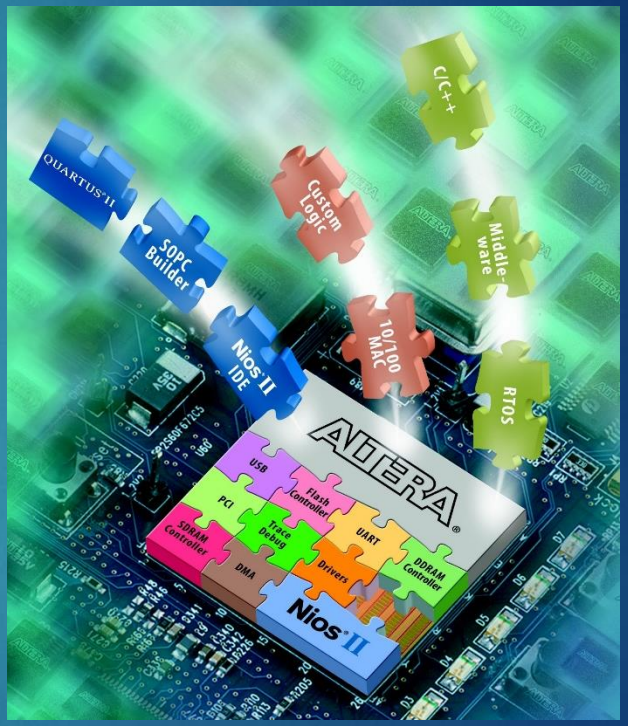
Zynq

Common FPGA Applications

- High Performance Computing
- Medical Equipment
- Data Servers
- Consumer Electronics
- Computer Networking
- Aerospace and Defense
- Etc.

Special FPGA functions

- Internal SRAM
- Embedded Multipliers and DSP blocks
- Embedded logic analyzer
- Embedded CPUs
- High speed I/O (~10GHz)
- DDR/DDRII/DDRIII SDRAM interfaces



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-metal
  - ~10x performance (larger circuits, faster clock)
  - ~10x power efficiency

FPGA vs ICs

- Single FPGA may replace several ICs
- No wire-wrapping
- Less power consumption, faster speed
- Increased Reliability

FPGA vs ASIC

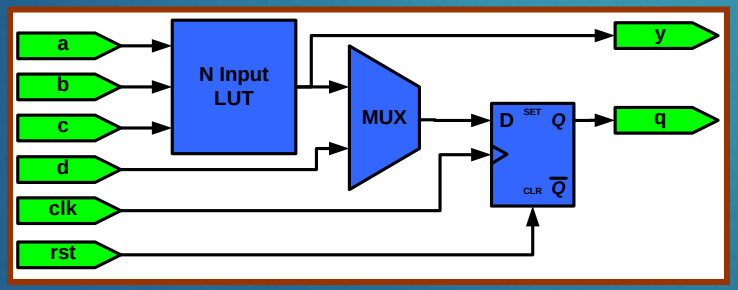
FPGAs are programmable on site

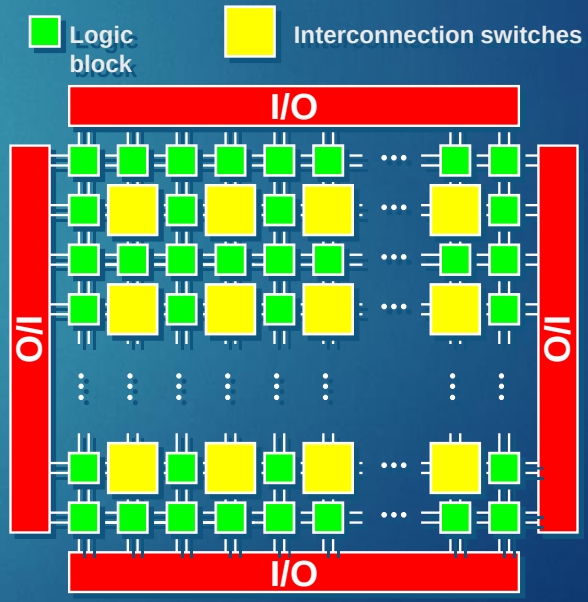
ASICs have considerable design cost and time

