L12: Reconfigurable Logic Architectures

Acknowledgements:

Materials in this lecture are courtesy of the following people and used with permission.

- Randy H. Katz (University of California, Berkeley, Department of Electrical Engineering & Computer Science)

- Gaetano Borriello (University of Washington, Department of Computer Science & Engineering, http://www.cs.washington.edu/370)

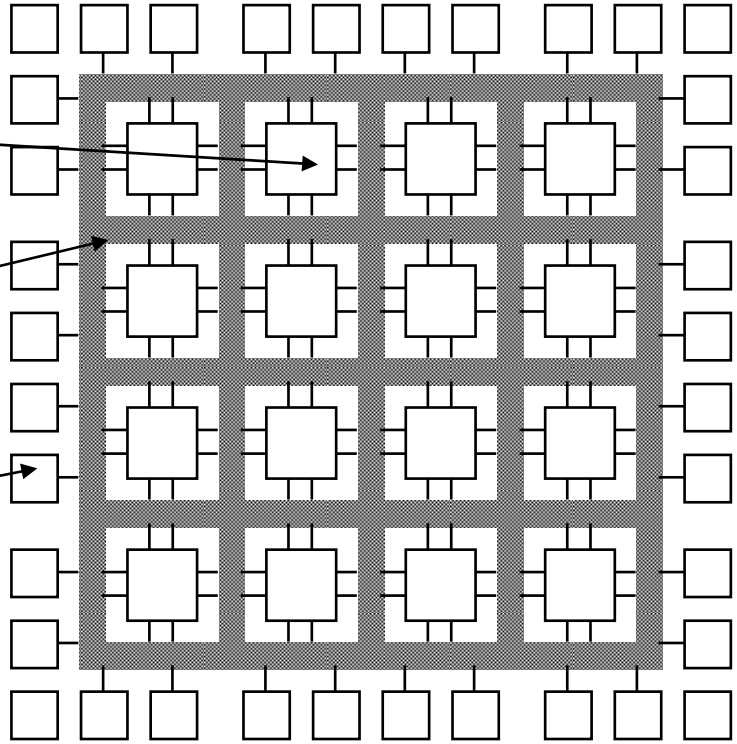
- Frank Honore

History of Computational Fabrics

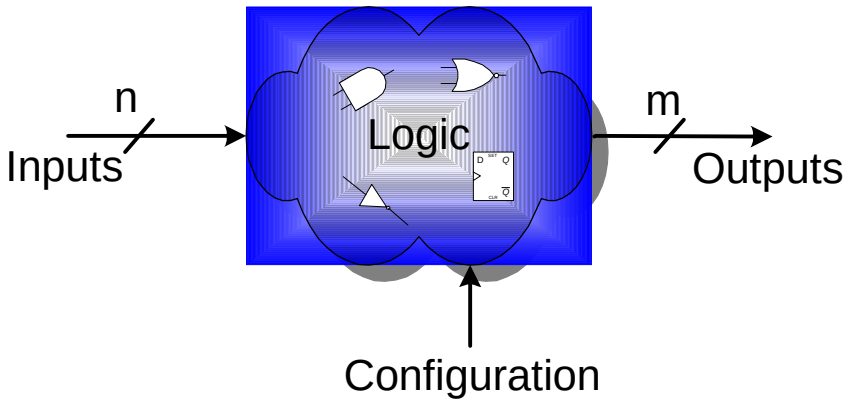
- Discrete devices: relays, transistors (1940s-50s)
- Discrete logic gates (1950s-60s)
- Integrated circuits (1960s-70s)
  - e.g. TTL packages: Data Book for 100's of different parts
- Gate Arrays (IBM 1970s)
  - Transistors are pre-placed on the chip & Place and Route software puts the chip together automatically – only program the interconnect (mask programming)
- Software Based Schemes (1970's- present)
  - Run instructions on a general purpose core
- Programmable Logic (1980's to present)
  - A chip that be reprogrammed after it has been fabricated
  - Examples: PALs, EPROM, EEPROM, PLDs, FPGAs
  - Excellent support for mapping from Verilog
- ASIC Design (1980's to present)
  - Turn Verilog directly into layout using a library of standard cells
  - Effective for high-volume and efficient use of silicon area

Reconfigurable Logic

- **Logic blocks**
  - To implement combinational and sequential logic
- **Interconnect**
  - Wires to connect inputs and outputs to logic blocks
- **I/O blocks**
  - Special logic blocks at periphery of device for external connections

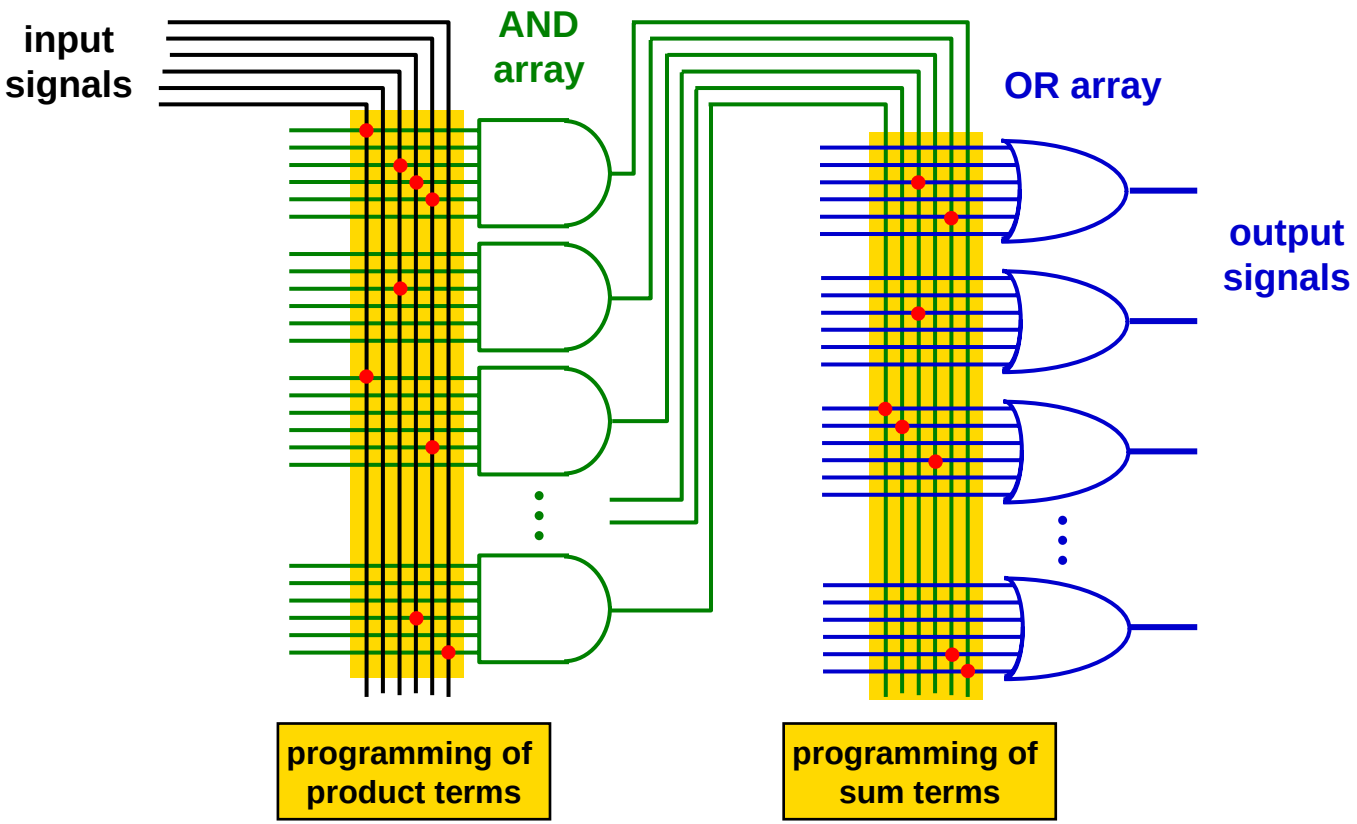


- **Key questions:**
  - How to make logic blocks programmable? (after chip has been fabbed!)
  - What should the logic granularity be?
  - How to make the wires programmable? (after chip has been fabbed!)
  - Specialized wiring structures for local vs. long distance routes?
  - How many wires per logic block?



Programmable Array Logic (PAL)

- Based on the fact that any combinational logic can be realized as a sum-of-products
- PALs feature an array of AND-OR gates with programmable interconnect



Inside the 22v10 PAL

- Each input pin (and its complement) sent to the AND array
- OR gates for each output can take 8-16 product terms, depending on output pin
- “Macrocell” block provides additional output flexibility...

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Cypress PAL CE22V10

From Cypress

From Lattice Semiconductor

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- **Outputs may be registered or combinational, positive or inverted**

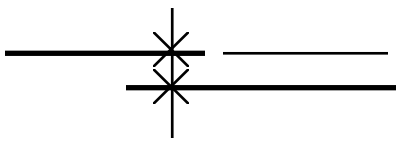
Anti-Fuse-Based Approach (Actel)

