Topic 16
Programmable Logic Device

Outline

- Programmable Logic Devices (PLD)
- Programmable Logic Array (PLA)
- Programmable Array Logic (PAL)
- Complex Programmable Logic Device (CPLD)
- Field Programmable Gate Array (FPGA)

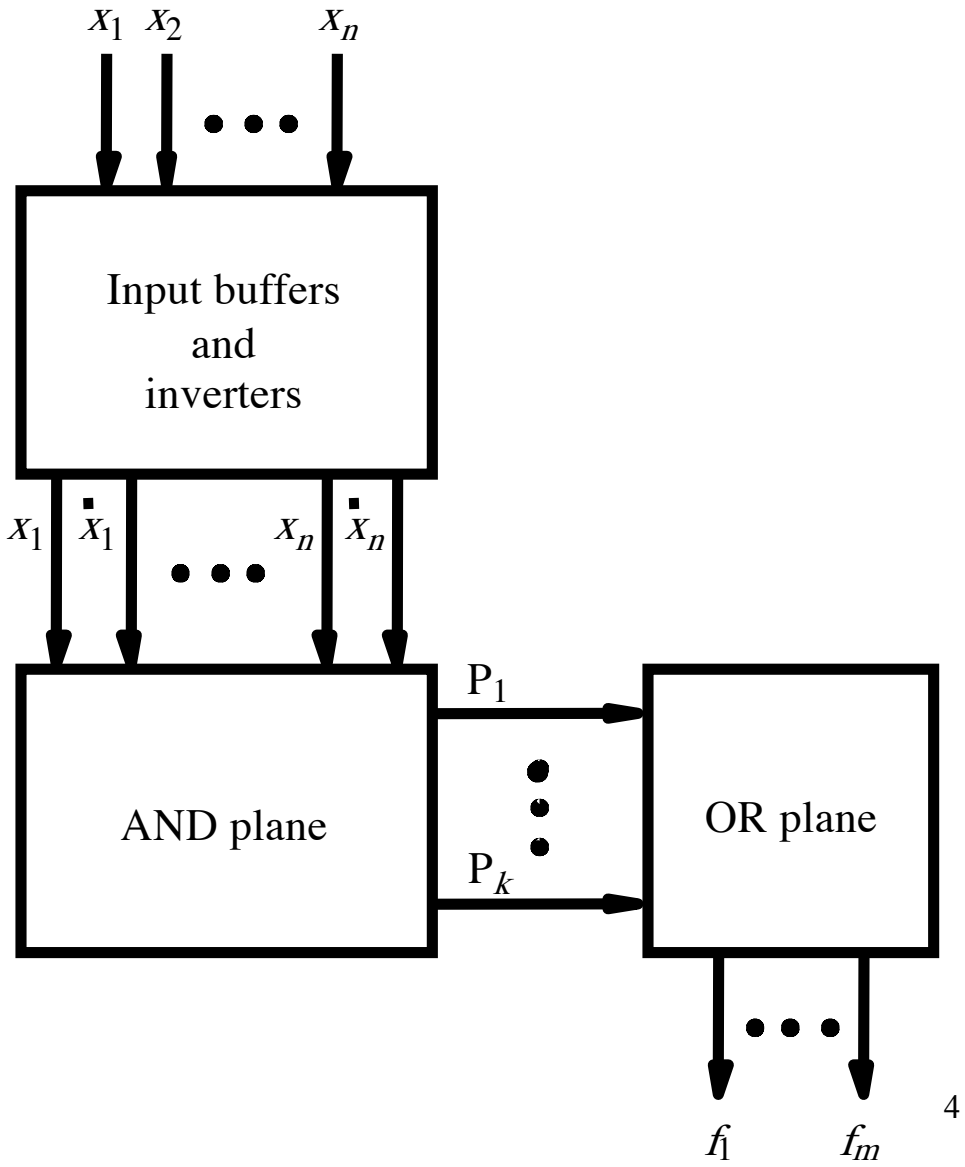
Programmable Logic Devices

- PLD
  - First introduced in 1970s
  - Can be viewed as a “black box” containing logic gates and programmable switches
    - The logic gates and programmable switches can be customized to implement specific logic circuit
  - Simple programmable logic devices (SPLD)
    - Programmable logic array (PLA)
    - Programmable array logic (PAL)
  - Complex programmable logic array (CPLD)
  - Field-programmable gate array (FPGA)

Programmable Logic Array (PLA)

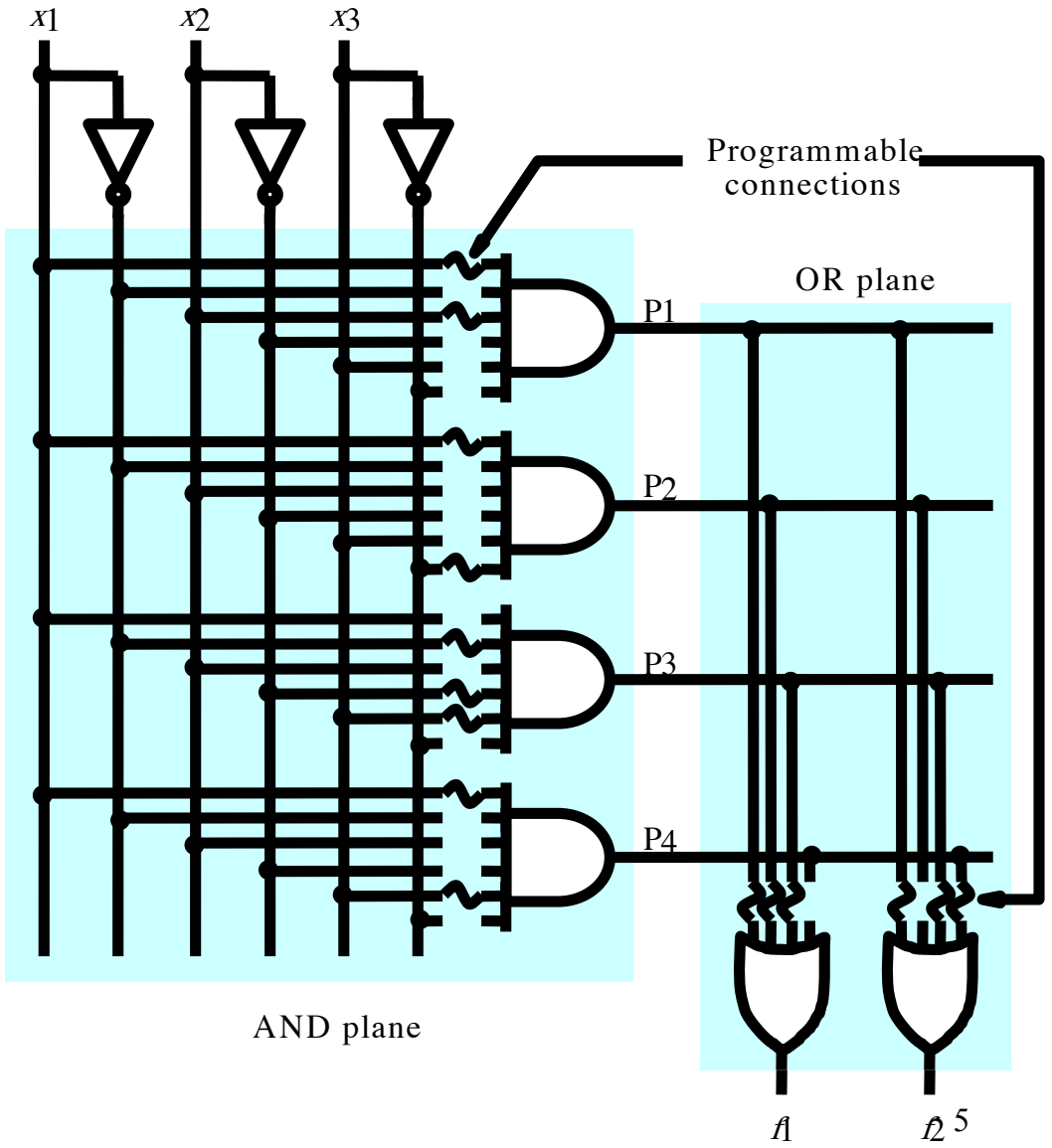
- Comprises a collection of buffers, inverters, AND gates, OR gates
- Can be used to realize logic circuit in sum-of-products (SOP) form,
- Example:

  f = x'yz + xy'z'



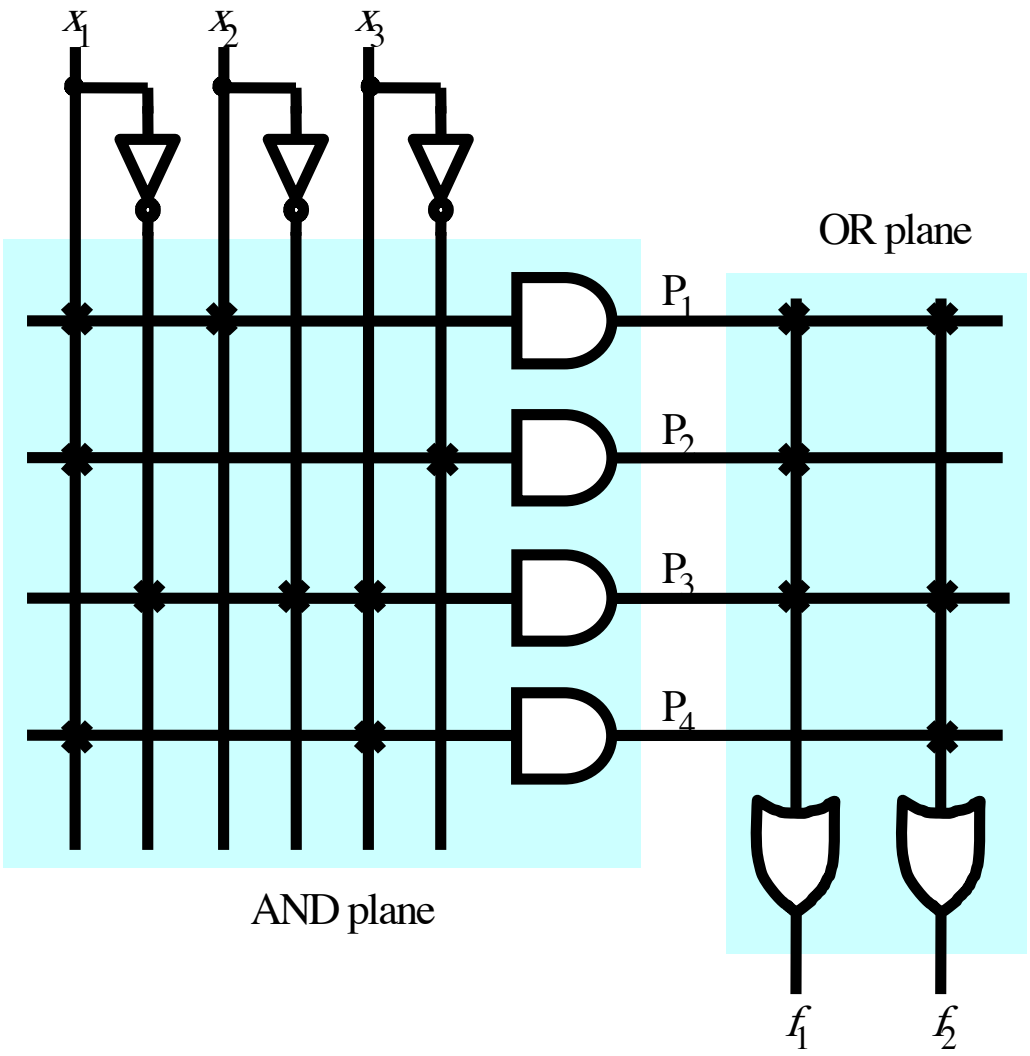
Programmable Logic Array (PLA)

- Buffers and inverters provide both true value and complement of each input
- AND plane provides the product terms
- OR plane provides the sum of the product terms
- Example:
  - P1 = x1x2
  - P2 = x1x3'
  - P3 = x1'x2'x3
  - P4 = x1x3
  - F1 = P1 + P2 + P3
  - F2 = P1 + P3 + P4



Programmable Logic Array (PLA)