ASICs have to be fabricated, mistakes are costly

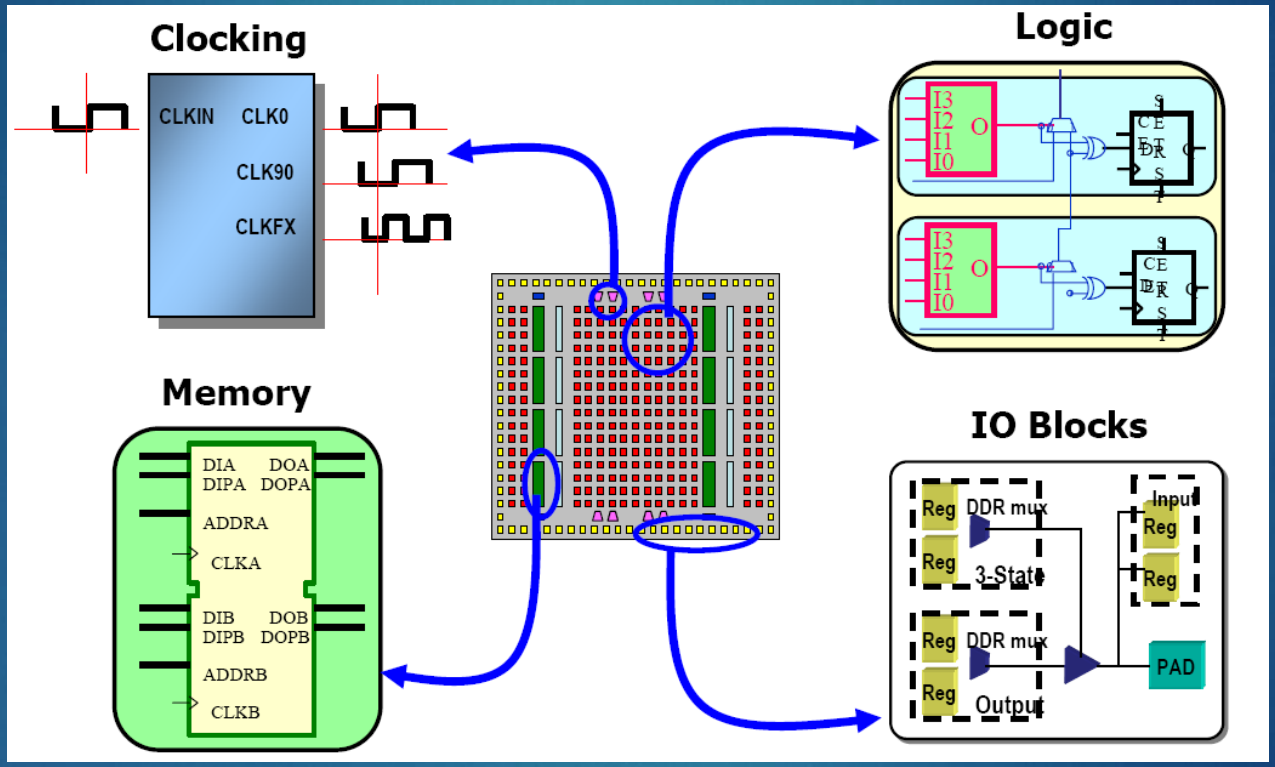
FPGA - Field Programmable Gate Array

- **Programmable logic blocks (Logic Element "LE")**
  Implement combinational and sequential logic. Based on LUT and DFF.
- **Programmable I/O blocks**
  Configurable I/Os for external connections supports various voltages and tri-states.
- **Programmable interconnect**
  Wires to connect inputs , outputs and logic blocks.
  - clocks
  - short distance local connections
  - long distance connections across chip