Rows of programmable logic building blocks

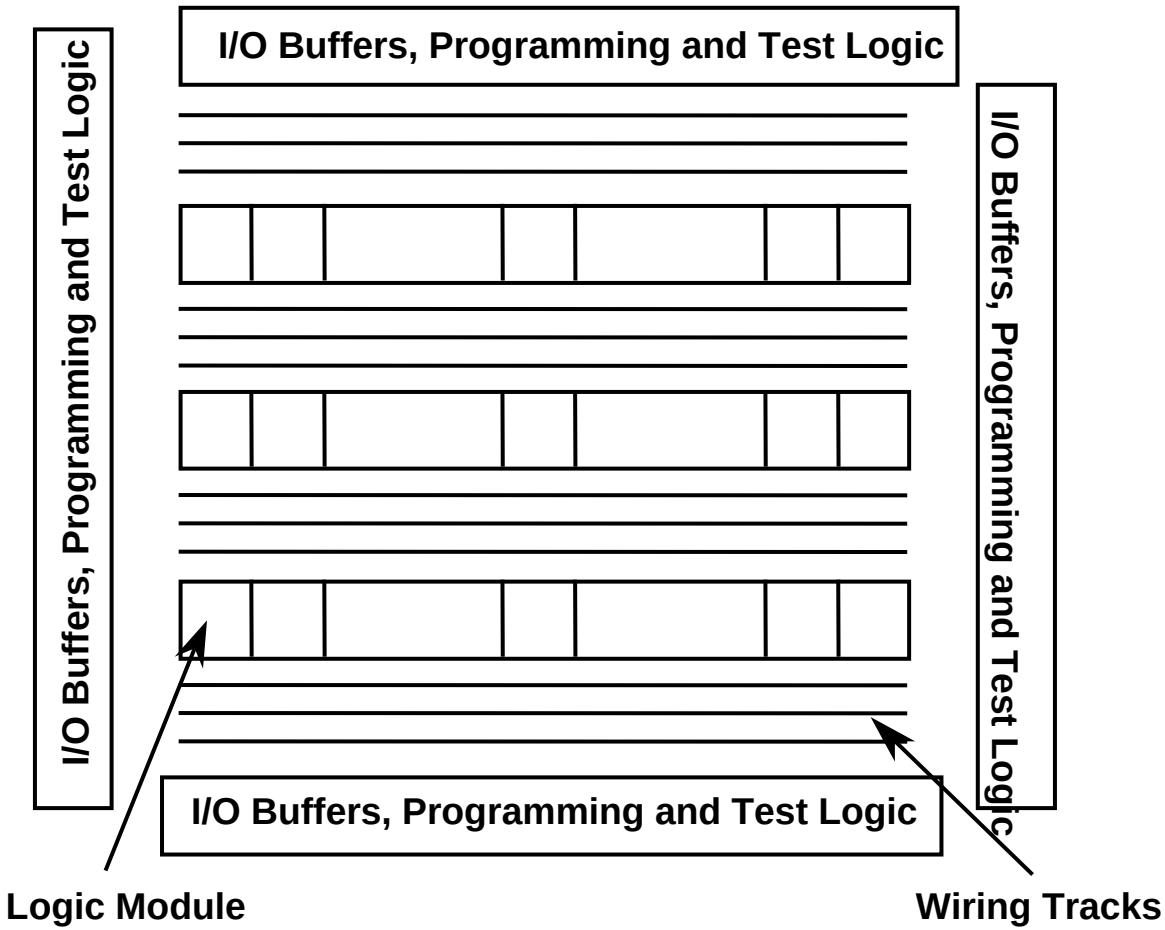
+

rows of interconnect

Anti-fuse Technology: Program Once



Use Anti-fuses to build up long wiring runs from short segments

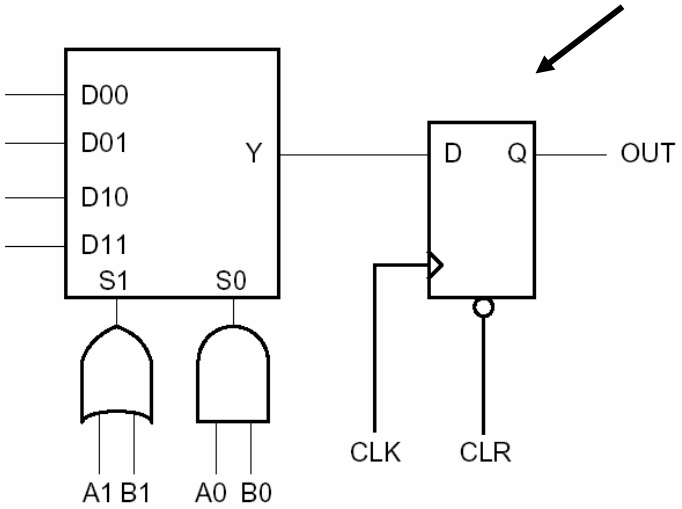


8 input, single output combinational logic blocks

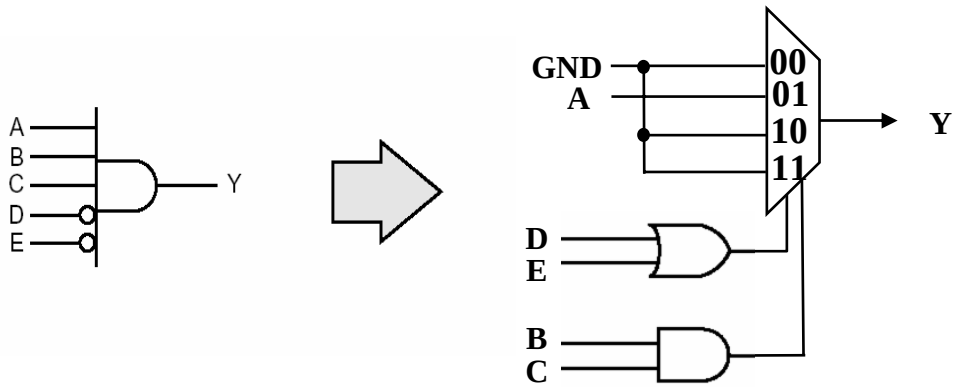
FFs constructed from discrete cross coupled gates

Actel Logic Module

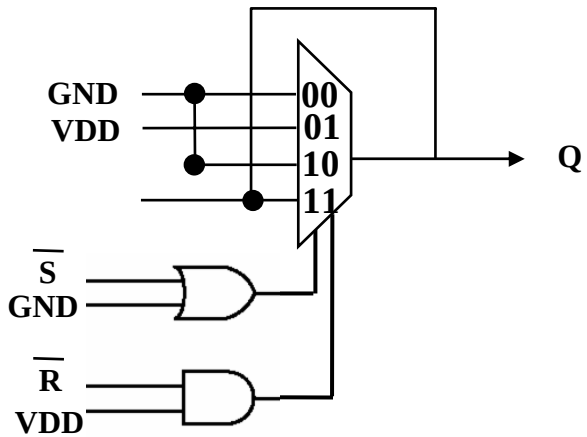
Combinational block does not have the output FF



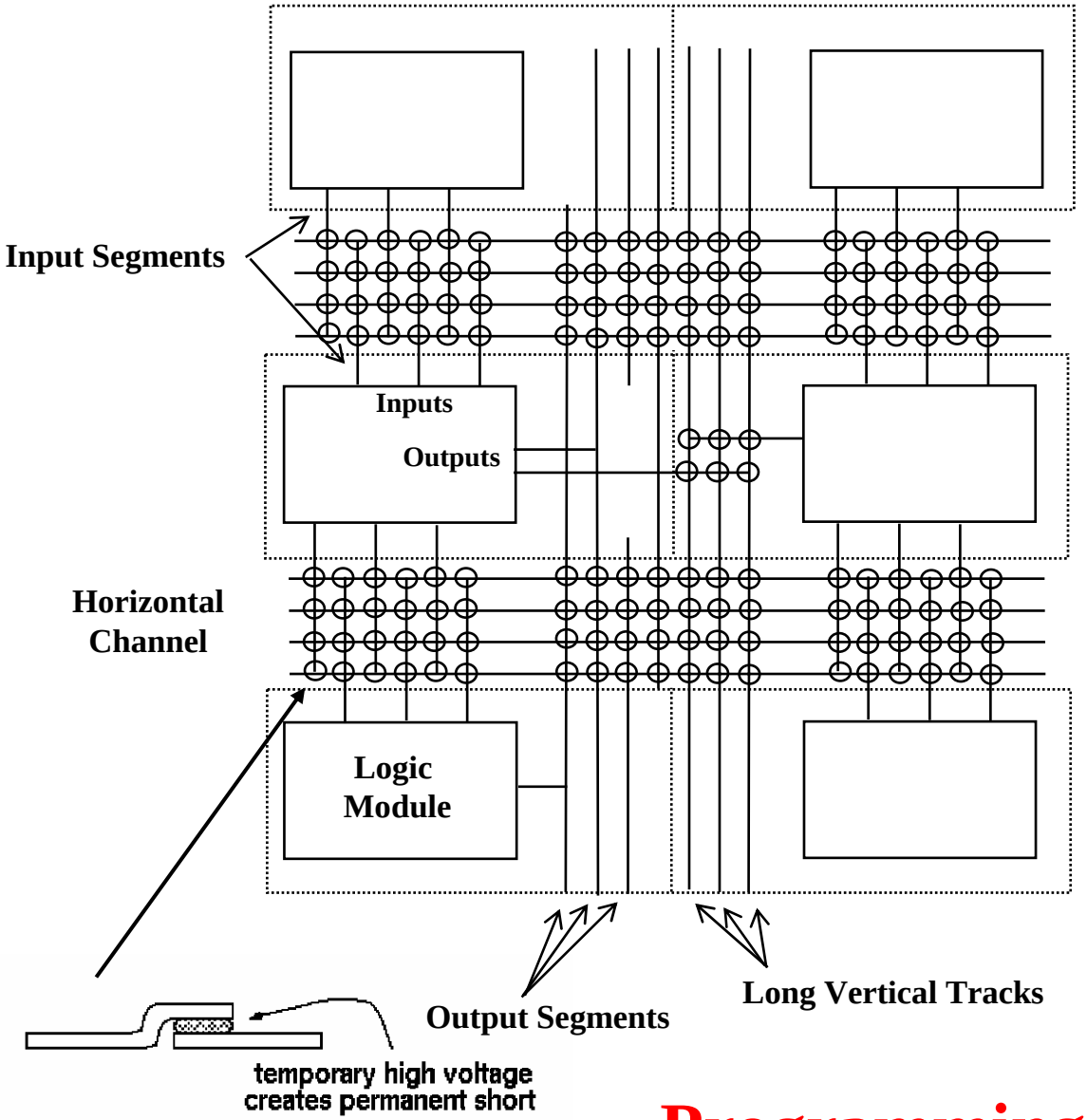
Example Gate Mapping

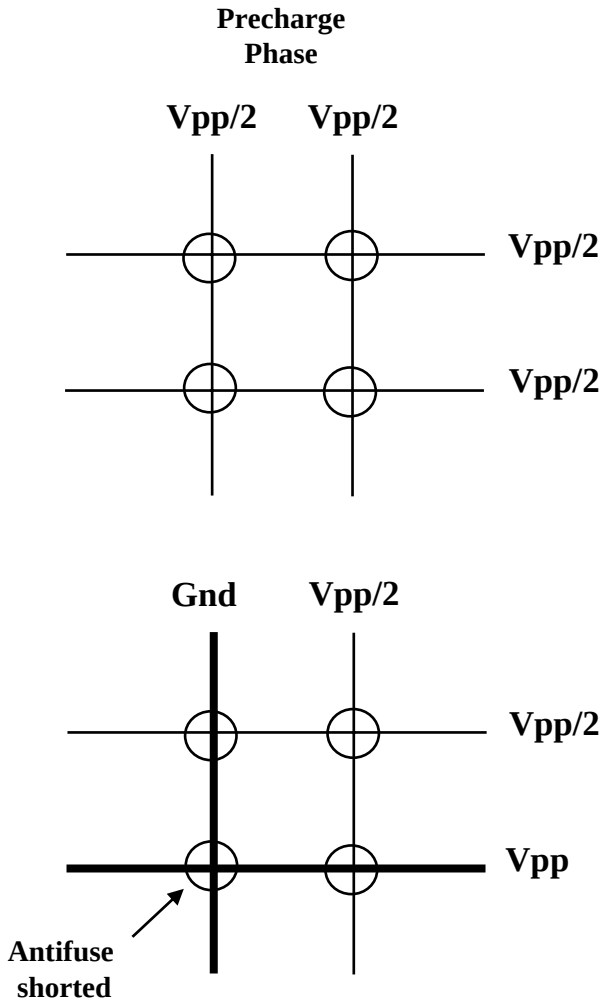


S-R Flip-Flop



Actel Routing & Programming

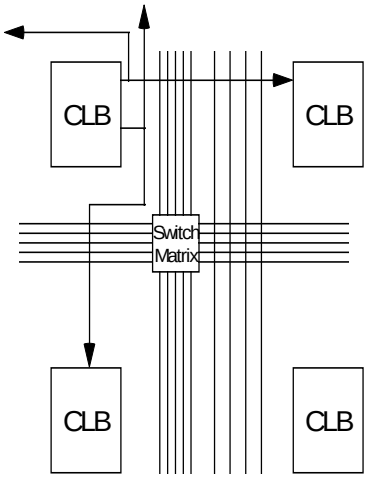




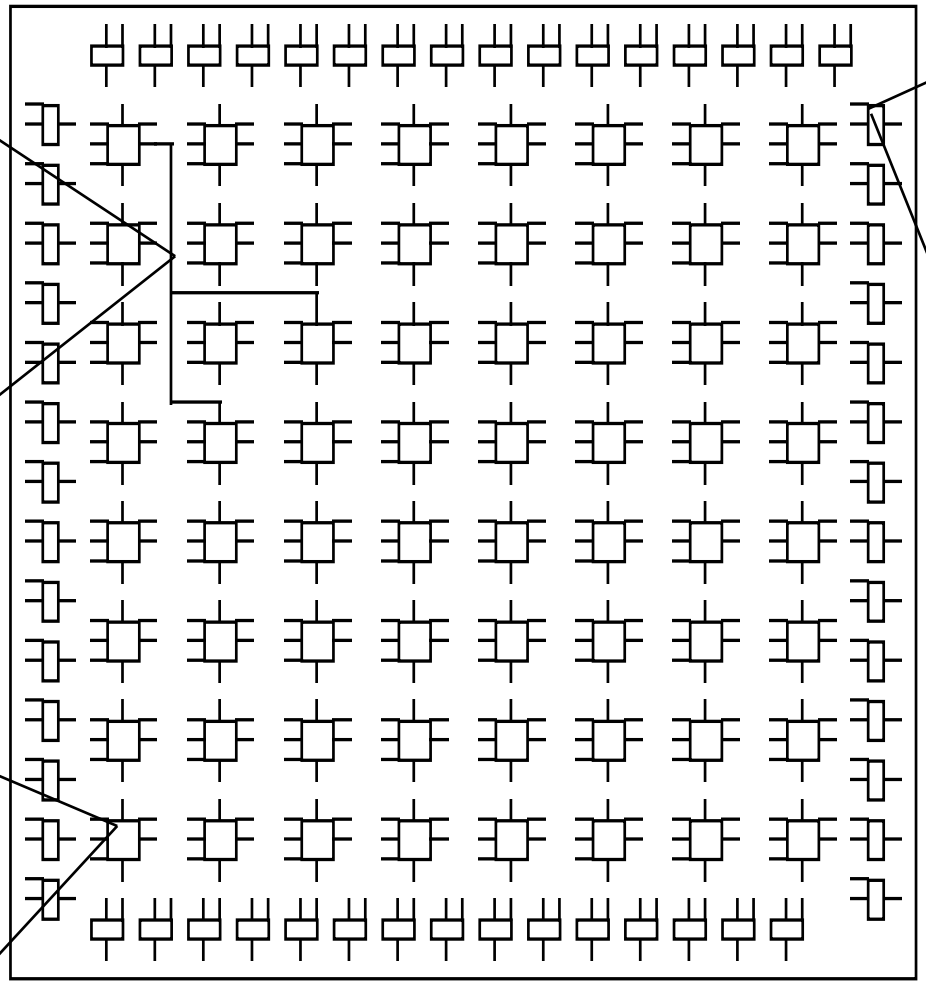
Programming an Antifuse

Programming is Permanent (one time)