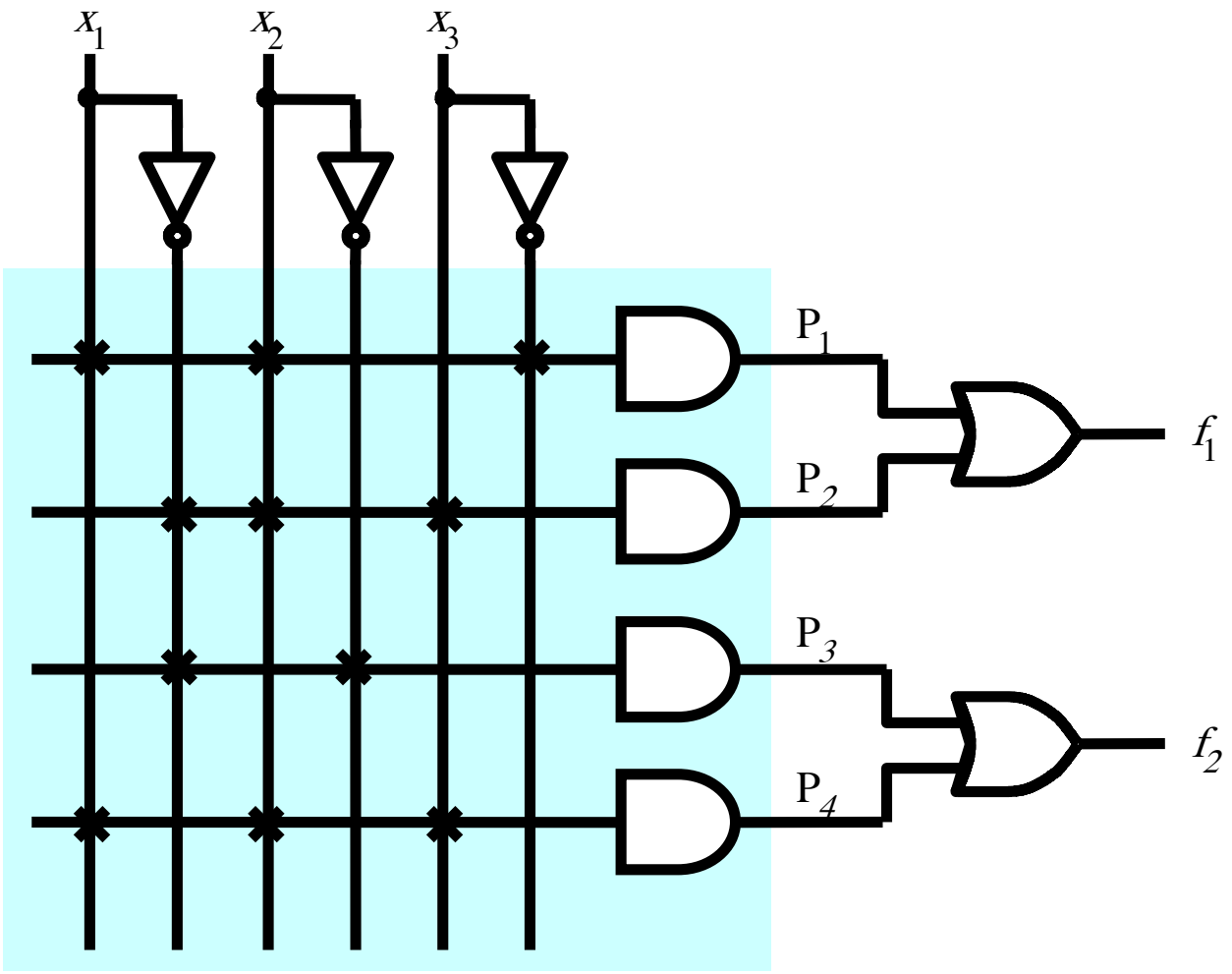
- Each AND gate has 2xN inputs
  - N, number of primary inputs
- Each OR gate has M inputs
  - M, number of and gates
- **Problem**: size of the inputs
- Commercially available PLAs typically have:
  - 16 inputs
  - 32 AND gates
  - 8 OR gates
- Connections replaced by single lines, “x” indicates a connected input to the gate



Programmable Array Logic (PAL)

- Drawbacks of PLA
  - Hard to fabricate correctly due to the programmable connections
  - Special implementation of the programmable connections reduce the speed of circuits in PLA
- Solution: fix the OR plane – PAL
  - Less expensive
  - Better performance
  - Became popular in practical applications

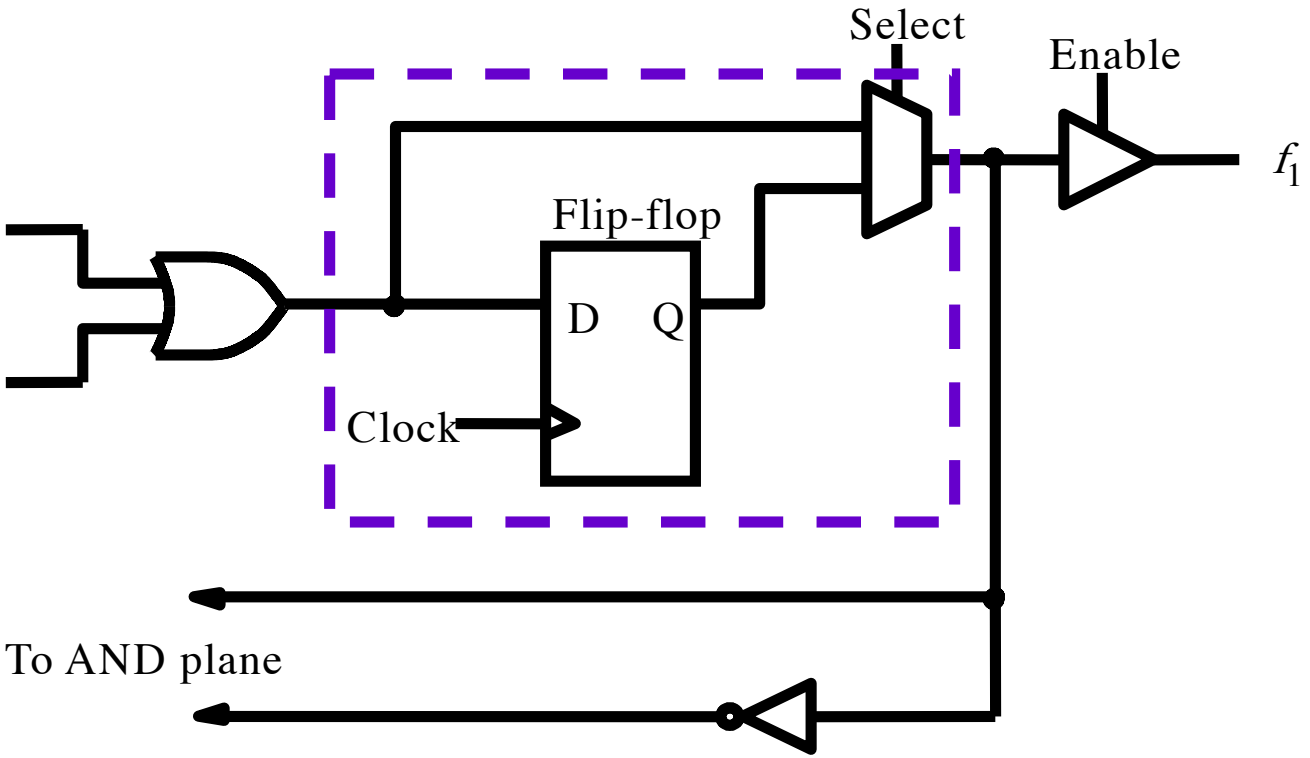
Programmable Array Logic (PAL)



AND plane

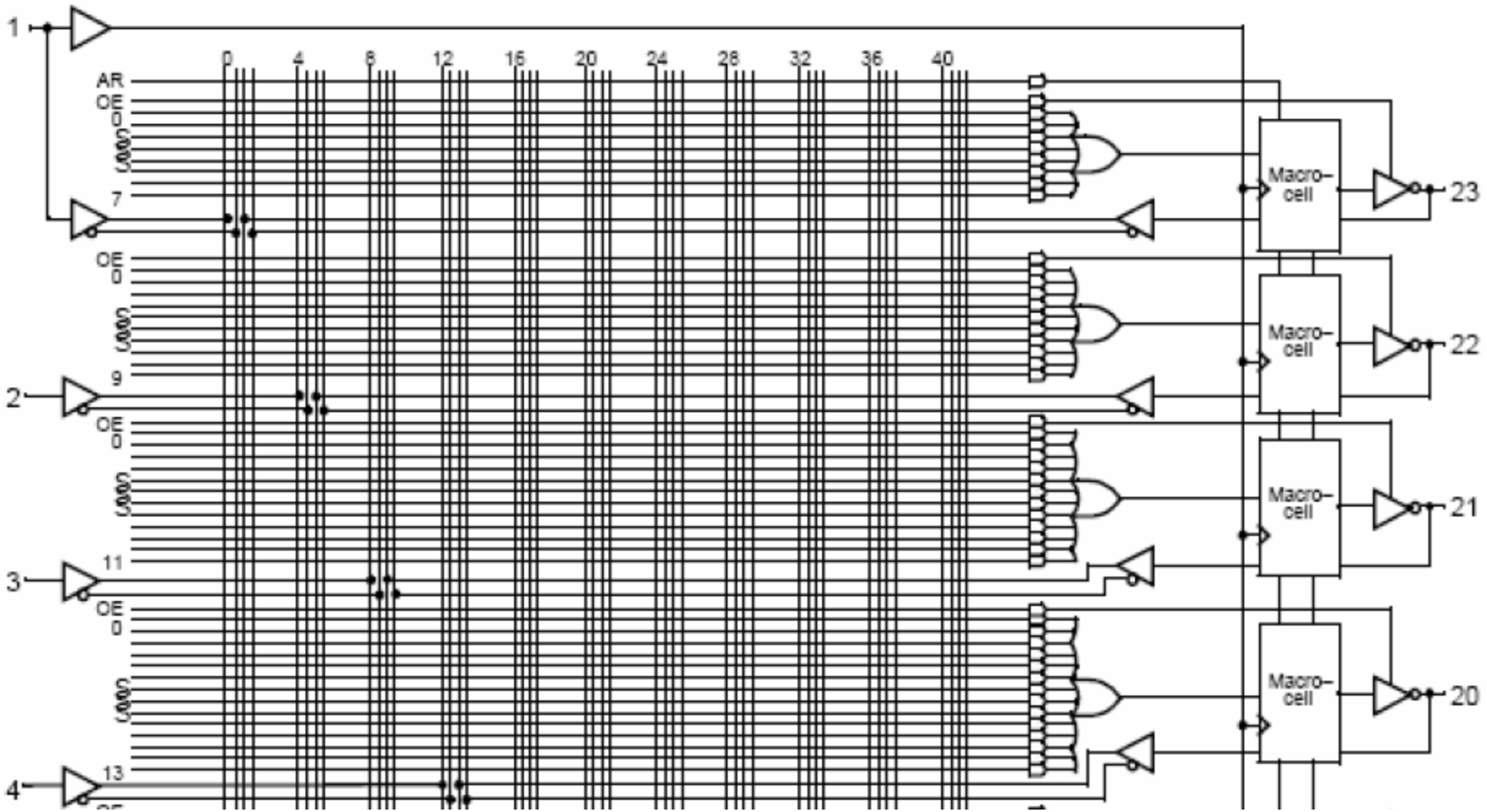
Programmable Array Logic (PAL)

- In order to provide additional flexibility, an extra circuit is inserted between the OR output and the chip pin - *Macrocell*