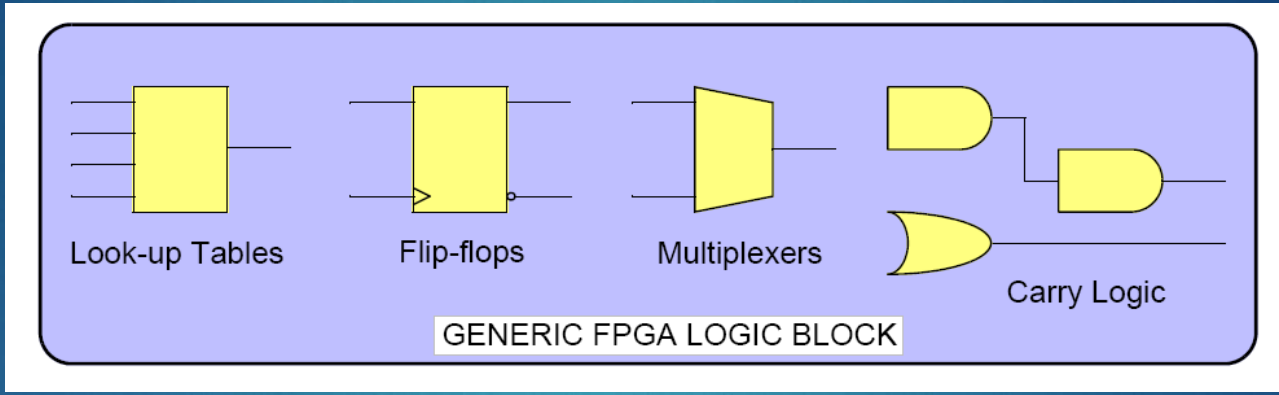




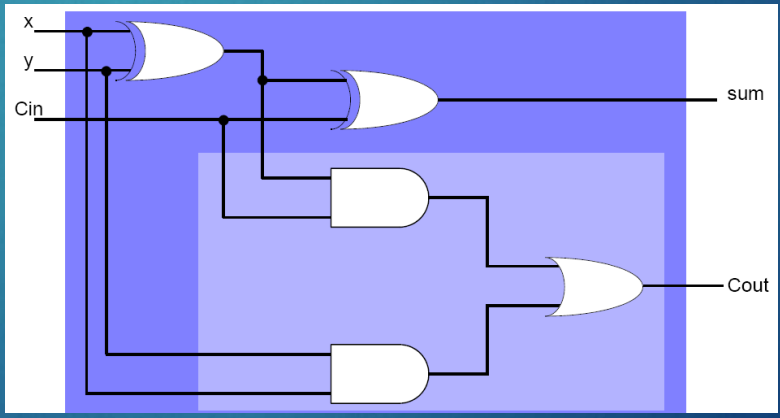
Basic FPGA architecture



The logic block: a summary view



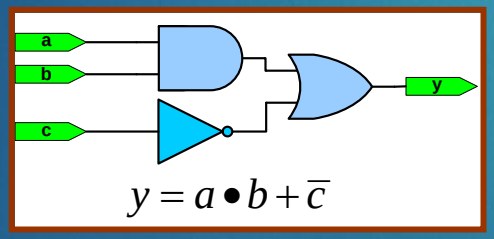
Example: using a LUT as a full adder.



Configuring LUT

- LUT is a RAM with data width of 1bit.
- The contents are programmed at power up