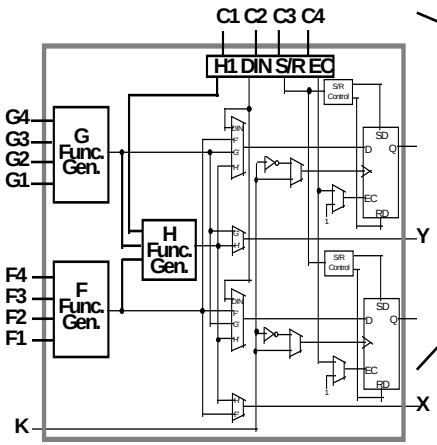
RAM Based Field Programmable Logic - Xilinx

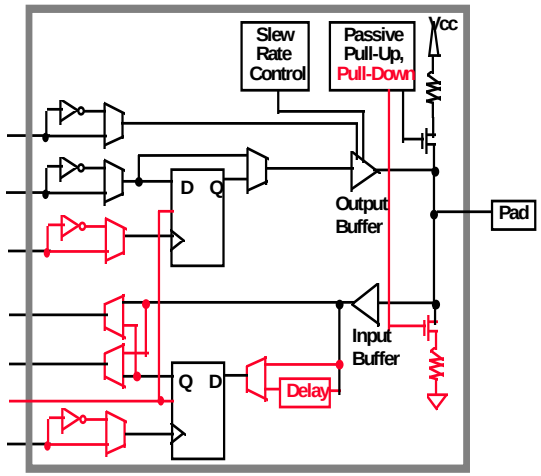


Programmable Interconnect



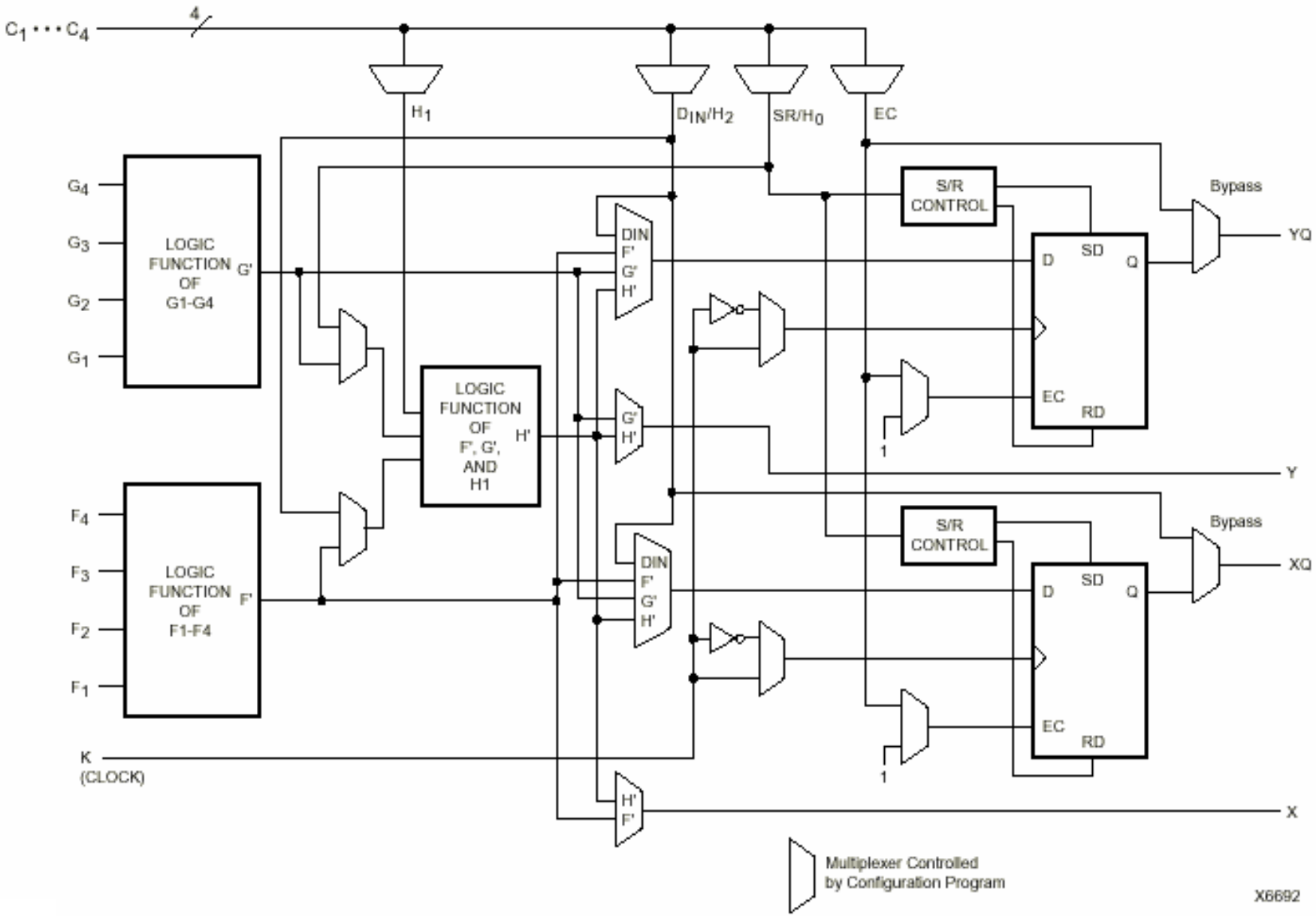
Configurable Logic Blocks (CLBs)





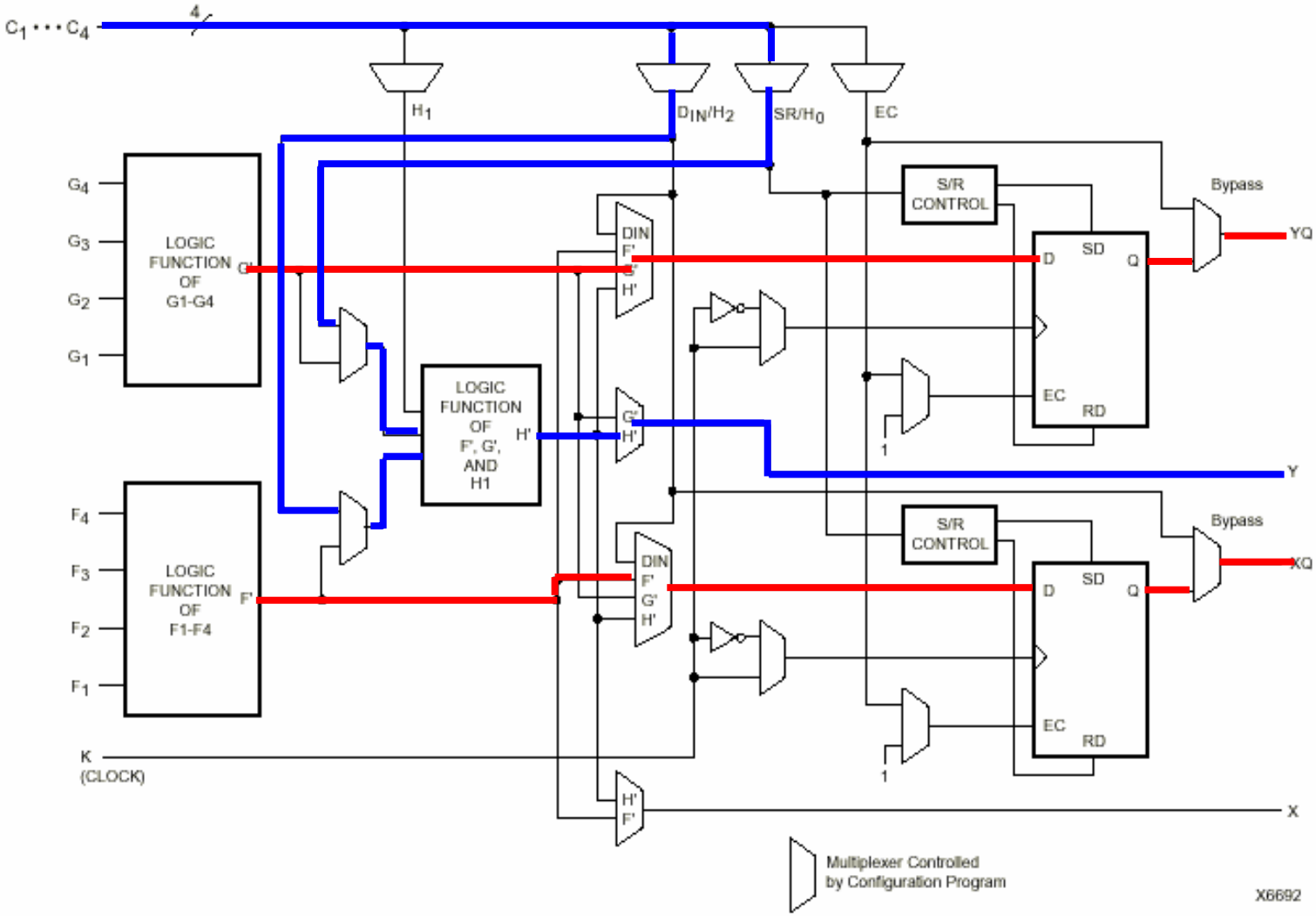
I/O Blocks (IOBs)

The Xilinx 4000 CLB



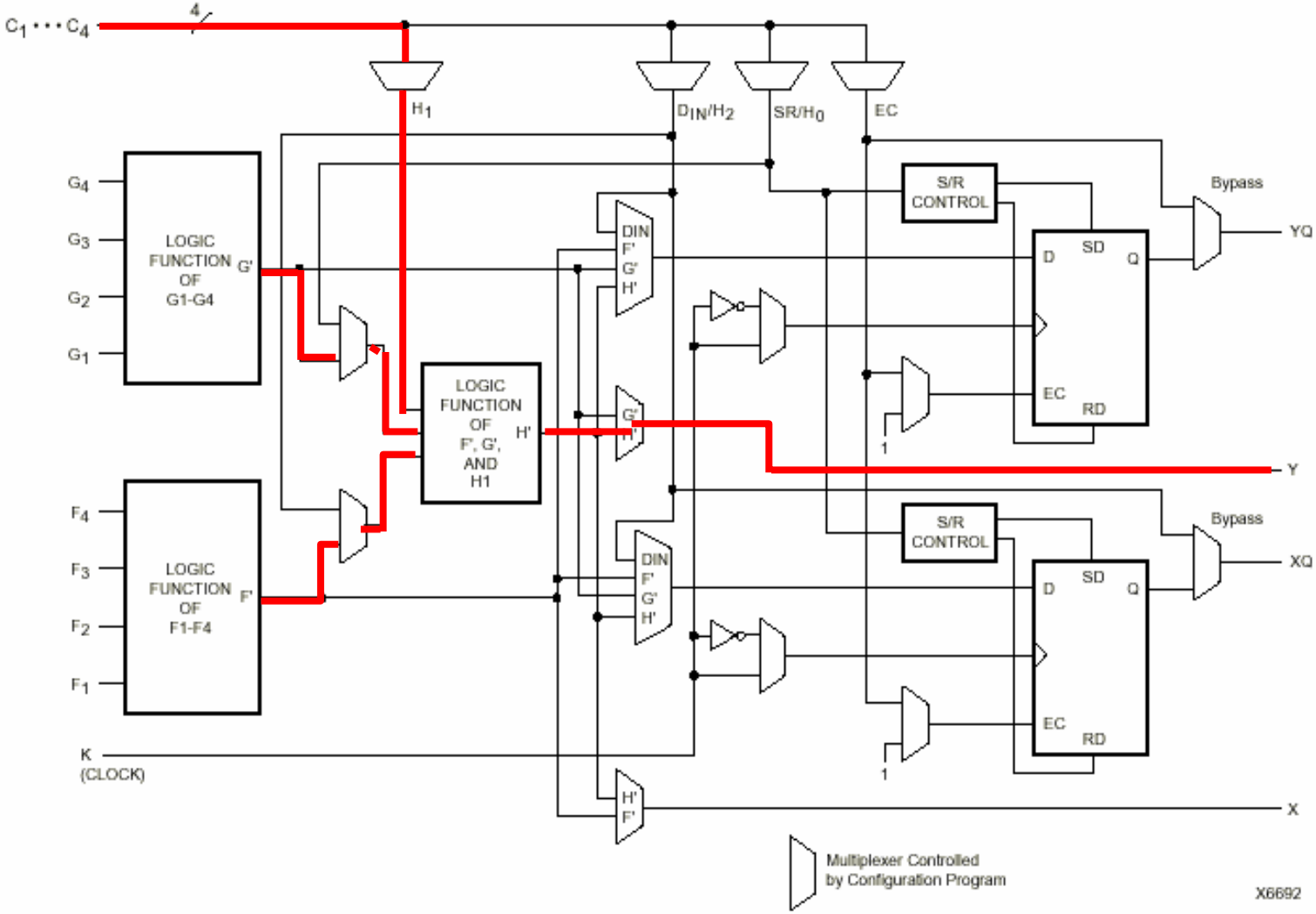
Simplified Block Diagram of XC4000 Series CLB (RAM and Carry Logic functions not shown)