PAL Example

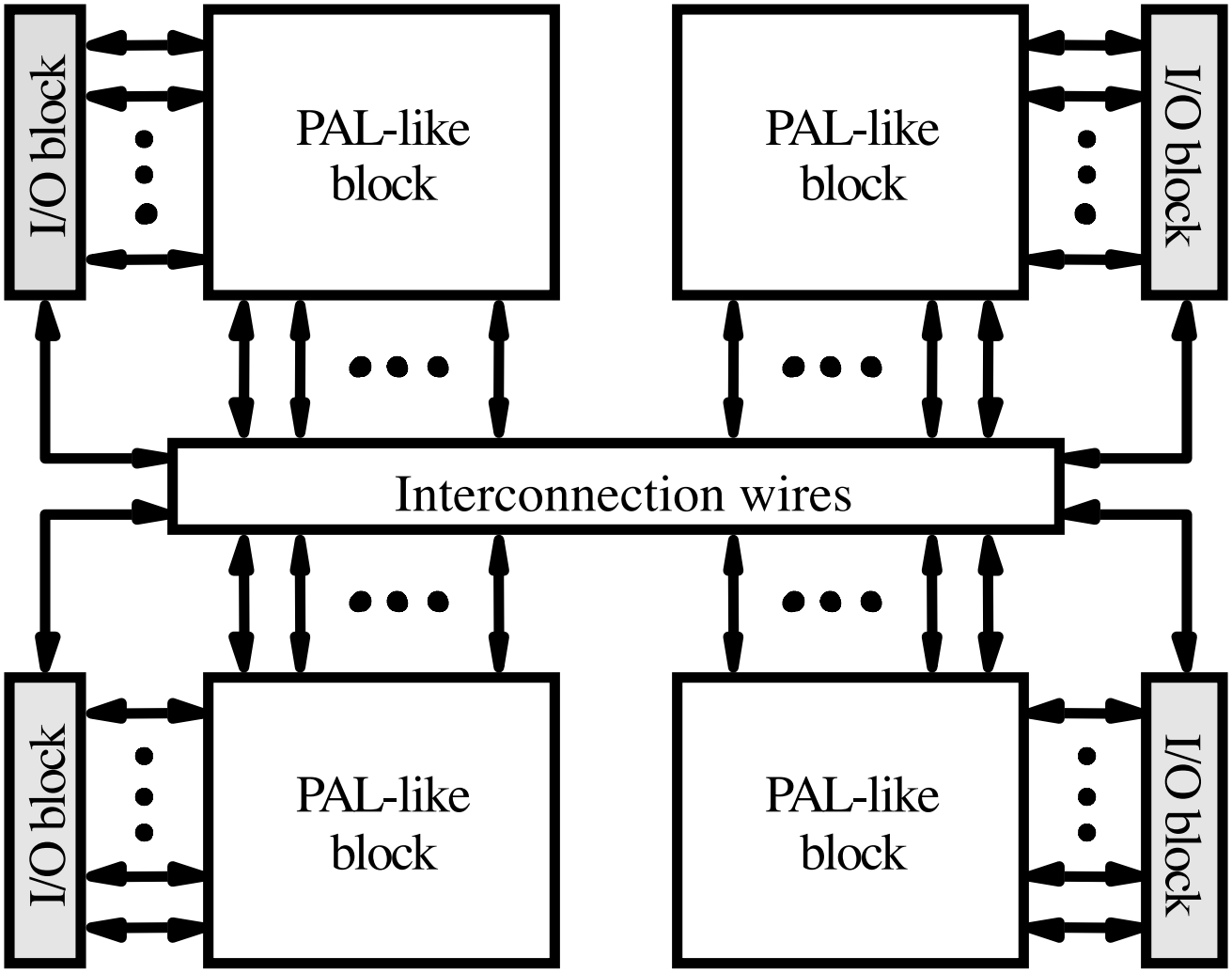
- Compensate for the reduced flexibility
  - Various numbers of inputs to the OR gates

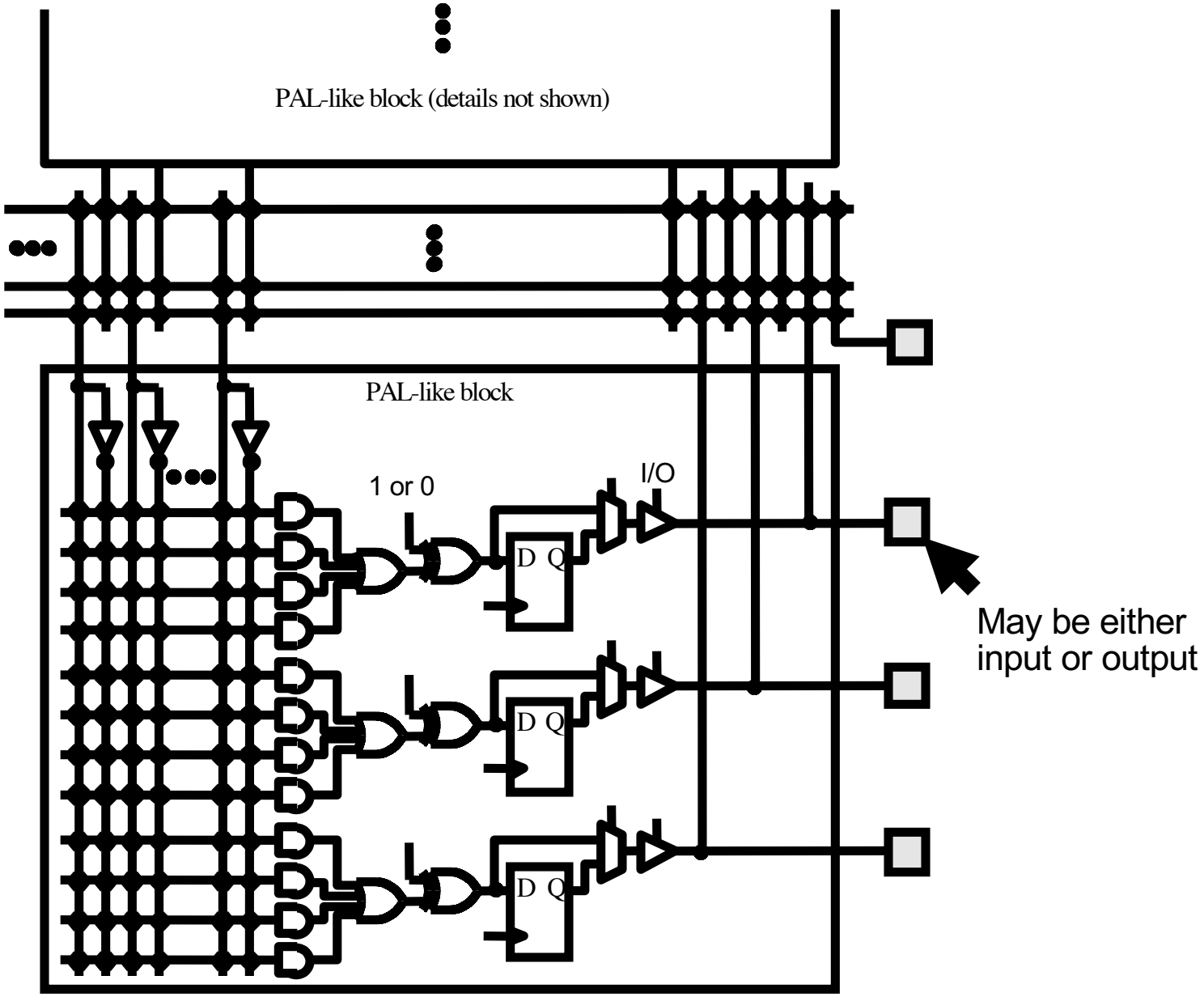


Complex Programmable Logic Devices (CPLD)

- Composed of multiple PAL/PLA-like circuit blocks
  - Blocks are connected through a set of interconnection wires
  - Blocks are connected to the IC chip pins through a set of I/O blocks
  - Number of blocks may vary from 2 to over 100
- Provides more inputs and outputs
- Provides more flexibility
- May accommodate bigger size circuit

CPLD


I/O block
PAL-like block
PAL-like block
I/O block
Interconnection wires
I/O block
PAL-like block
PAL-like block
I/O block


PAL-like block (details not shown)
PAL-like block
1 or 0
I/O
D Q
D Q
D Q
May be either
input or output

Field Programmable Gate Array (FPGA)

- First introduced by Xilinx in 1985
- Most FPGA providers are "fabless", allows
  - focus on device capability
  - improvement of design software
  - offering IP cores

Types of FPGA

- Reprogrammable
  - SRAM-based FPGA
    - Volatile, often the best choice for prototyping and development
    - Supports in-system-programming (ISP)
    - What we used in the labs
  - EEPROM-based (Flash-based) FPGA
- One-Time Programmable (OTP)
  - Anti-Fuse-based FPGA
  - EPROM-based FPGA

Configuration Technologies FPGA

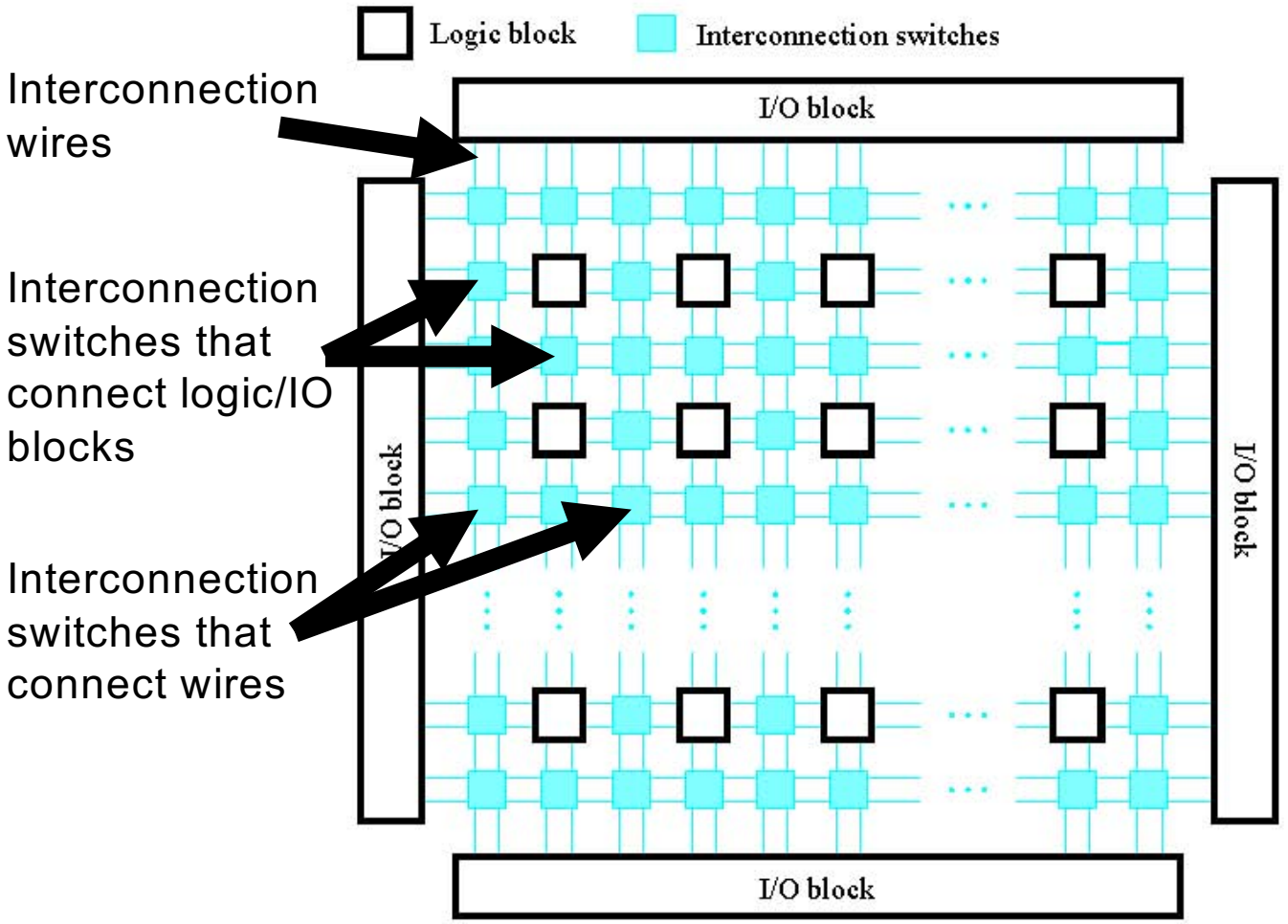
- Configure SRAM-based FPGA
  - ISP, fast reconfiguration, but volatile
  - External device (EEPROM, may be onboard), programming on power up
- Configure flash-based FPGA
  - Similar to EEPROM programming devices
  - nonvolatile, may or may not support ISP
- Configure EPROM-based FPGA
  - Similar to EPROM programming devices
  - nonvolatile, off-board one-time configuration
- Configure Anti-Fuse-based FPGA
  - Fuse burning devices (electronically or optically)
  - nonvolatile, off-board one-time configuration