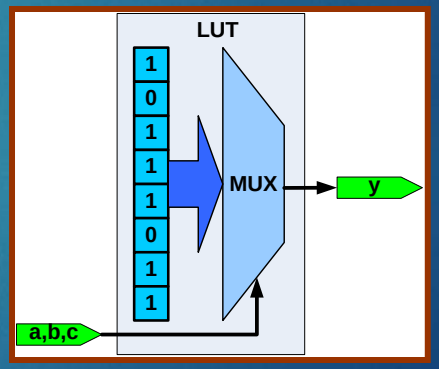
Required Function



Truth Table

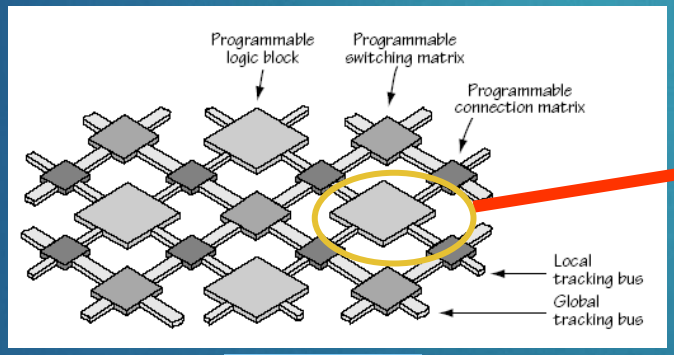
a	b	c	y
0	0	0	1
0	0	1	0
0	1	0	1
0	1	1	1
1	0	0	1
1	0	1	0
1	1	0	1
1	1	1	1

Programmed LUT

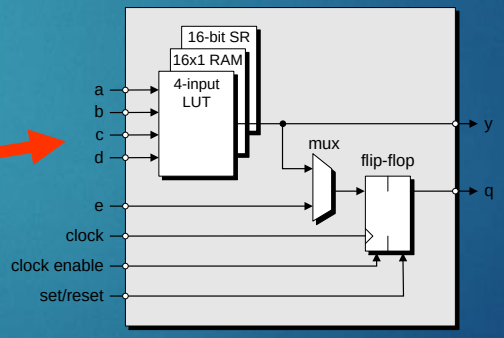


Logic Blocks

- Logic Functions implemented in Look Up Table LUTs.
- Flip-Flops. Registers. Clocked Storage elements.
- Multiplexers (select 1 of N inputs)