Two 4-input Functions, Registered Output and a Two Input Function



Simplified Block Diagram of XC4000 Series CLB (RAM and Carry Logic functions not shown)

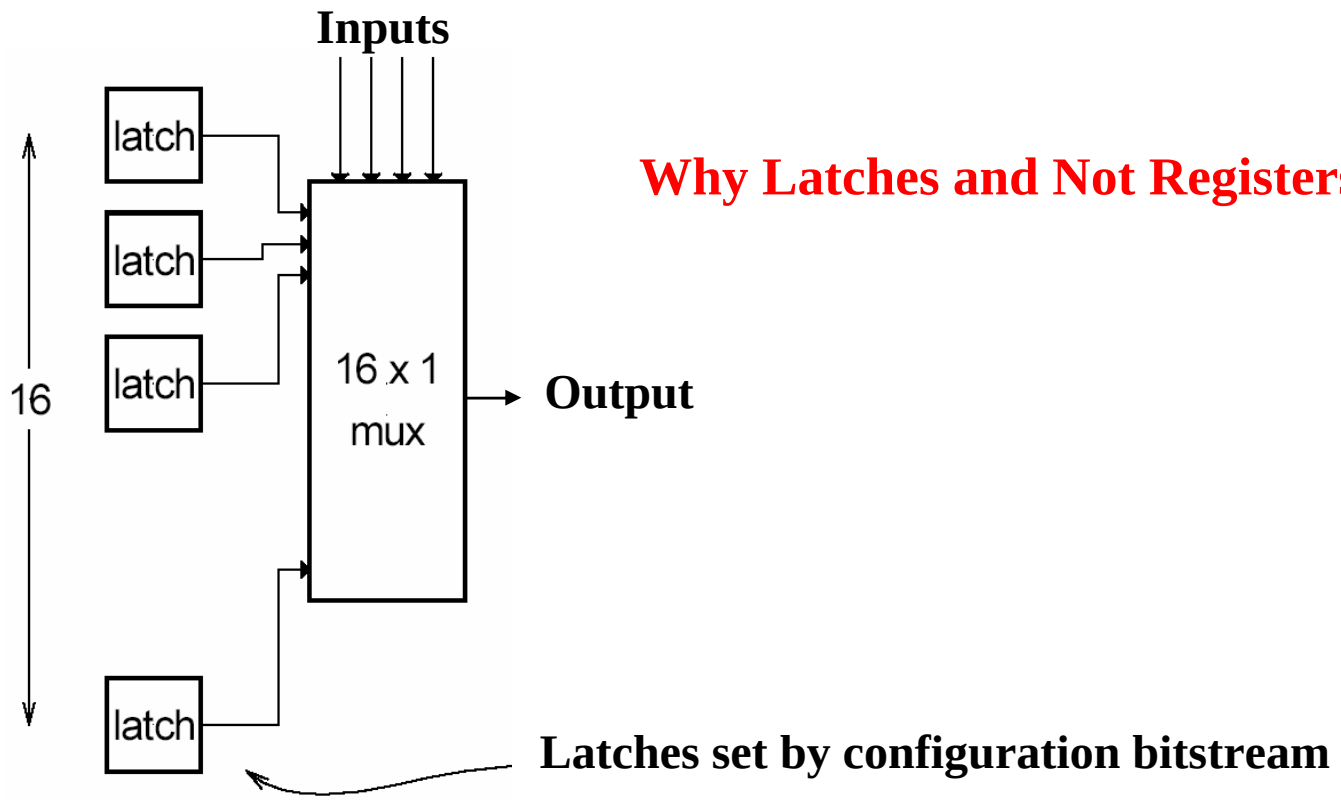
5-input Function, Combinational Output



Simplified Block Diagram of XC4000 Series CLB (RAM and Carry Logic functions not shown)

LUT Mapping

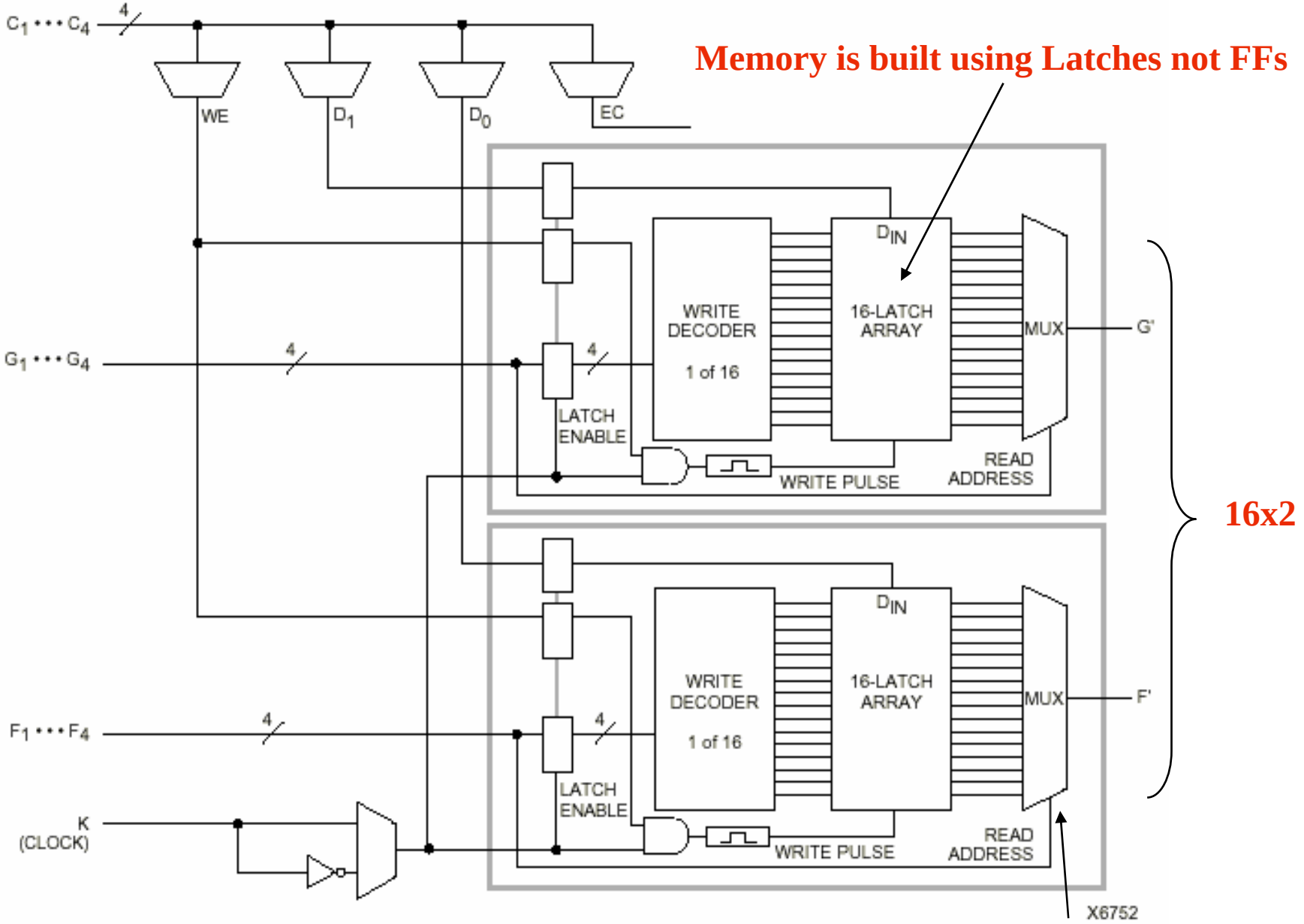
- N-LUT direct implementation of a truth table: any function of n-inputs.
- N-LUT requires 2^N storage elements (latches)
- N-inputs select one latch location (like a memory)



Why Latches and Not Registers?

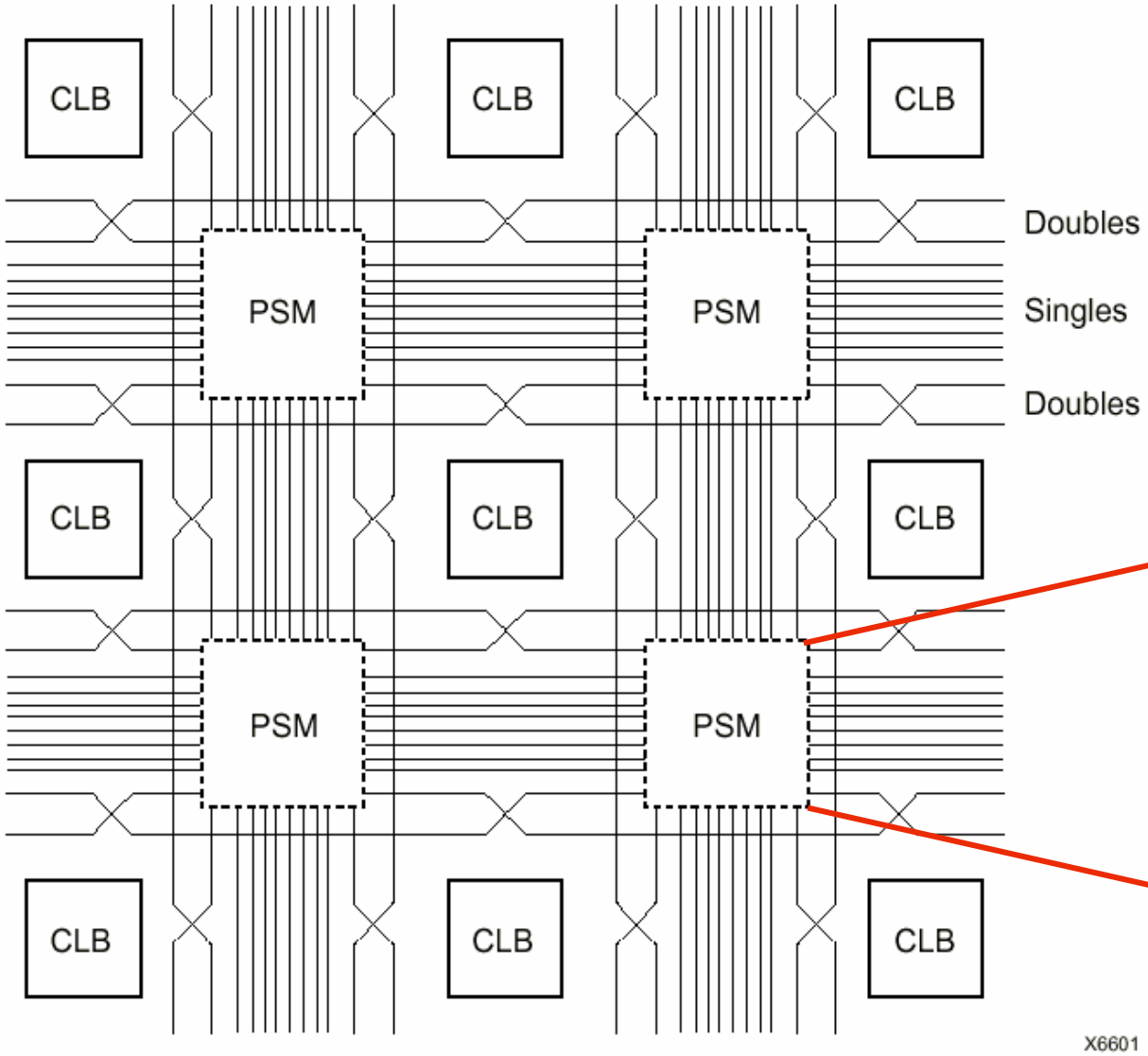
4LUT example

Configuring the CLB as a RAM

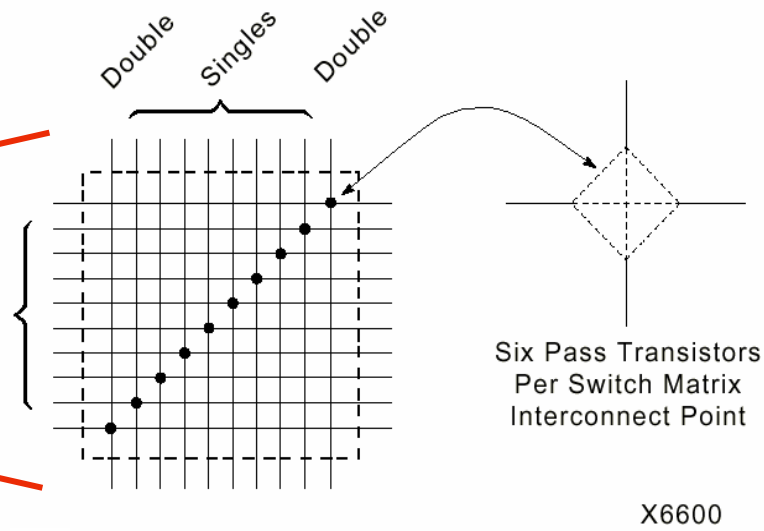


Read is same a LUT Function!