Internal Structure

- Composed of logic blocks and wires
  - Configurable Logic blocks (CLB)
  - I/O blocks (IOB)
  - Interconnection wires and switches

FPGA Architecture

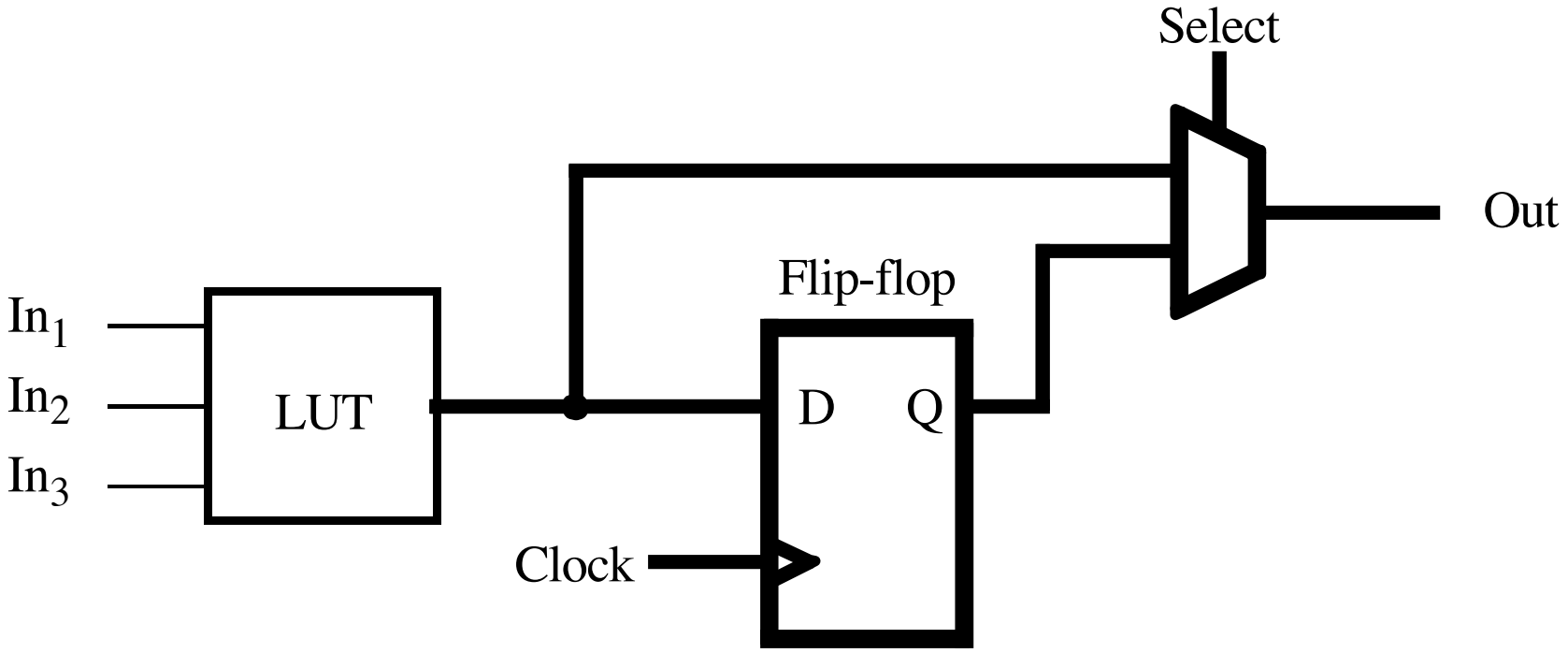
- Typical FPGA architecture



Courtesy of Xilinx Inc.

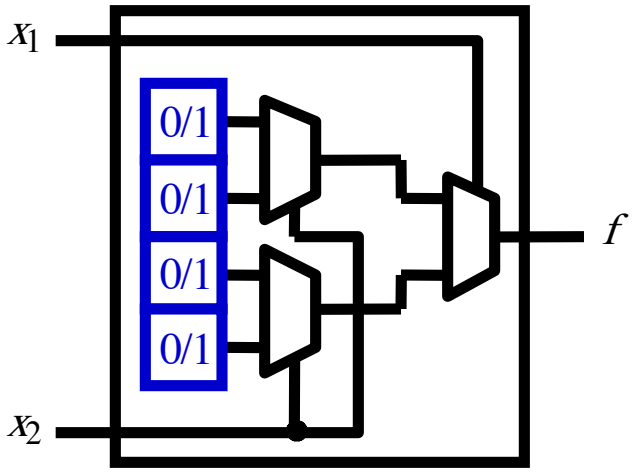
Programmable (Configurable) Logic Block

- PLB (or CLB), like in SPLD and CPLD, macrocell is added to provide more flexibility



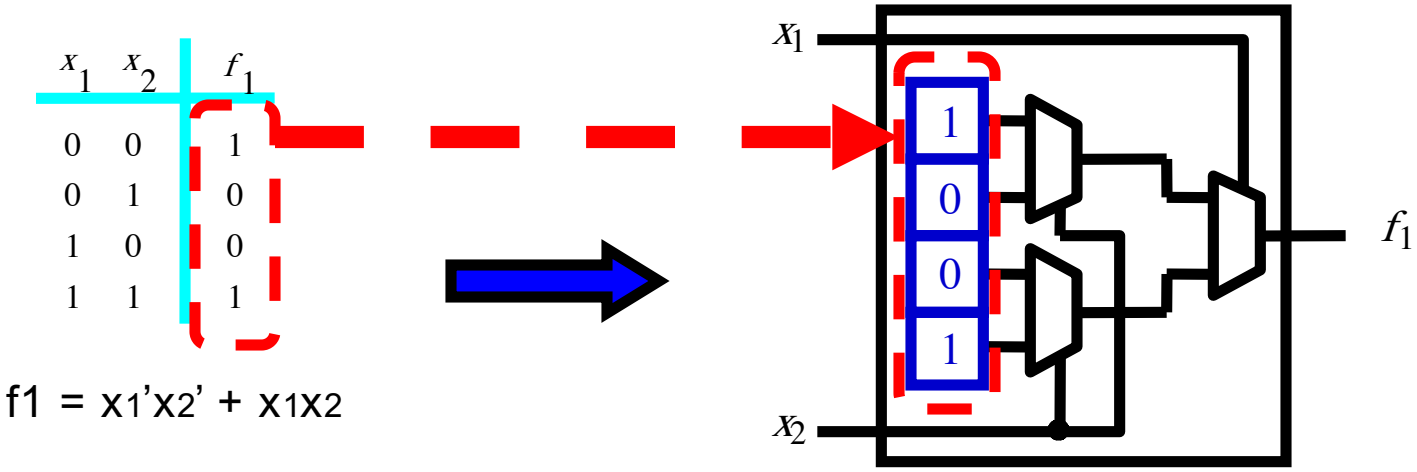
Look Up Table (LUT)

- A typical PLB has a LUT
- Each LUT contains 2^N storage cells, N is the number of inputs to the LUT
  - **SRAM** for storage cell
  - Each storage cell can hold a value, either “1” or “0”
  - The cells are programmed to implement particular logic functions
  - The cells may be reconfigured to implement a different logic function in the same LUT
- N input LUT can implement any N variable logic function