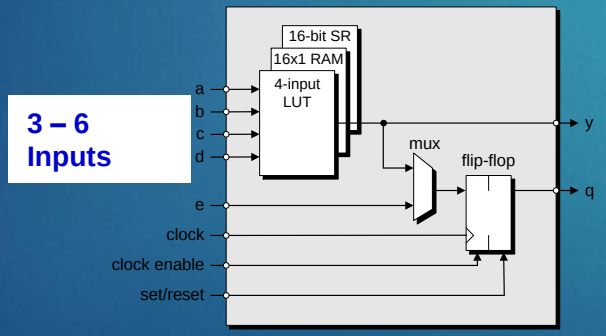
FPGA Fabric

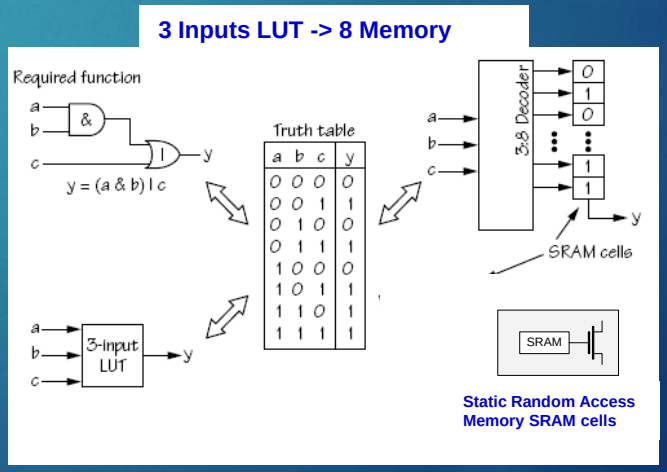


Logic Block

Look Up Tables LUTs

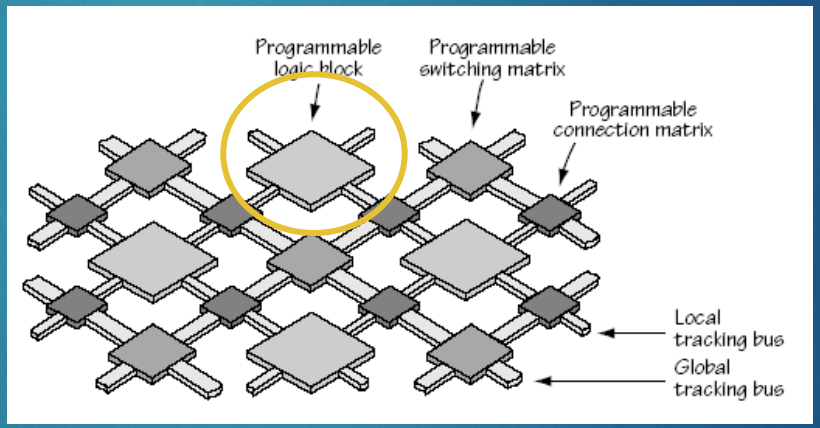
- LUT contains Memory Cells to implement small logic functions
- Each cell holds ‘0’ or ‘1’ .
- Programmed with outputs of Truth Table
- Inputs select content of one of the cells as output
- Configured by re-programmable SRAM memory cells