Xilinx 4000 Interconnect

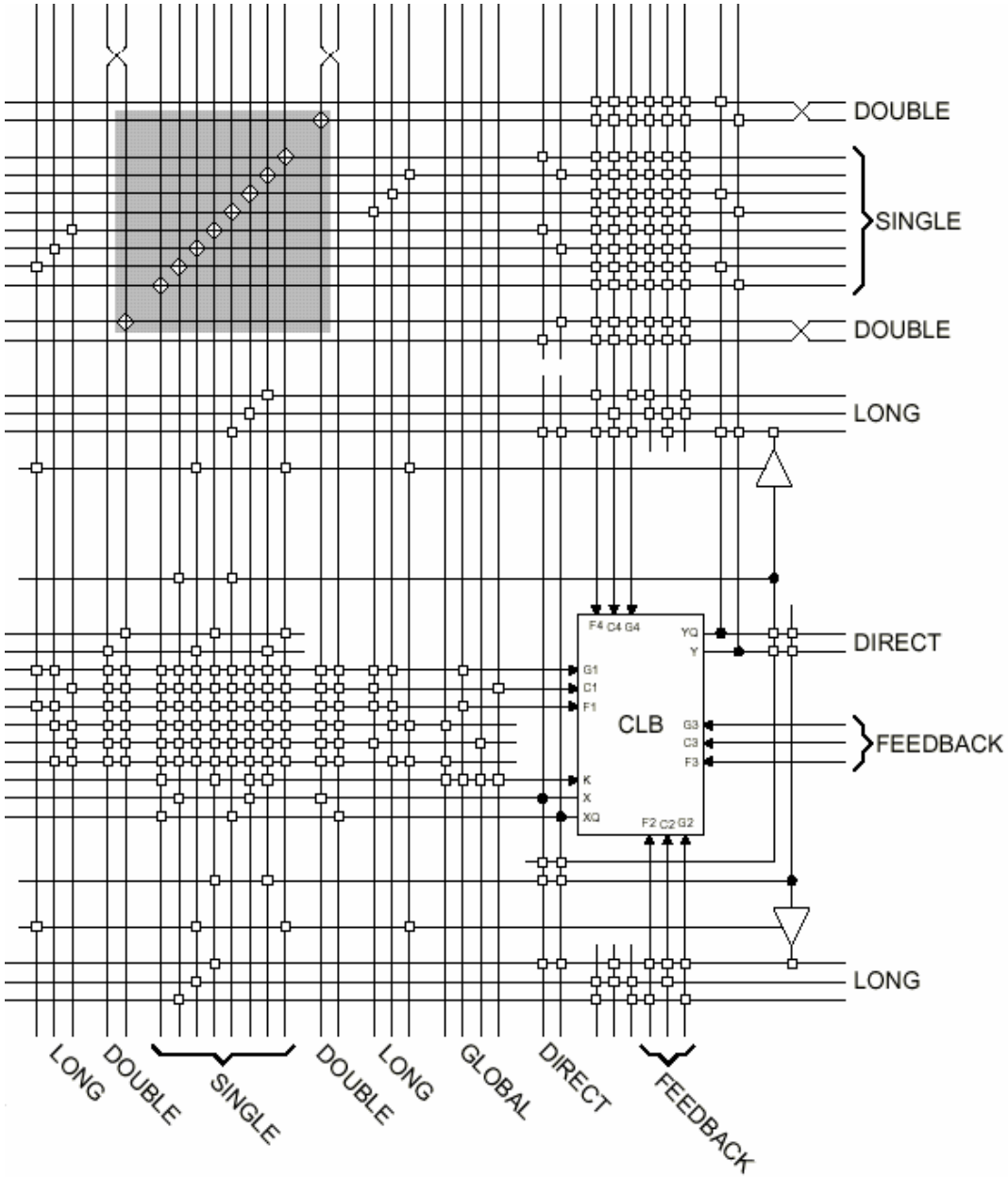


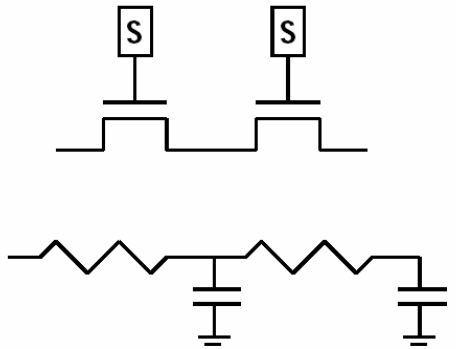
Single- and Double-Length Lines, with Programmable Switch Matrices (PSMs)



Programmable Switch Matrix (PSM)

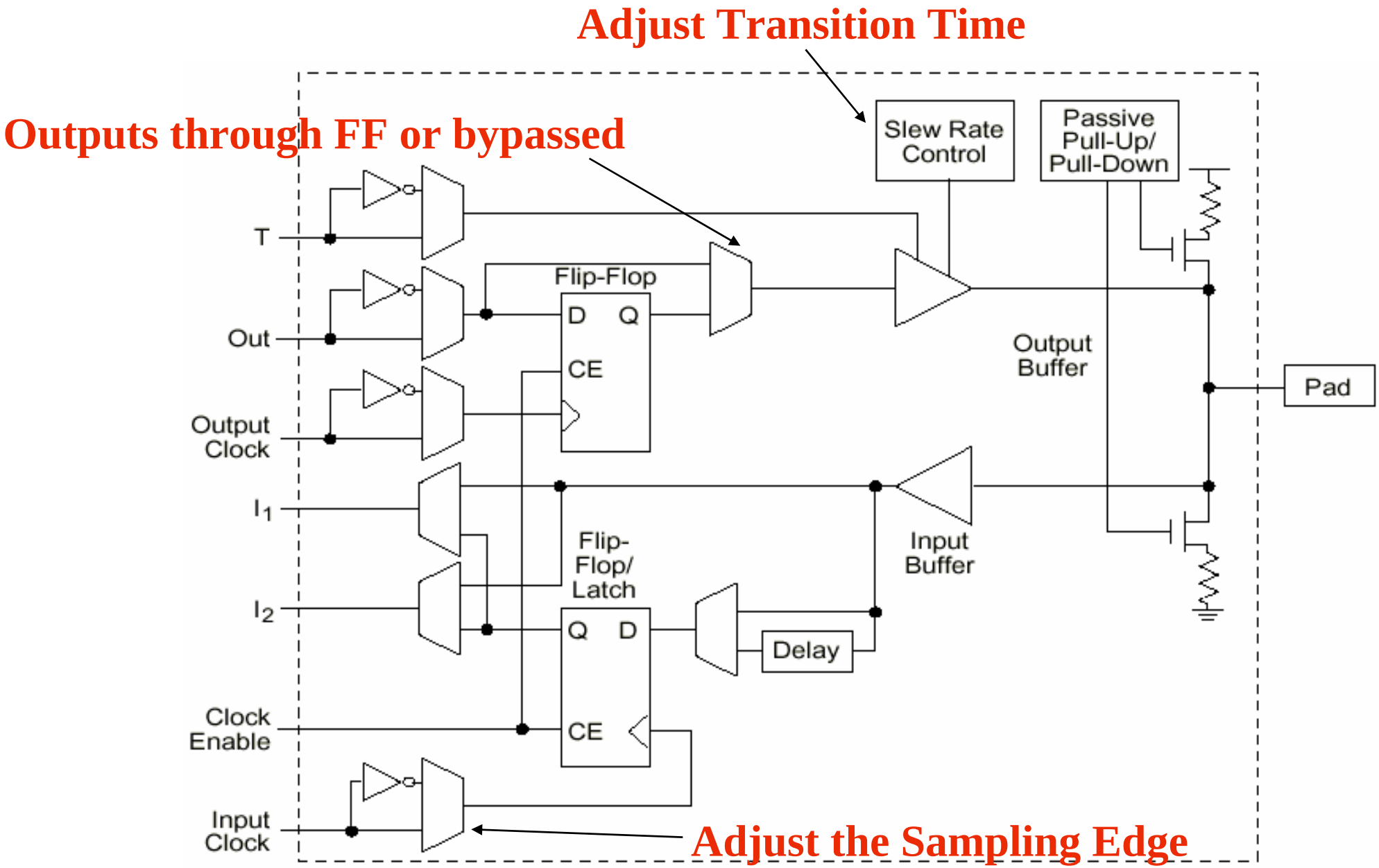
Xilinx 4000 Interconnect Details



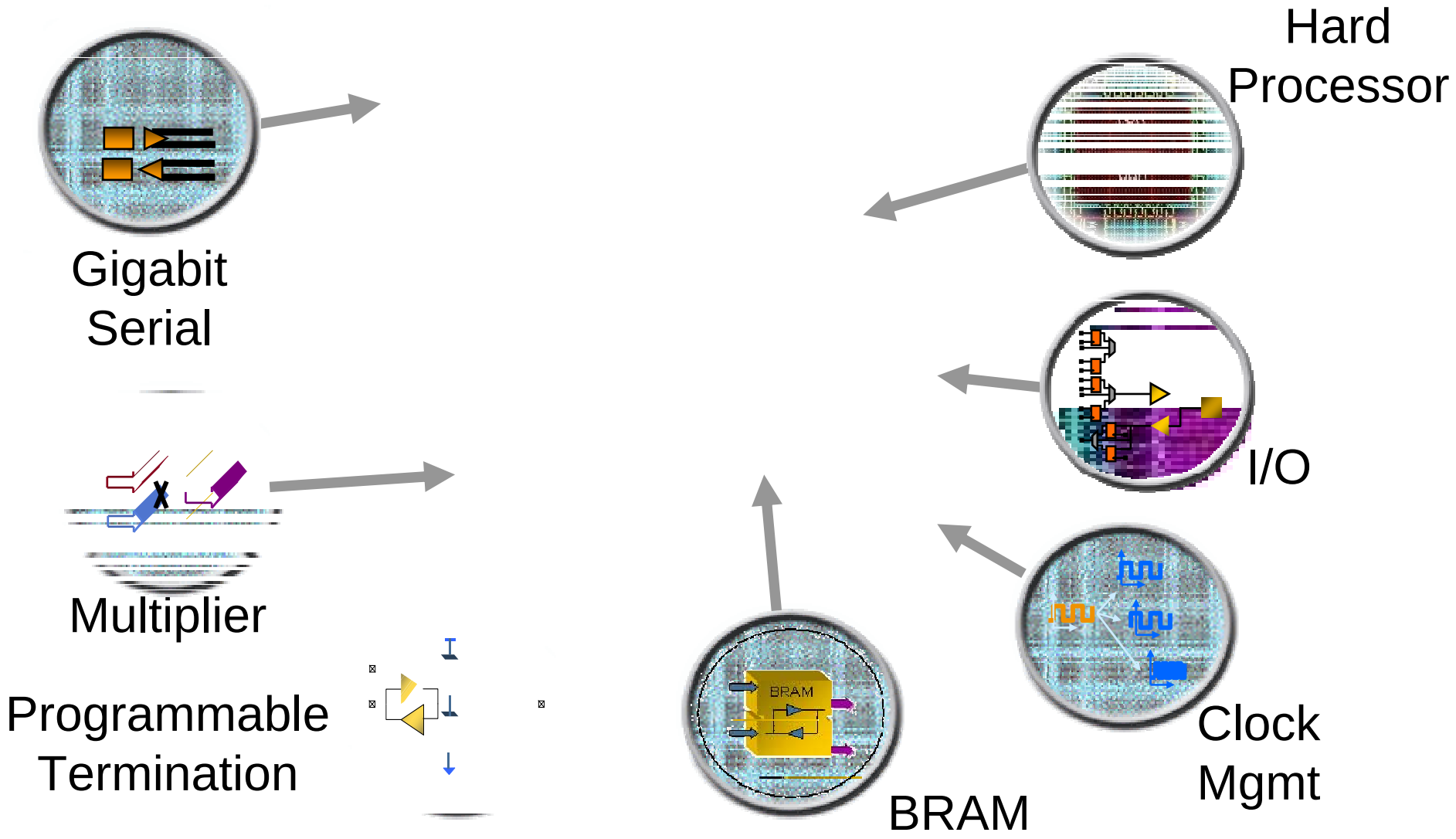


Wires are not ideal!