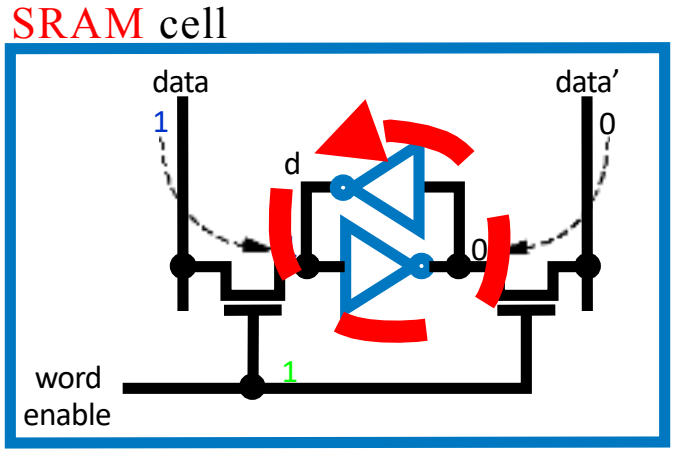
LUT Example

- Implement the logic function specified by the truth table using a 2-input LUT

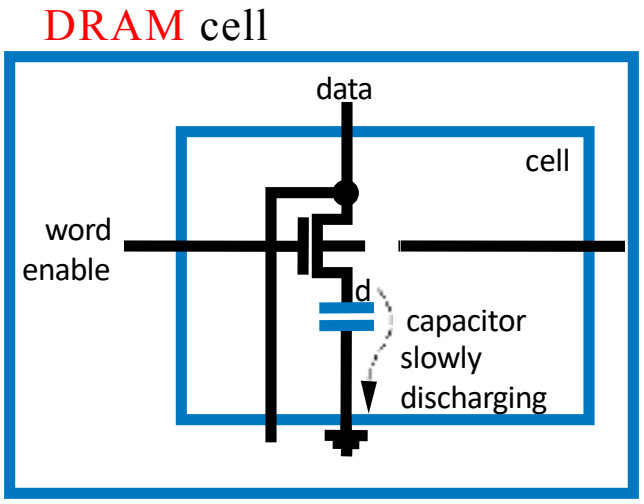


Static RAM (SRAM) Cell

- Static Random Access Memory (SRAM) cell

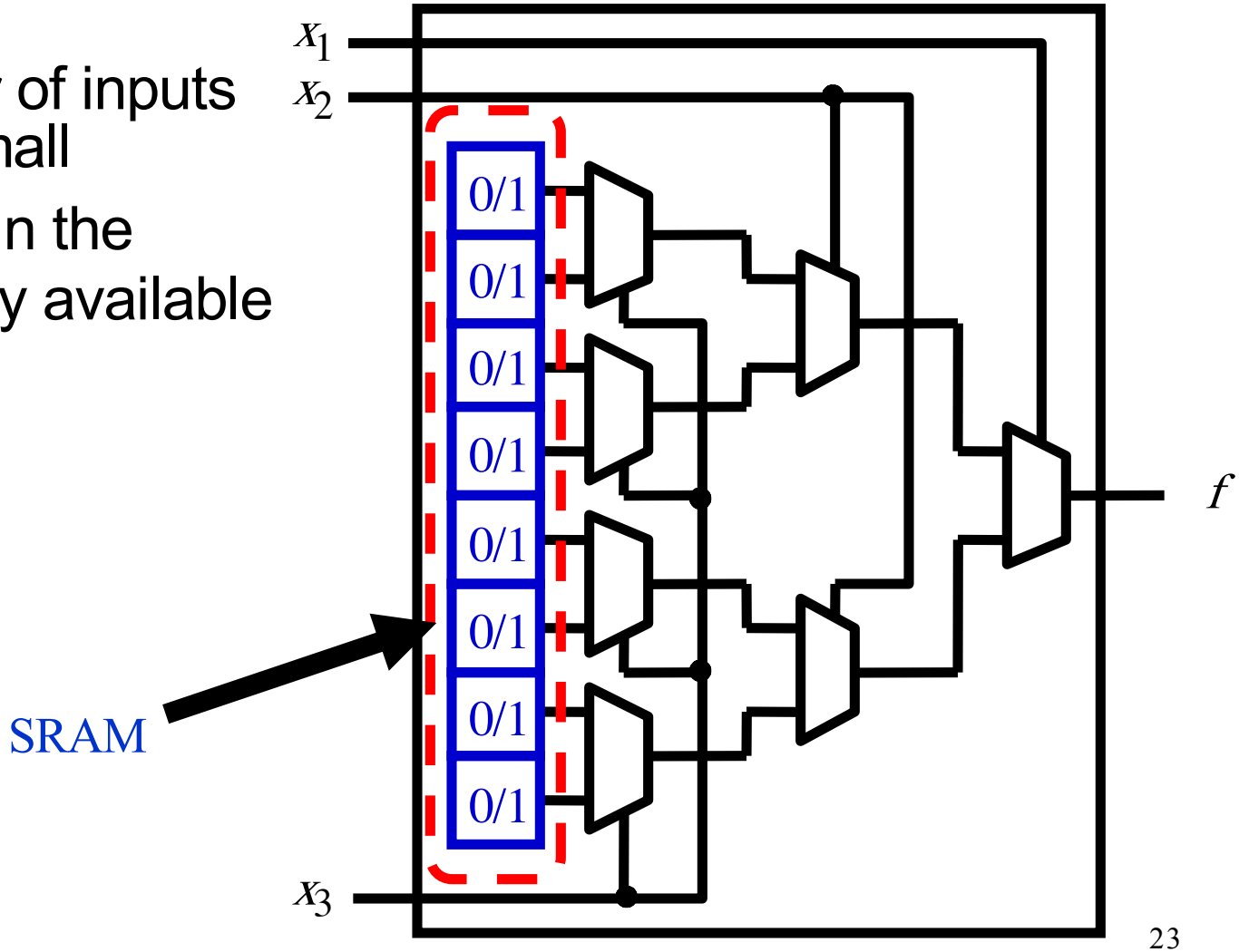


- Dynamic RAM (DRAM) cell



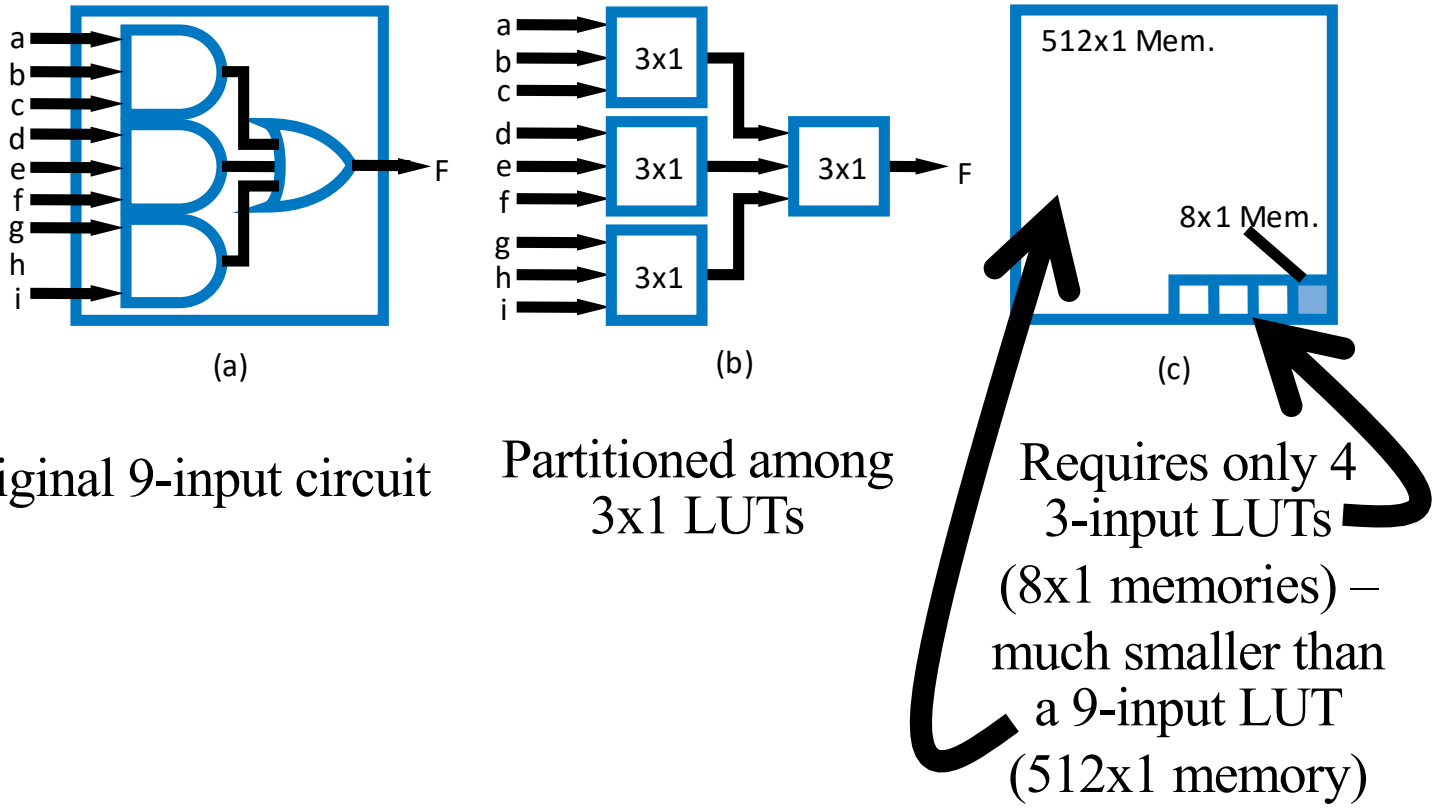
3-input LUT

- The number of inputs to LUT is small
- 4 - 6 inputs in the commercially available FPGAs



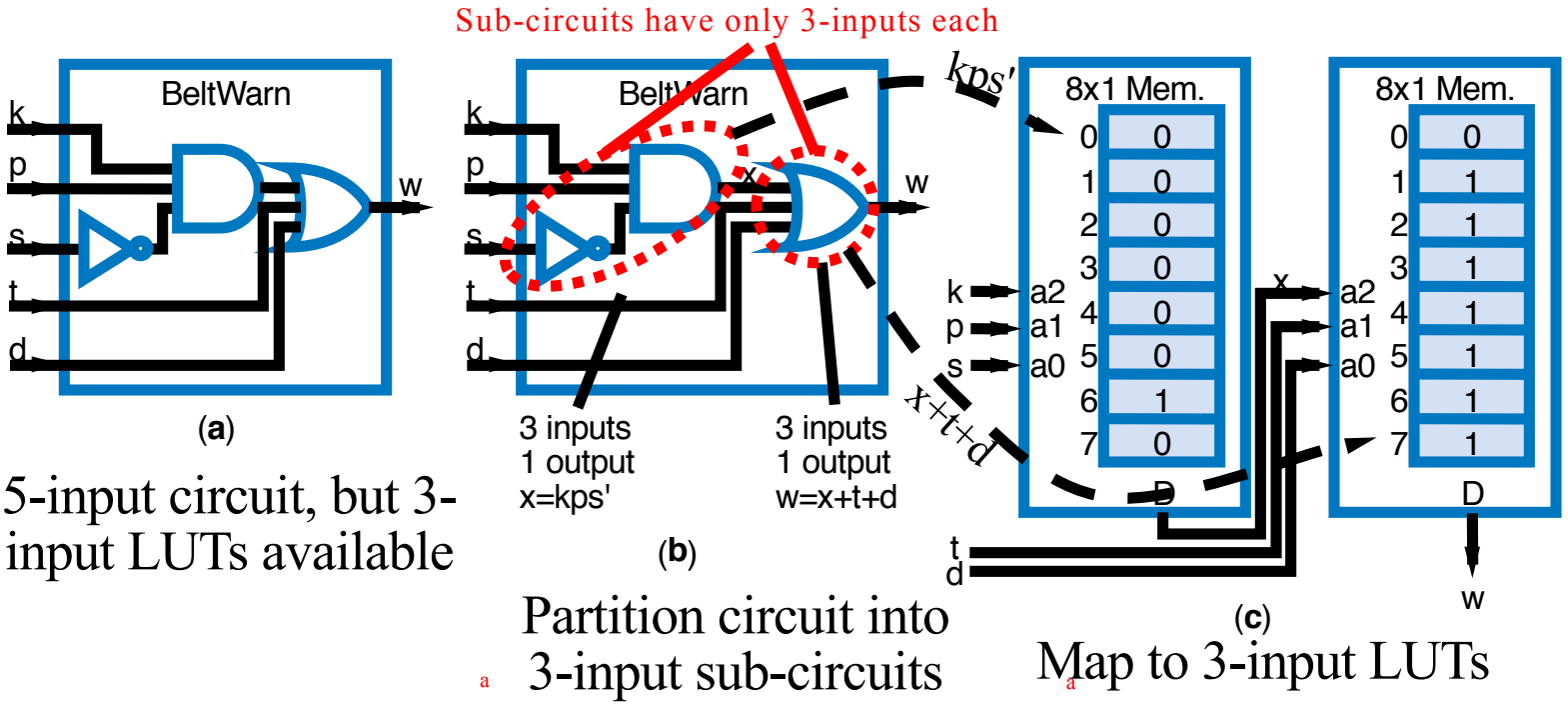
FPGA Internals: Lookup Tables (LUTs)

- Partitioning among smaller LUTs is more size efficient
  - Example: 9-input circuit