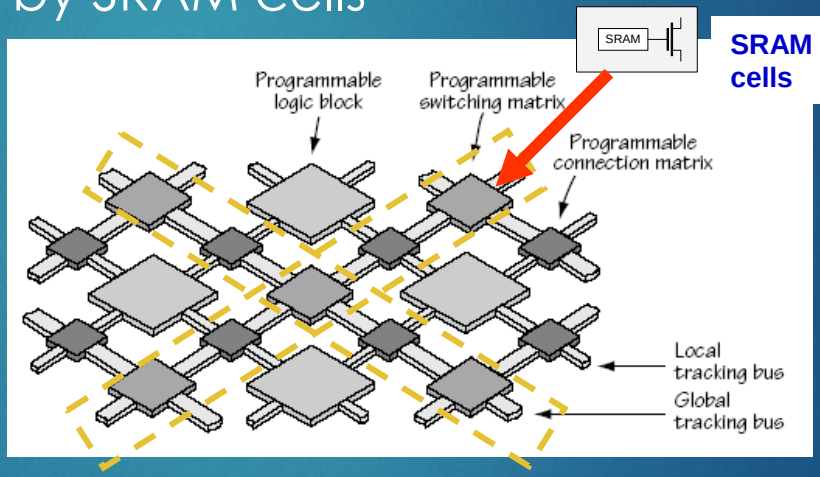
Logic Blocks

- Larger Logic Functions built up by connecting many Logic Blocks together

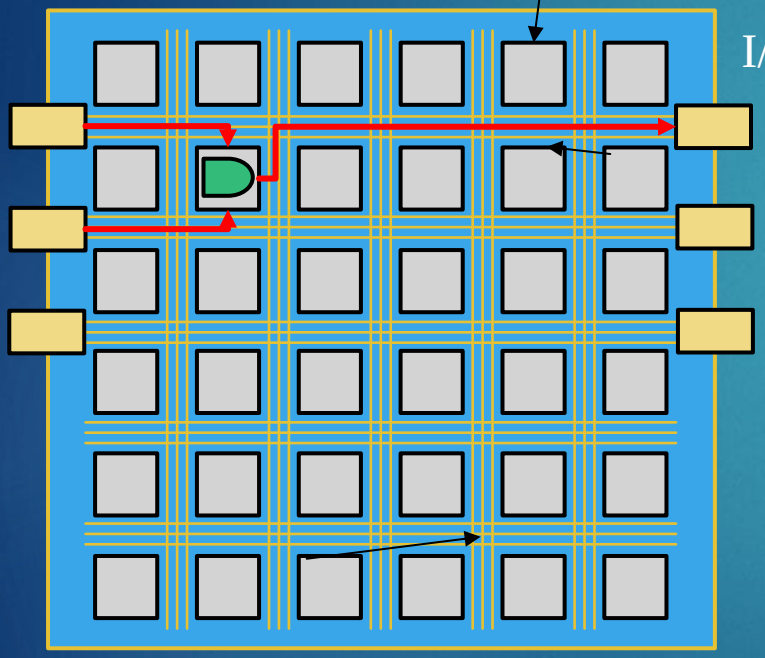


Logic Blocks

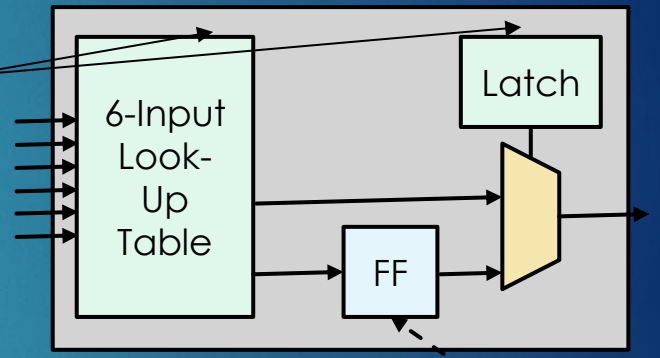
- Larger Logic Functions built up by connecting many Logic Blocks together
- Determined by SRAM cells



Basic FPGA Architecture



Programmable

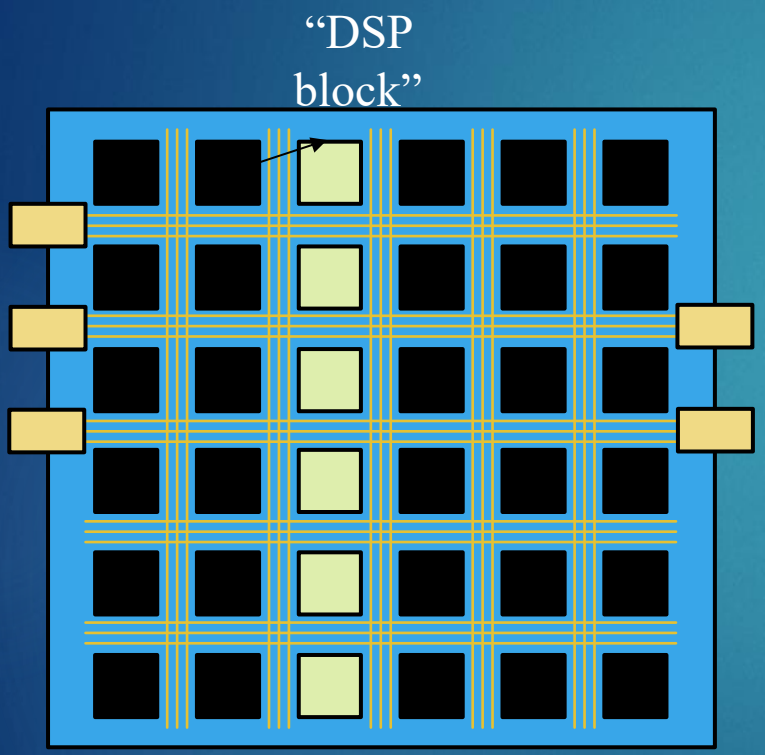


Sequential circuit construction

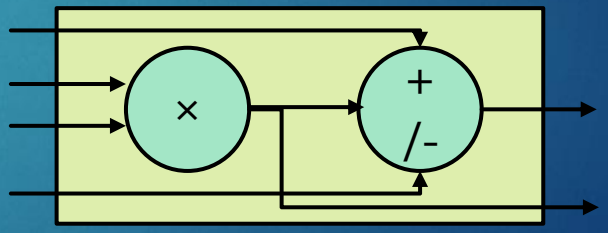
Ex) 2-LUT for "AND"