Xilinx 4000 Flexible IOB

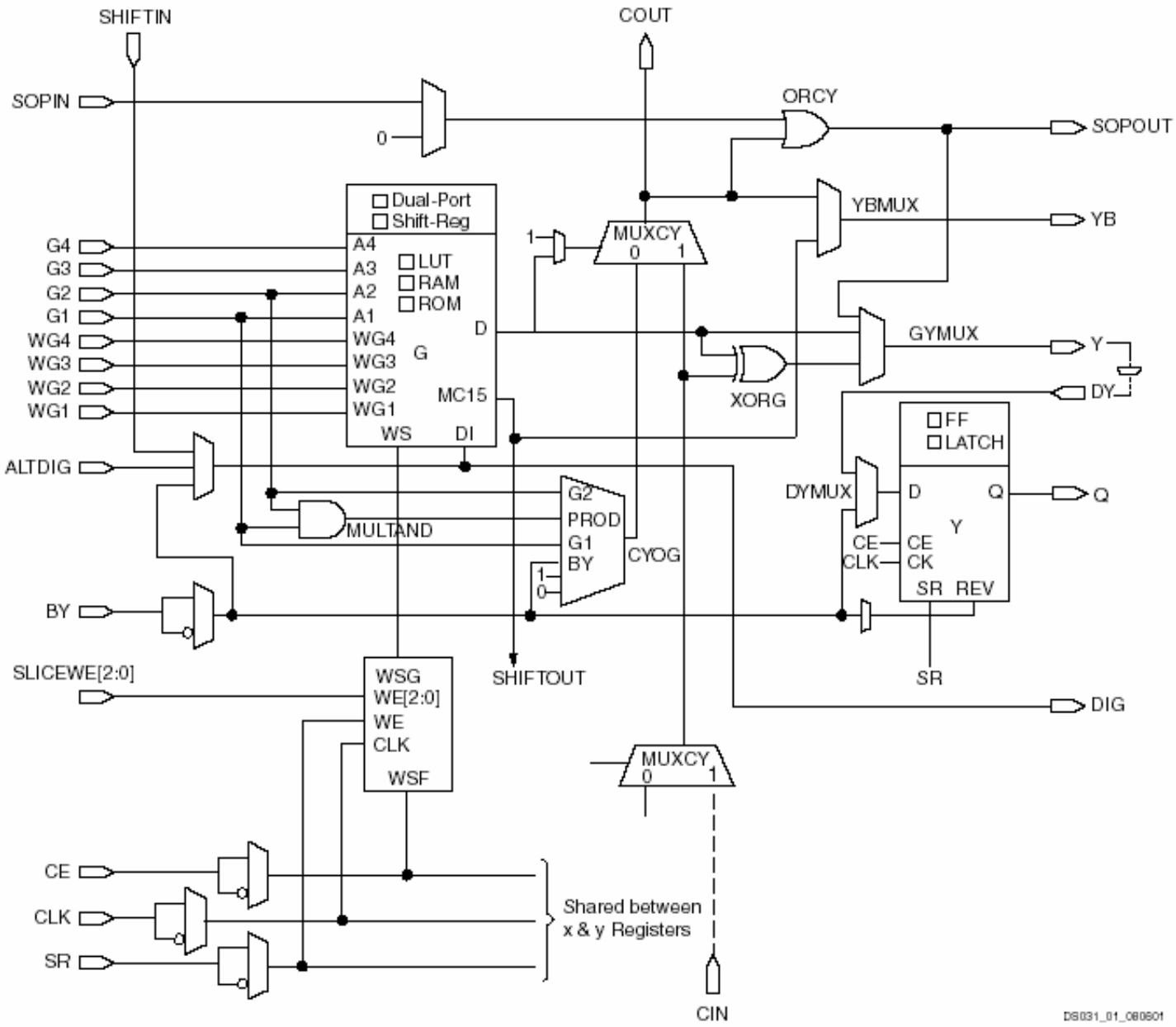


Add Bells & Whistles

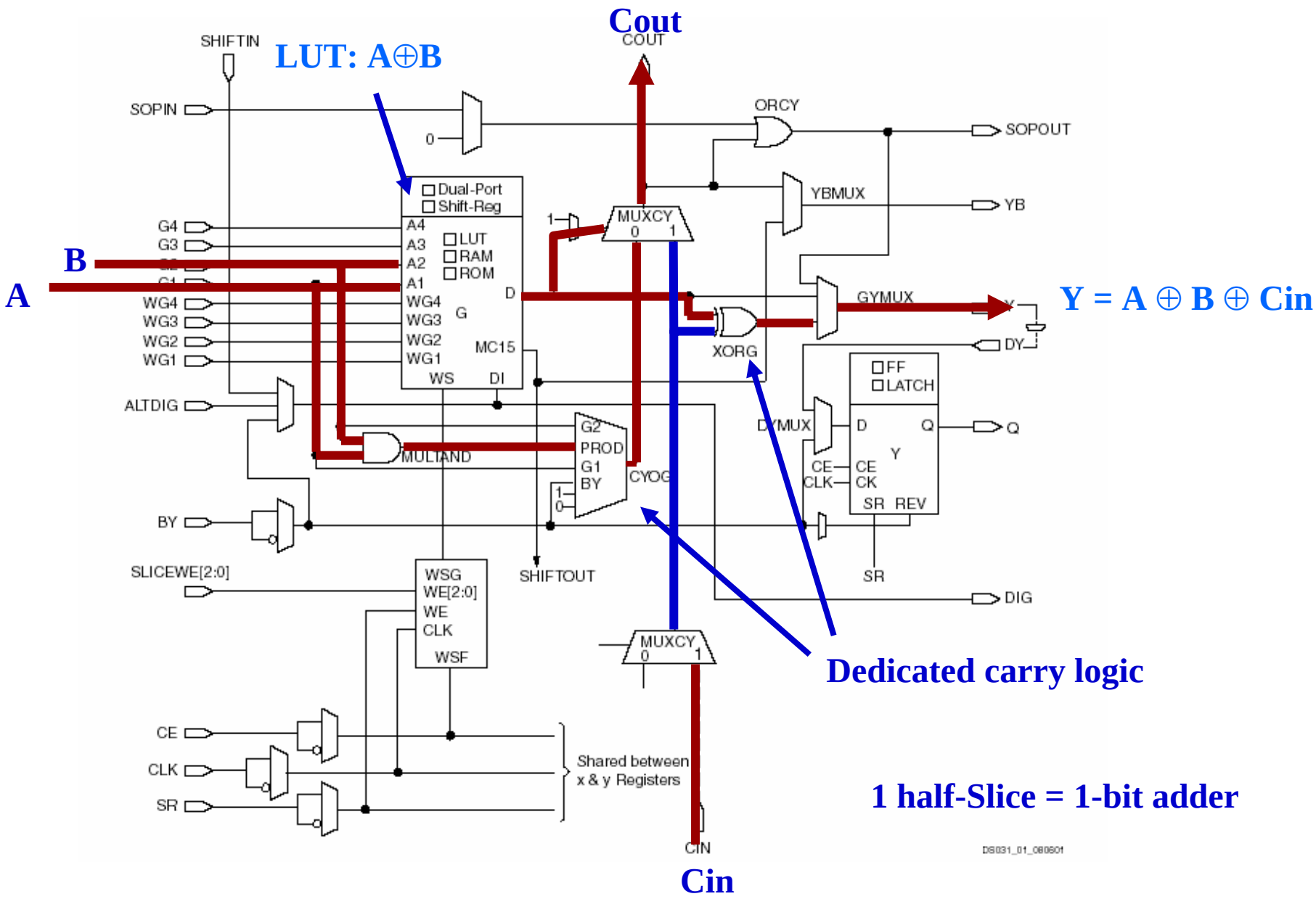


Courtesy of David B. Parlour, ISSCC 2004 Tutorial,
"The Reality and Promise of Reconfigurable Computing in Digital Signal Processing"

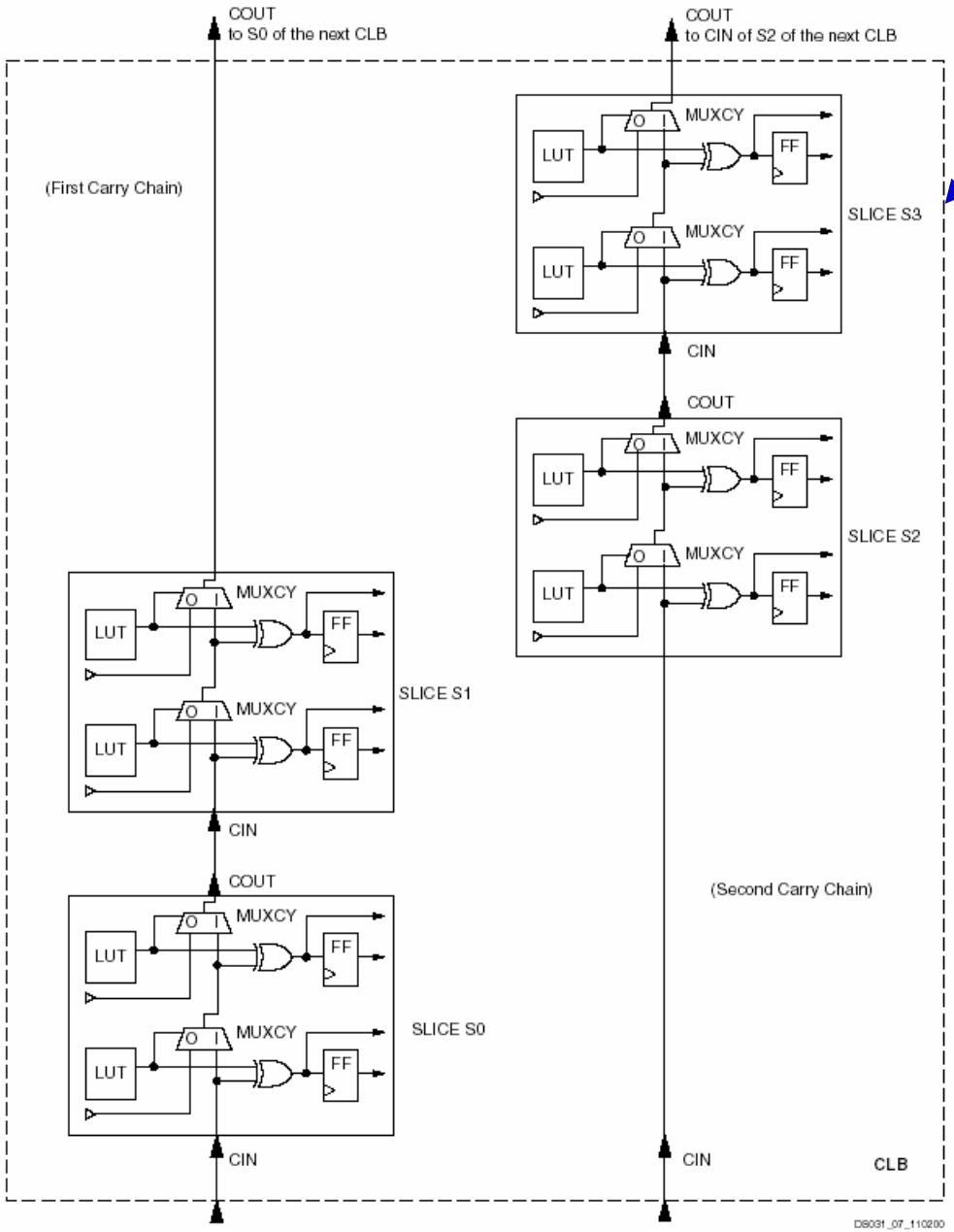
The Virtex II CLB (Half Slice Shown)