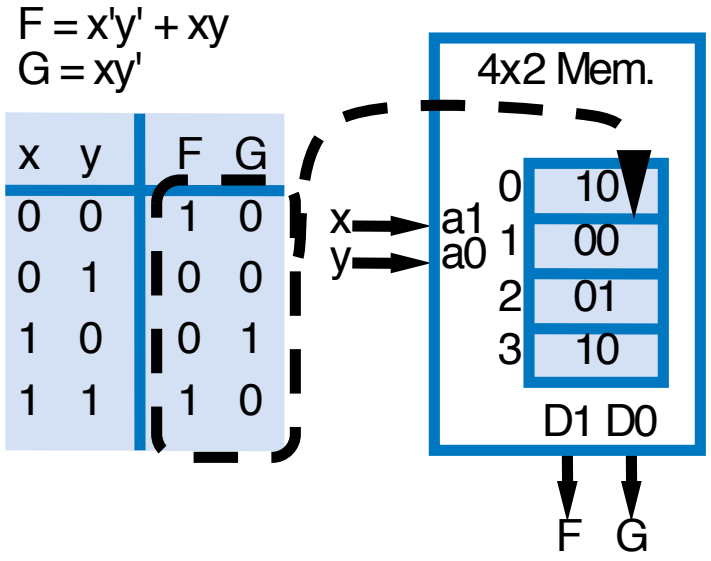
Logic Implemented with LUTs

- Circuits with more inputs



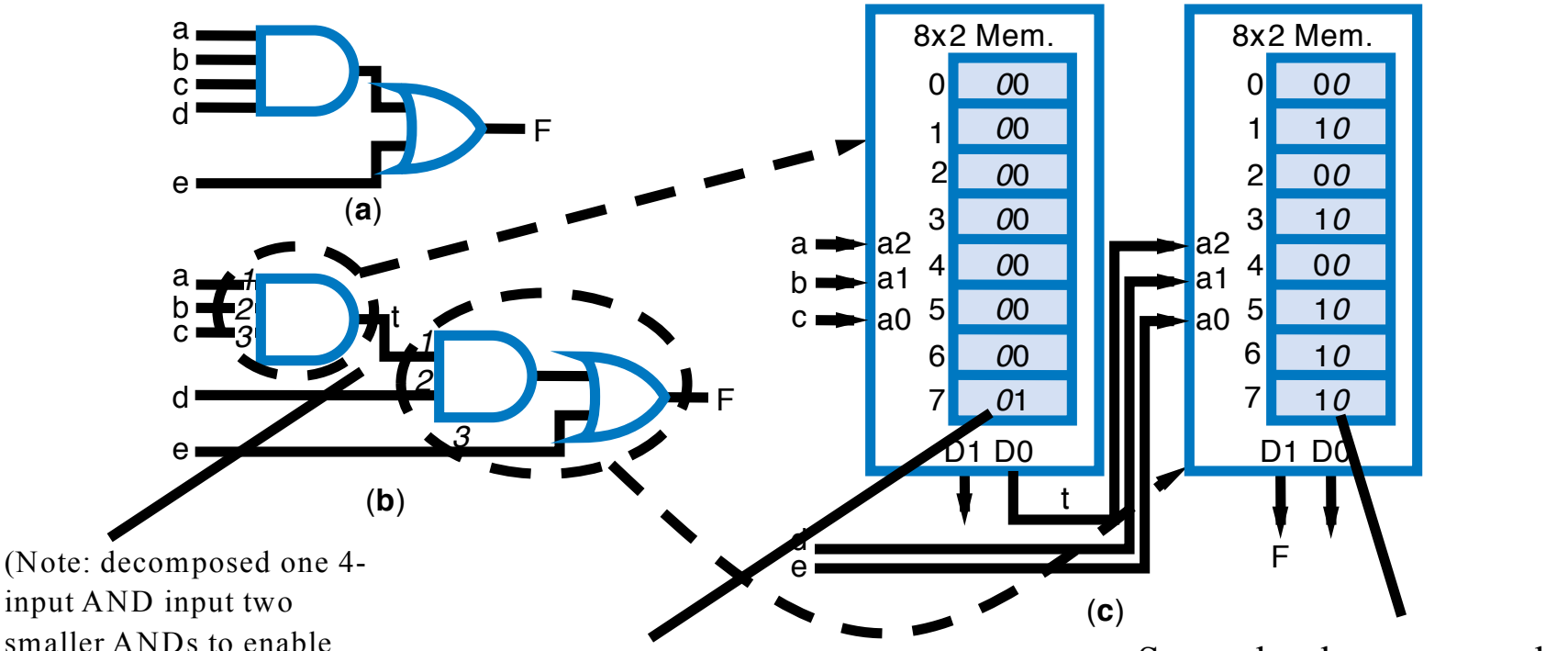
2-Output LUTs

- LUT typically has 2 (or more) outputs, not just one



2-Output LUTs

- Example: Partitioning a circuit among 3-input *2-output* lookup tables



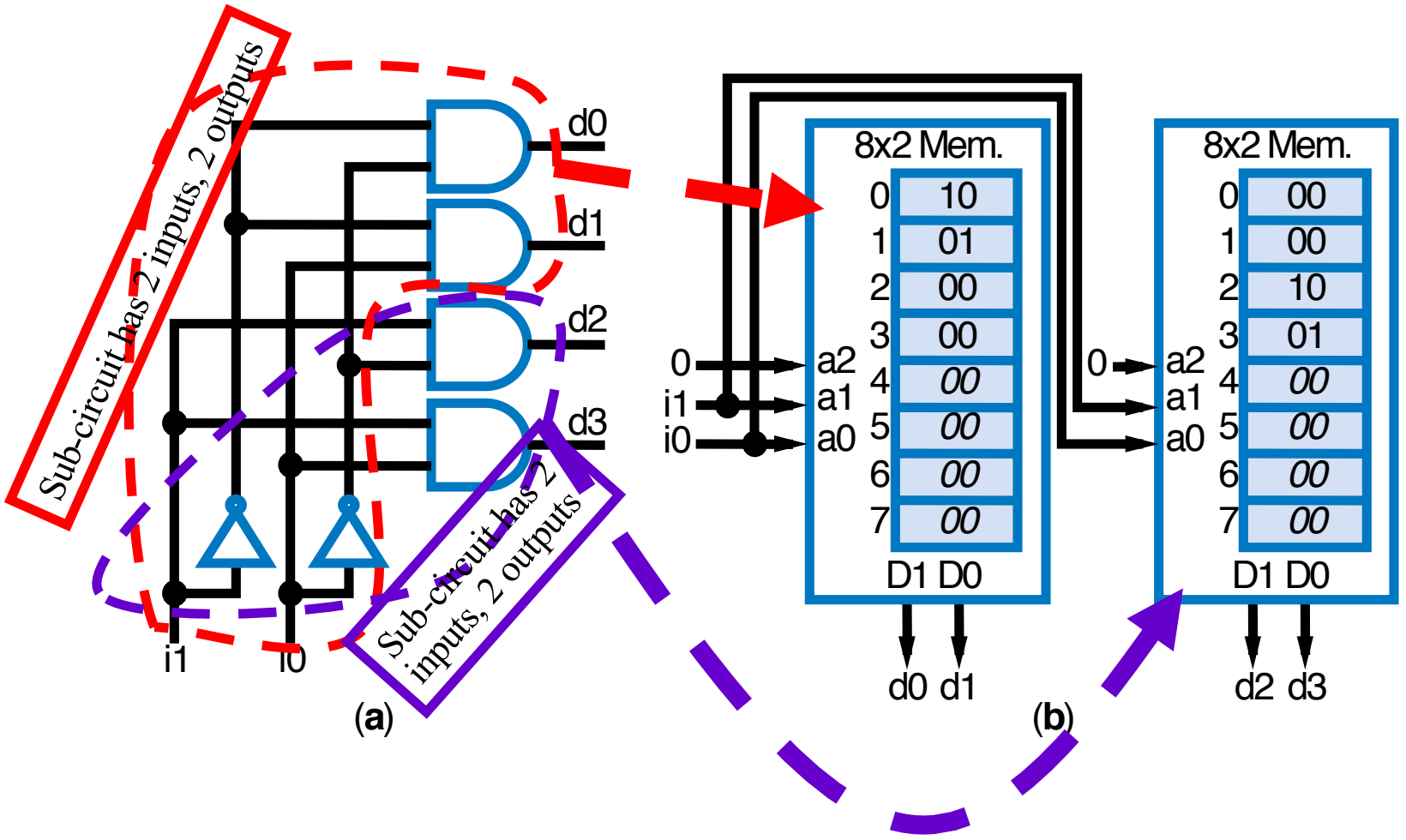
(Note: decomposed one 4-input AND input two smaller ANDs to enable partitioning into 3-input sub-circuits)