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

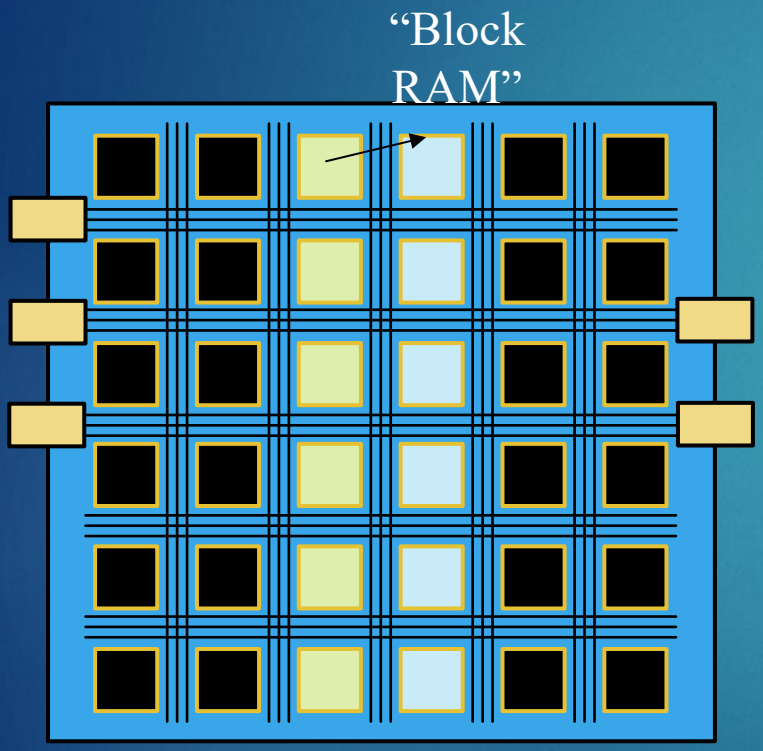
Basic FPGA Architecture – DSP Blocks



- 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

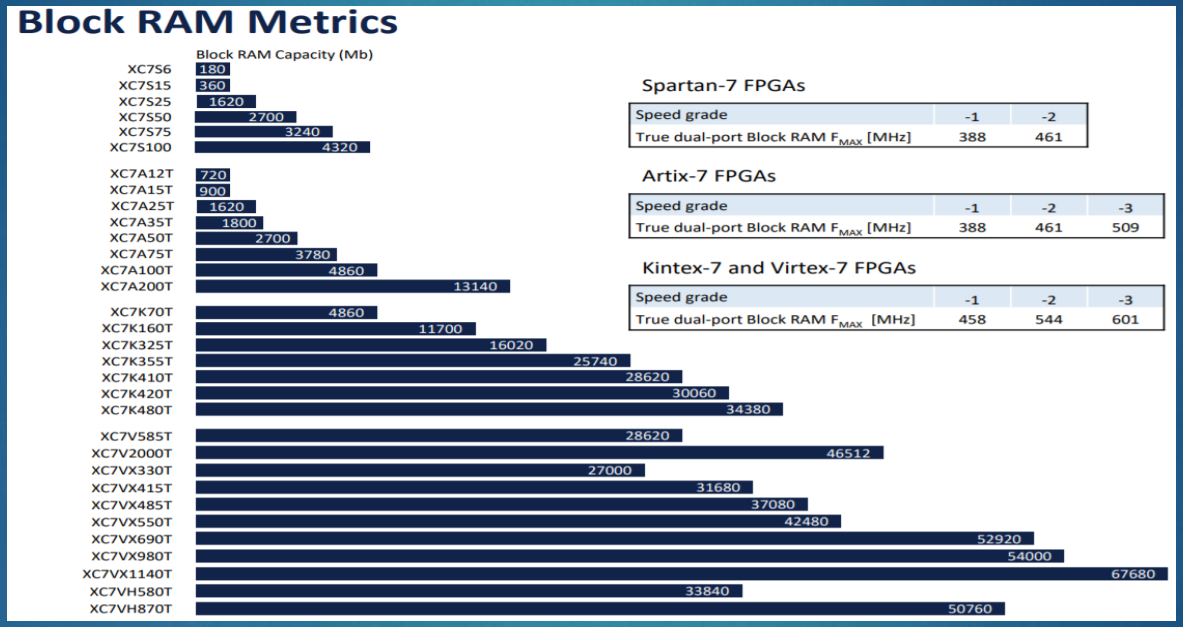


Basic FPGA Architecture – Block RAM



- 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

Block RAM Capacity in different Xilinx FPGAs



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