Adder Implementation

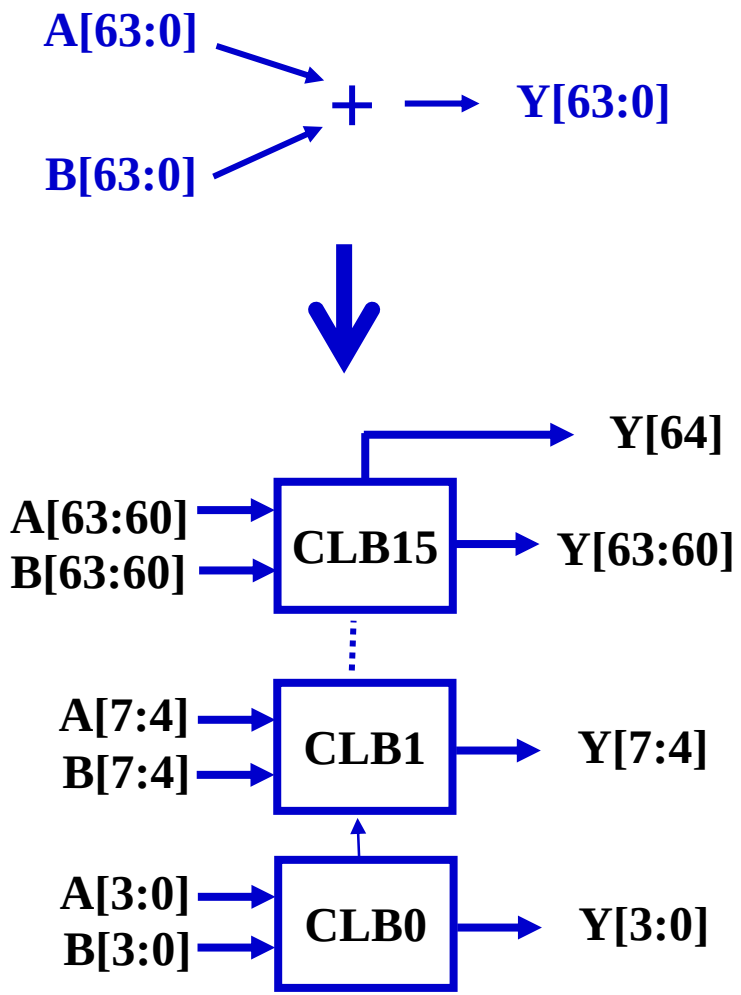


Carry Chain



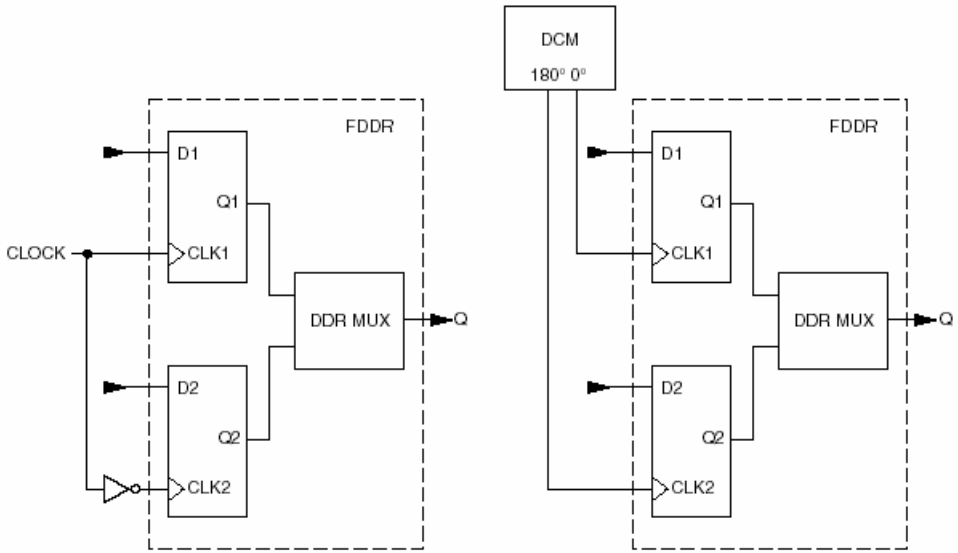
1 CLB = 4 Slices = 2, 4-bit adders

64-bit Adder: 16 CLBs

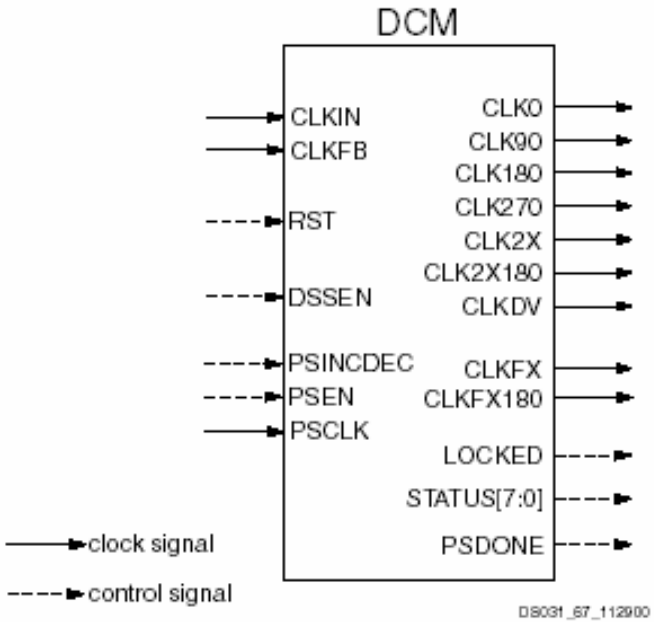


CLBs must be in same column

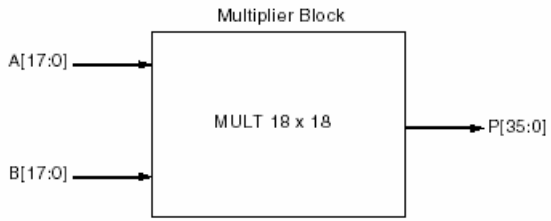
Virtex II Features



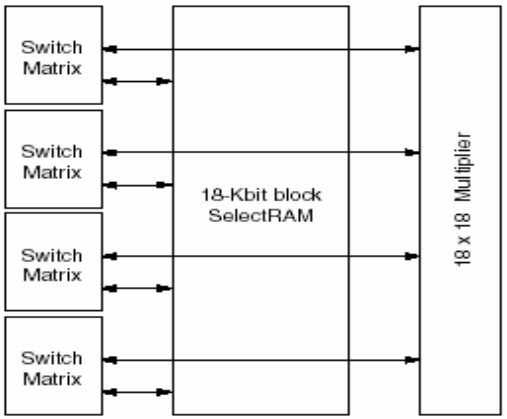
Double Data Rate registers



Digital Clock Manager

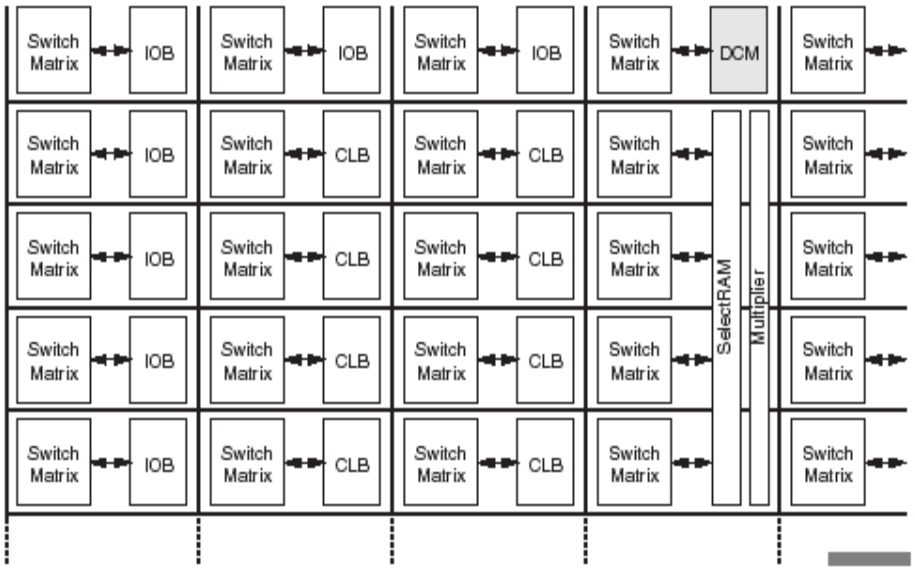


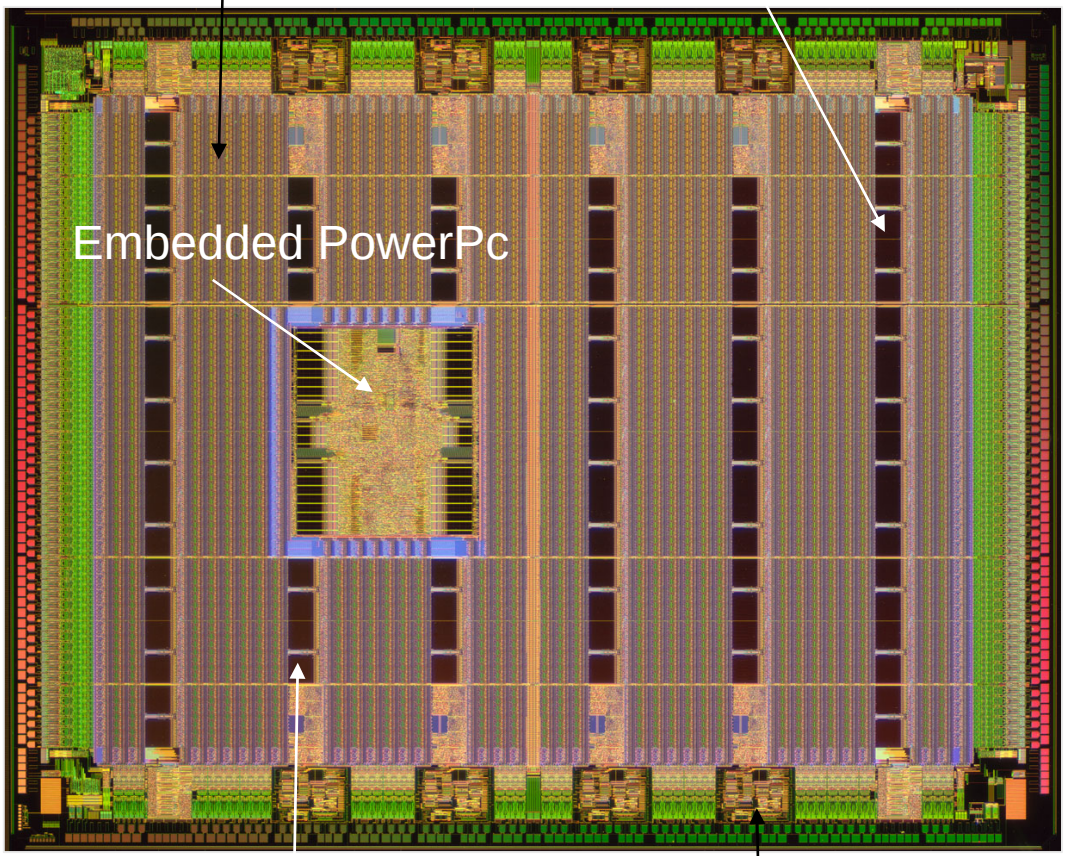
Embedded Multiplier



Block SelectRAM

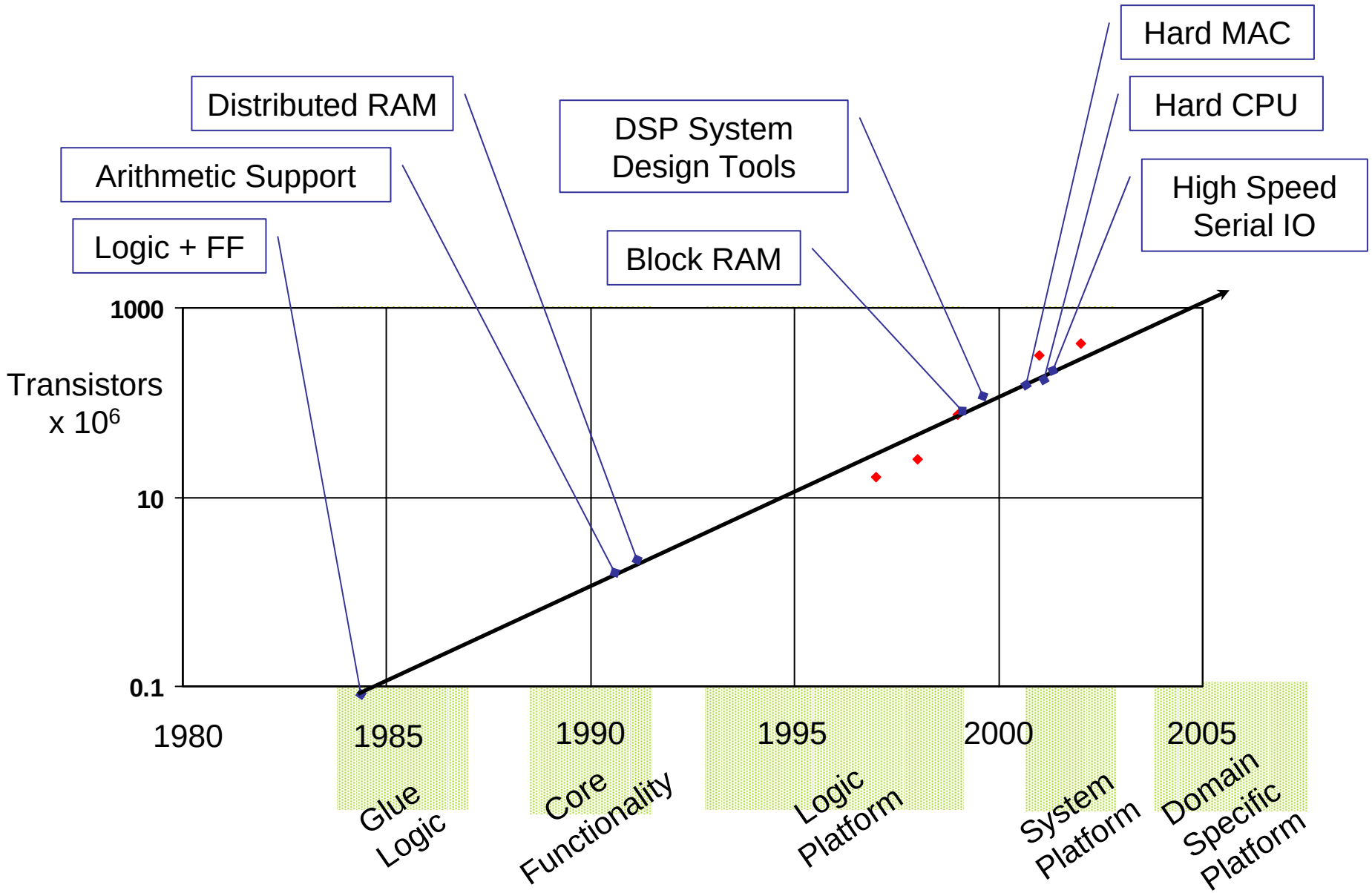
The Latest Generation: Virtex-II Pro





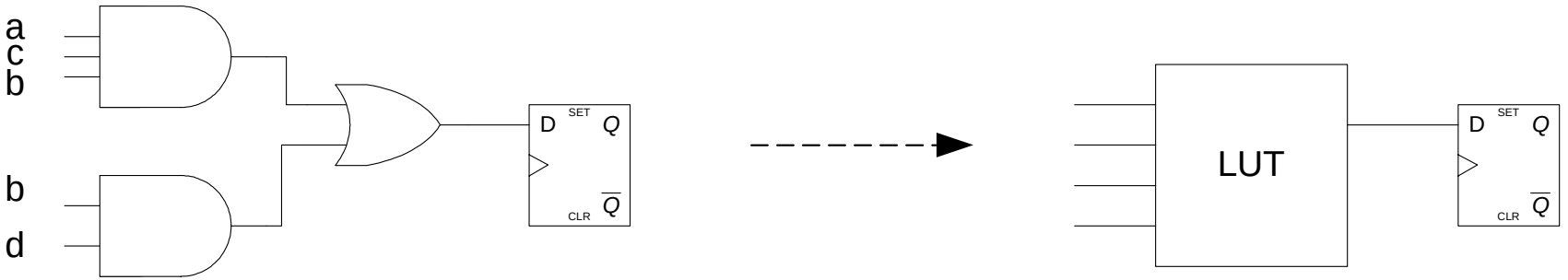
Courtesy Xilinx

FPGA Evolution Summary [Parlour04]



Design Flow - Mapping

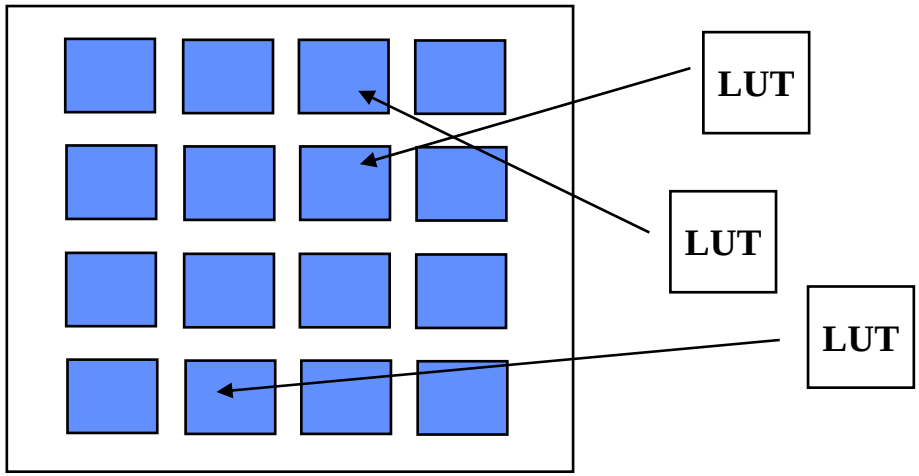
- **Technology Mapping: Schematic/HDL to Physical Logic units**
- **Compile functions into basic LUT-based groups (function of target architecture)**



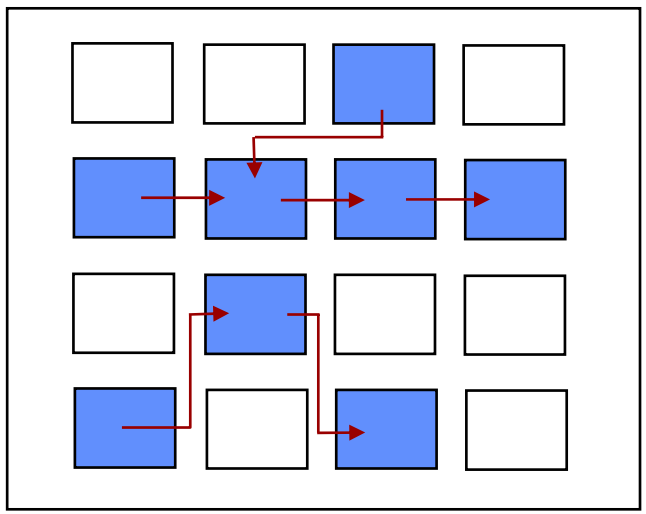

```
always @(posedge Clock or negedge Reset)
 begin
  if (! Reset)
    q <= 0;
  else
    q <= (a & b & c) | (b & d);
 end
```

Design Flow – Placement & Route

- **Placement** – assign logic location on a particular device



- **Routing** – iterative process to connect CLB inputs/outputs and IOBs. Optimizes critical path delay – can take hours or days for large, dense designs



Iterate placement if timing not met

Satisfy timing? → Generate Bitstream to config device

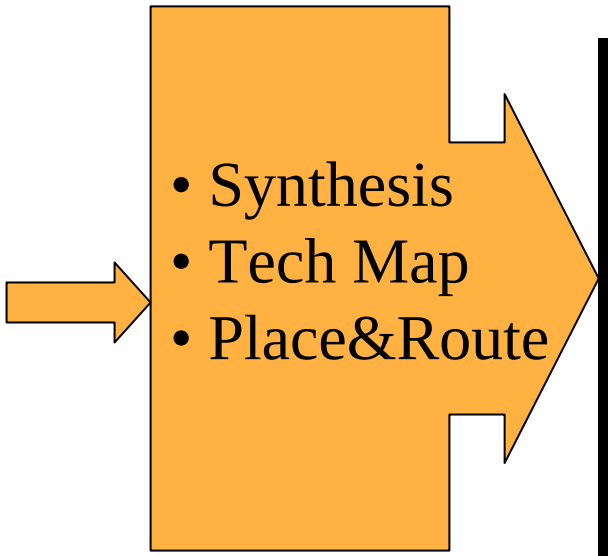