First column unused; second column implements AND

Second column unused; first column implements AND/OR sub-circuit

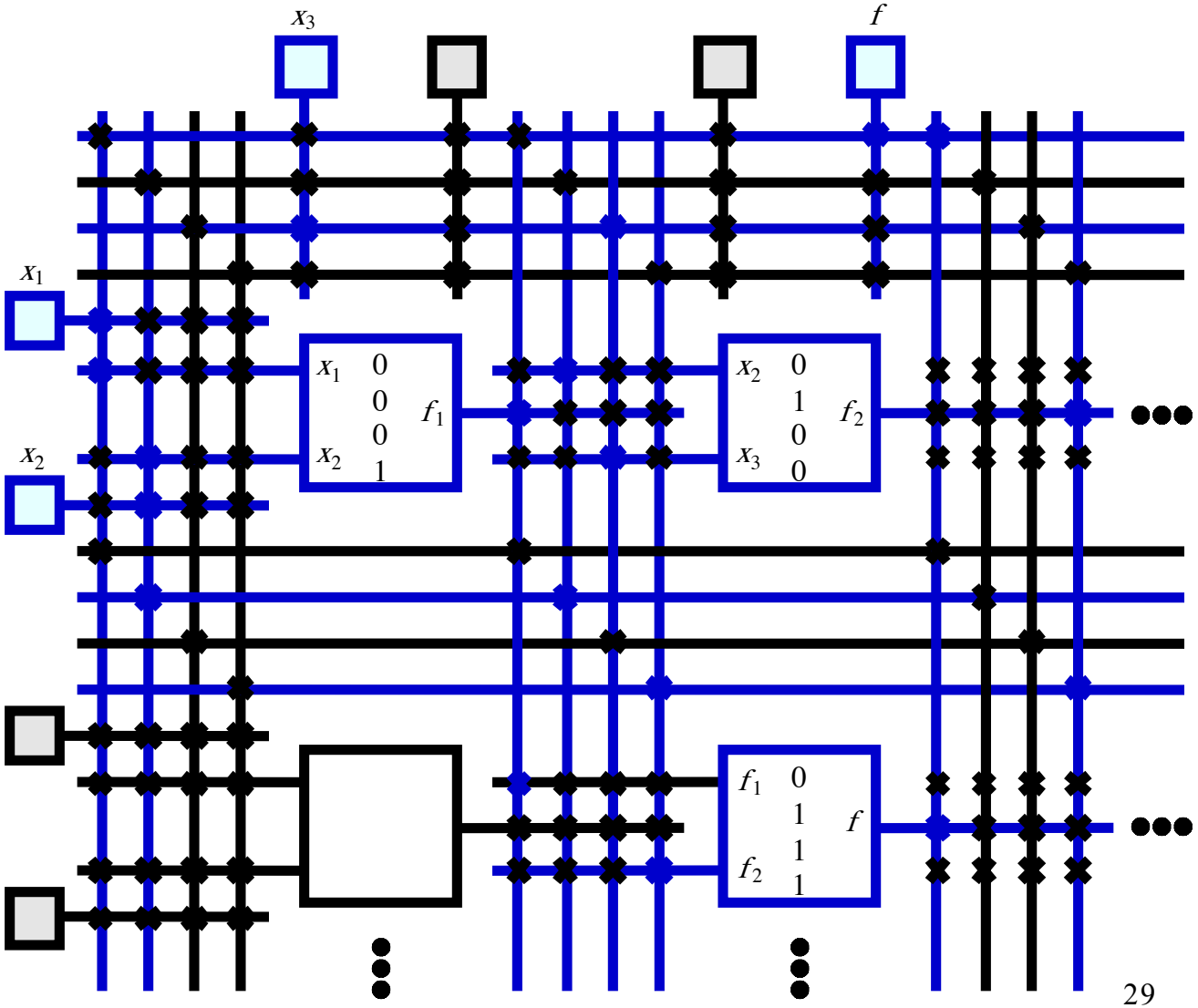
2-Output LUTs

- Example: Mapping a 2x4 decoder to 3-input 2-output LUTs

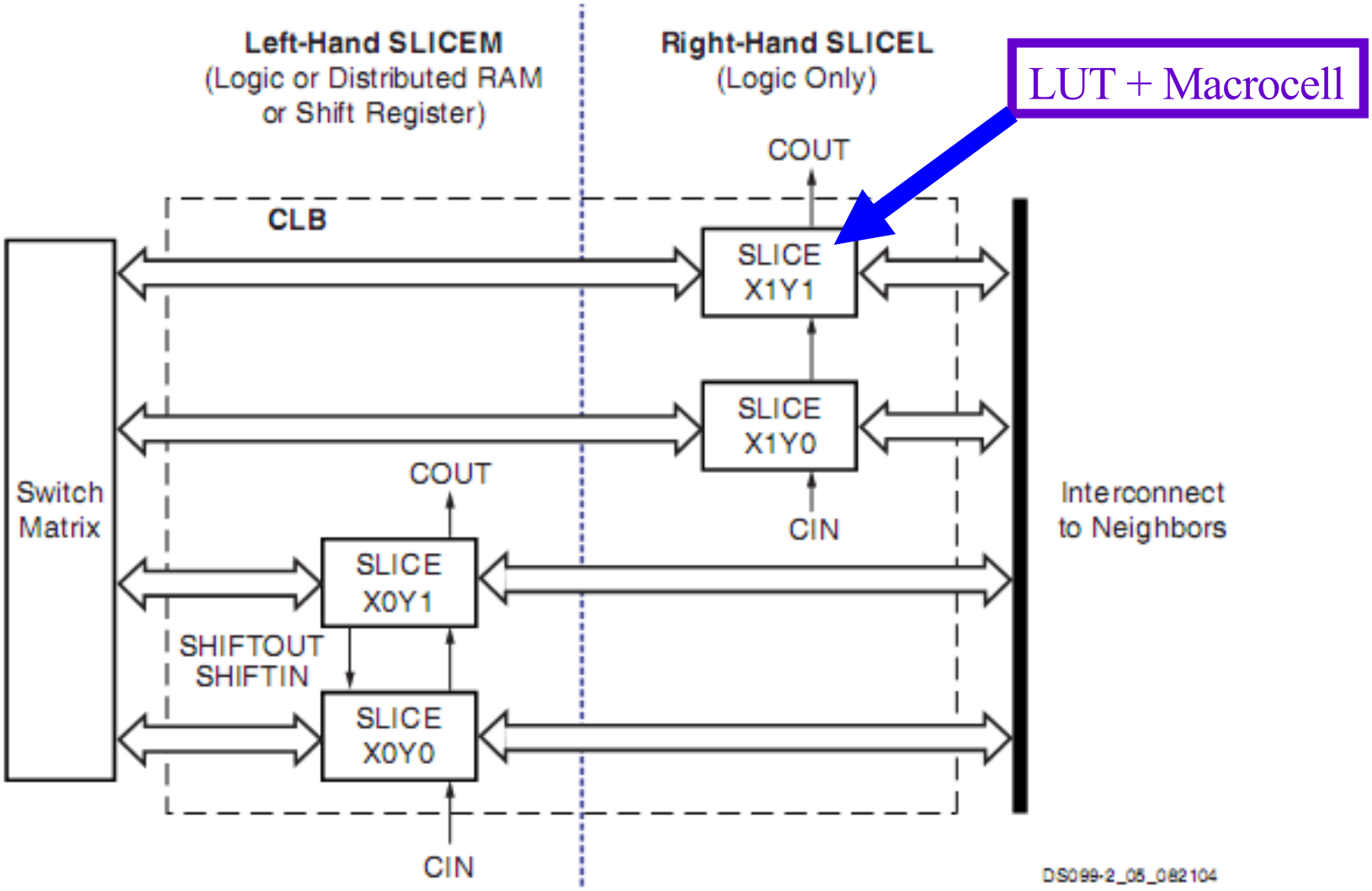


FPGA Configuration Example

- Blue x indicates a connection
- f1 = x_1x_2
- f2 = $x_2'x_3$
- f = f1 + f2

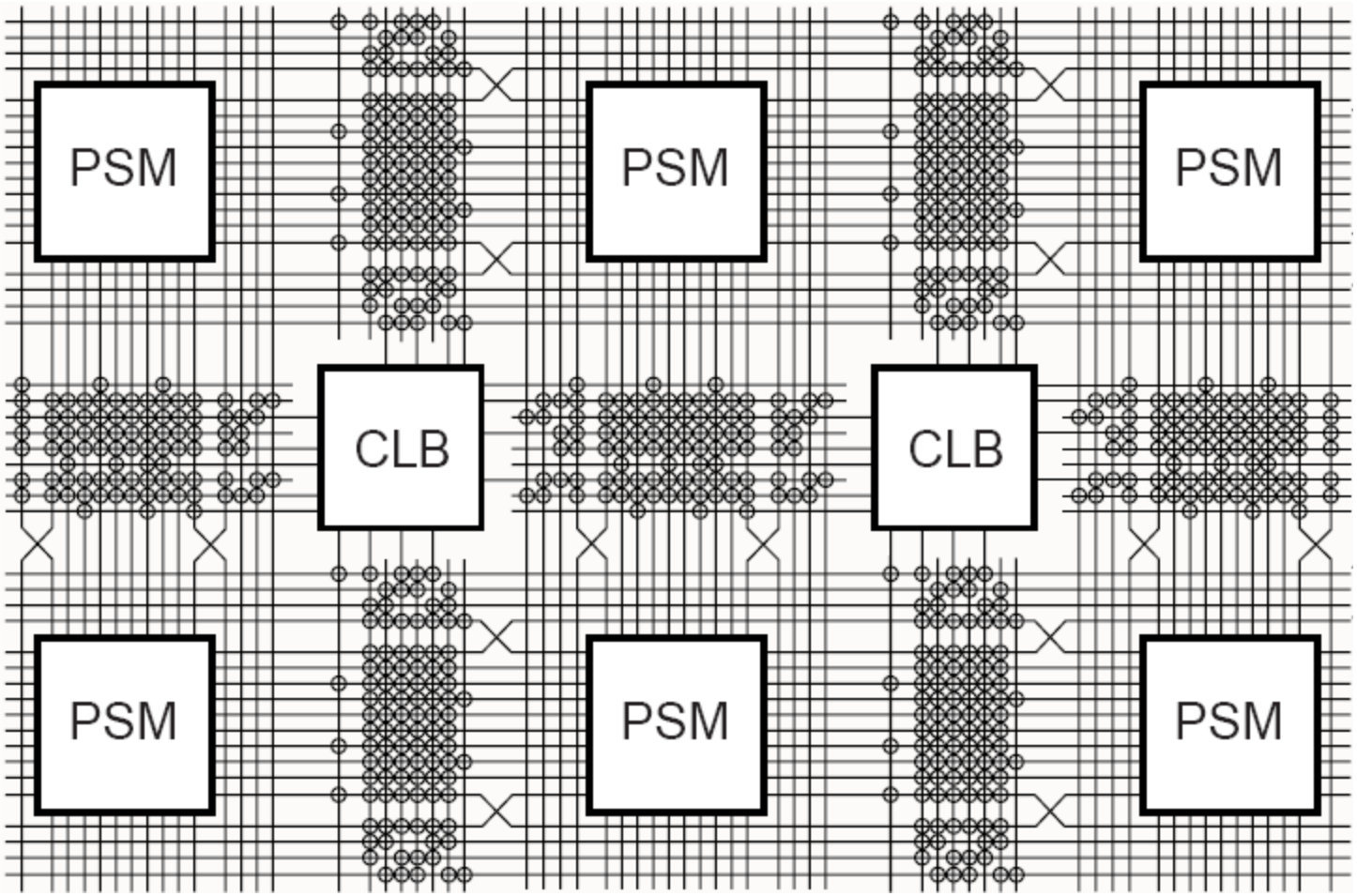


Xilinx Spartan 3 FPGA CLB Structure



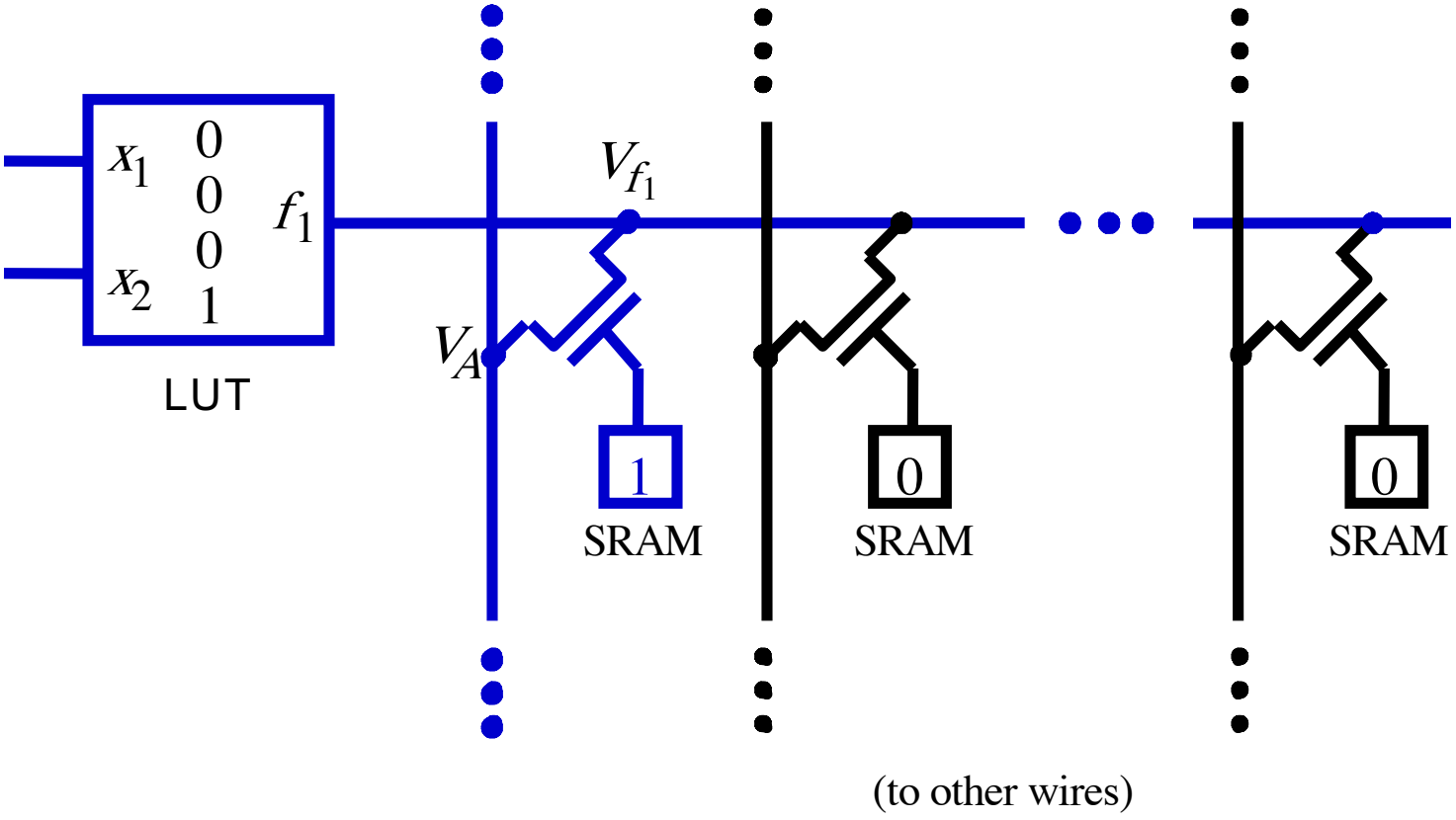
Courtesy of Xilinx Inc.

Xilinx FPGA Switches and Wires

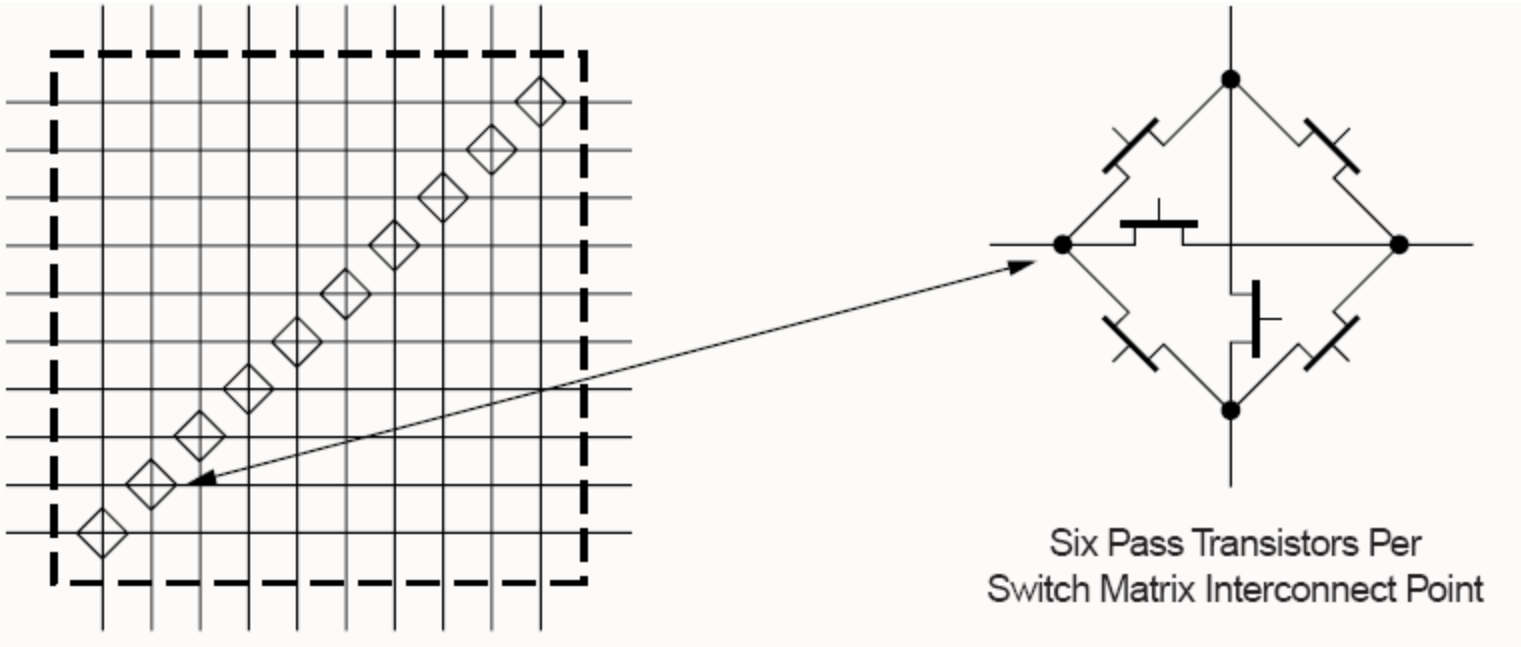


Courtesy of Xilinx Inc.