Challenge! Cannot use full chip for reasonable speeds (wires are not ideal).

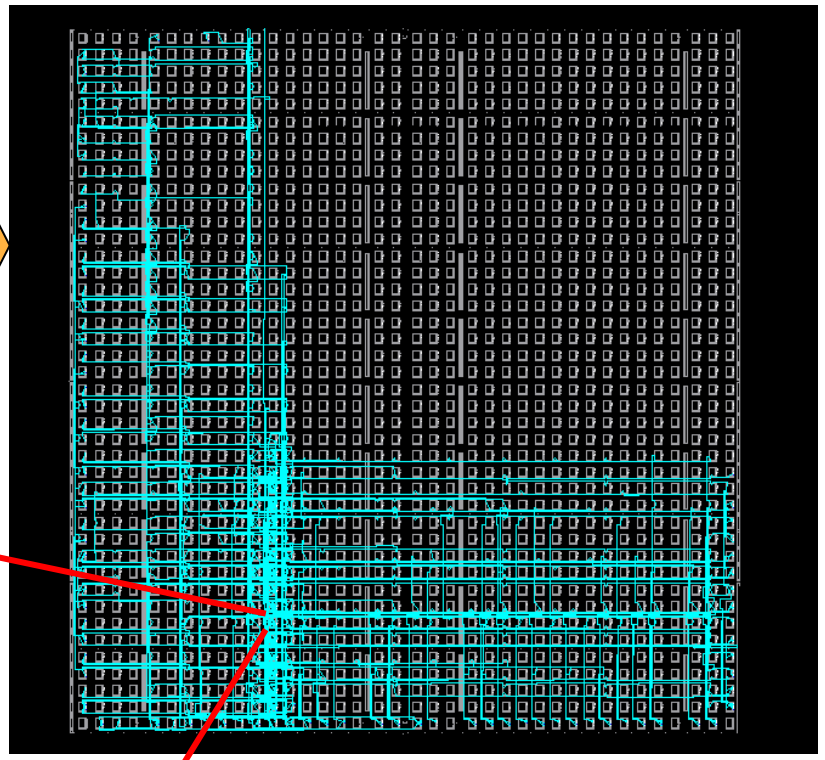
Typically no more than 50% utilization.

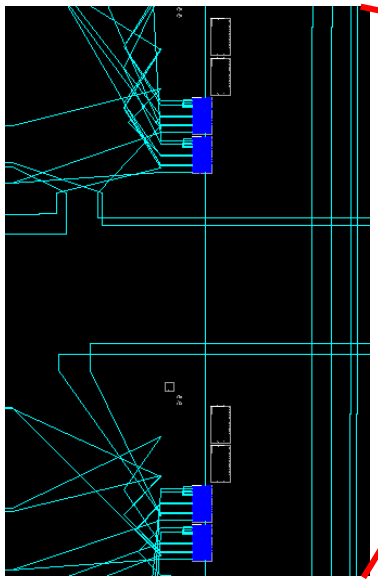
Example: Verilog to FPGA

```
module adder64 (a, b, sum);
  input  [63:0] a, b;
  output [63:0] sum;

  assign sum = a + b;
endmodule
```







64-bit Adder Example

Virtex II – XC2V2000

How are FPGAs Used?

Logic Emulation

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FPGA-based Emulator

(courtesy of IKOS)

- **Prototyping**
  - **Ensemble of gate arrays used to emulate a circuit to be manufactured**
  - **Get more/better/faster debugging done than with simulation**
- **Reconfigurable hardware**
  - **One hardware block used to implement more than one function**
- **Special-purpose computation engines**
  - **Hardware dedicated to solving one problem (or class of problems)**
  - **Accelerators attached to general-purpose computers (e.g., in a cell phone!)**

Summary

- FPGA provide a flexible platform for implementing digital computing
- A rich set of macros and I/Os supported (multipliers, block RAMS, ROMS, high-speed I/O)
- A wide range of applications from prototyping (to validate a design before ASIC mapping) to high-performance spatial computing
- Interconnects are a major bottleneck (physical design and locality are important considerations)

"College students will study concurrent programming instead of "C" as their first computing experience."

-- David B. Parlour, ISSCC 2004 Tutorial