Programmable Switch

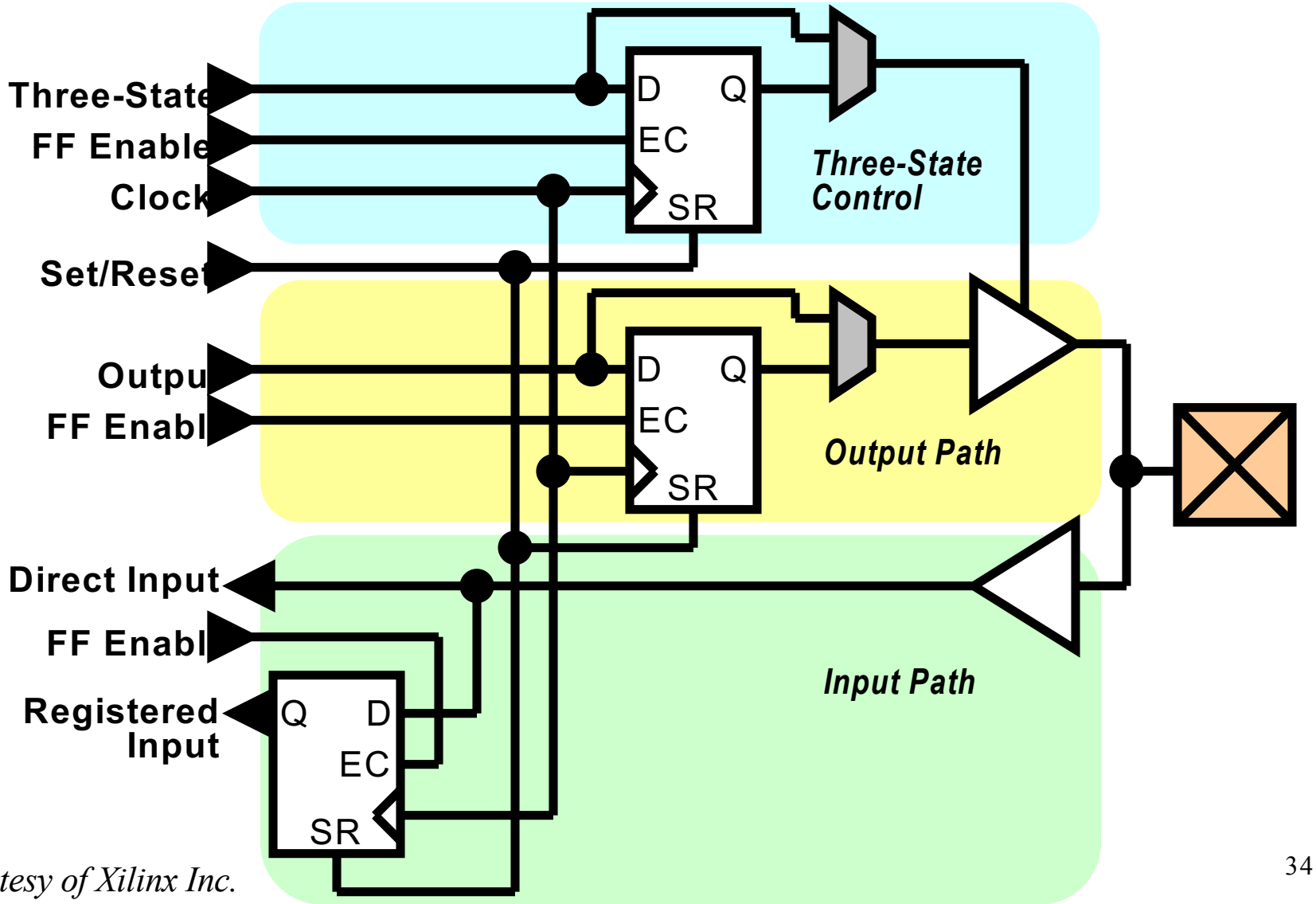


Xilinx FPGA PSM



Programmable Switch Matrix (PSM)

Basic I/O Block Structure

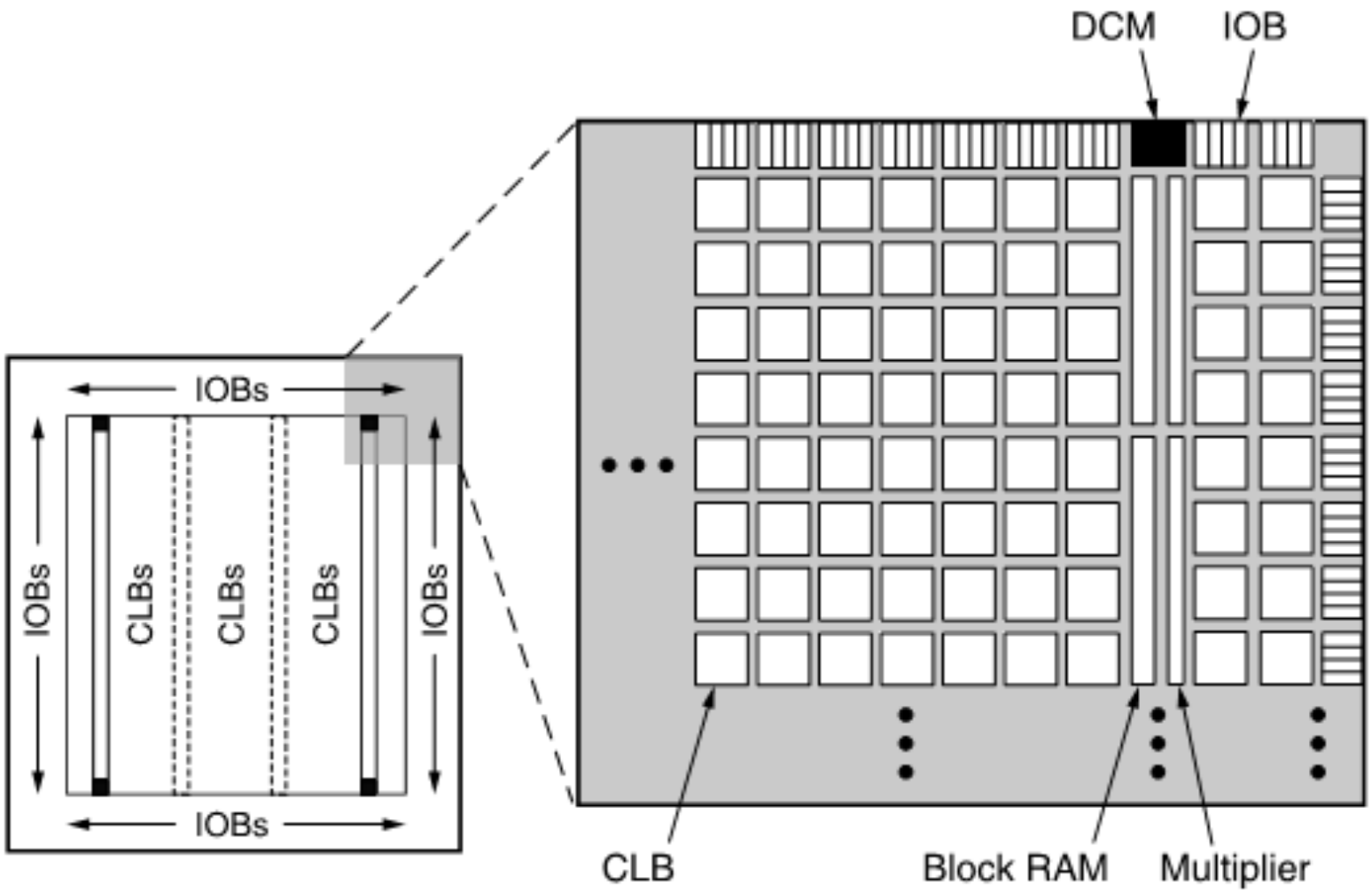


Courtesy of Xilinx Inc.

Advanced FPGA Features

- Dozens of millions of equivalent logic gates
- Enhanced clock features
- Flexible embedded memory blocks
- Intellectual property (IP) cores
- Embedded processors (hard and soft)
- Digital signal processing (DSP) blocks, tools, design flows (specific FPGA vendors)
- Dedicated hardware multipliers
- high-speed communication capabilities
- Advanced I/O standards and protocol support

FPGA Example – Spartan 3



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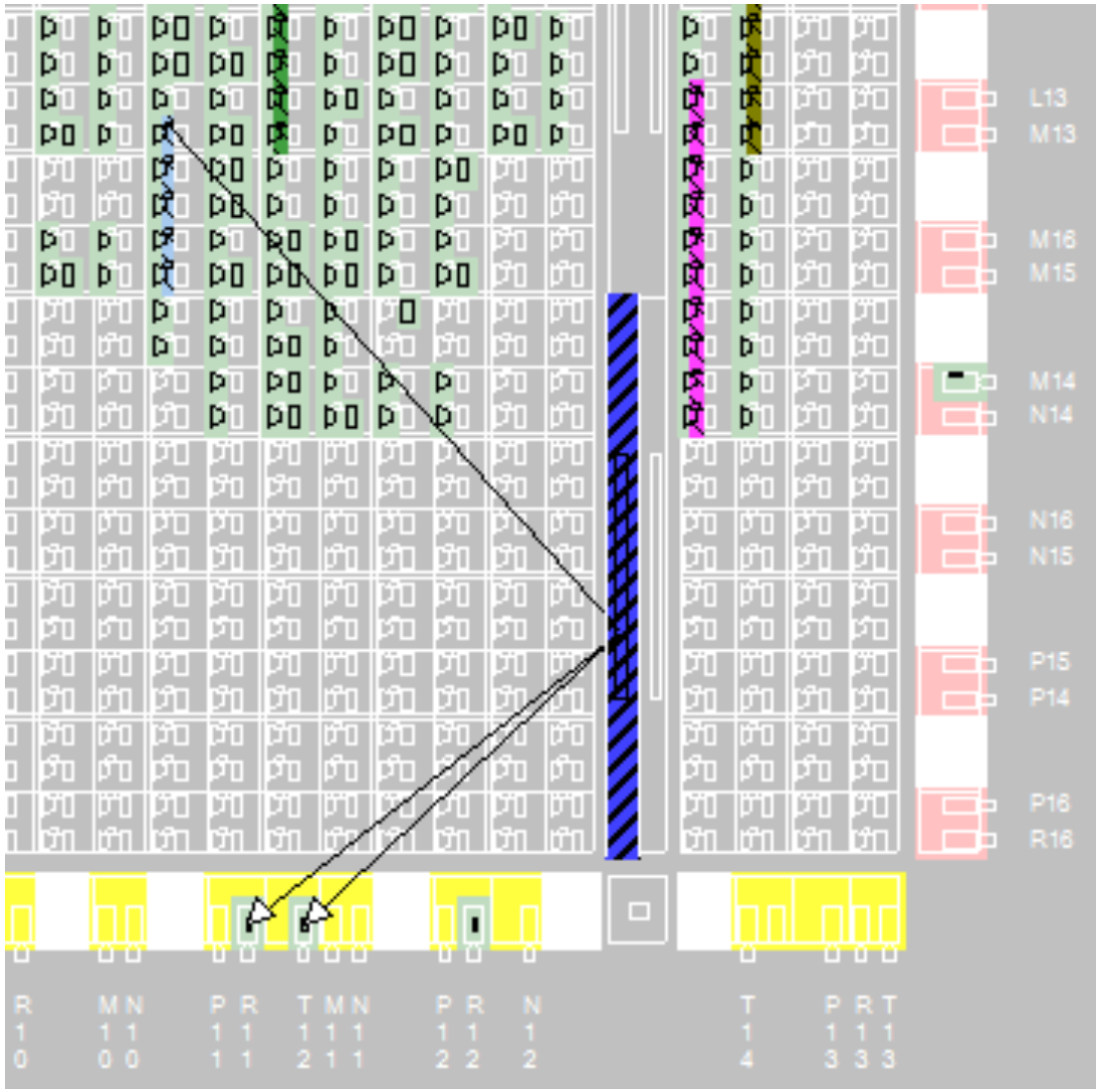
Example of FPGA Implementation



Pros and Cons of FPGA

- Pros
  - Fast turnaround.
  - Low NRE (non-recurring engineering) cost.
  - Low risk.
  - Effective design verification.
  - Low testing cost.
- Cons (compare to regular IC chip implementation, and are improving)
  - *Bigger chip size*
  - *Higher cost*
  - *Higher power consumption*
  - *Slower speed*
- Technology is still advancing