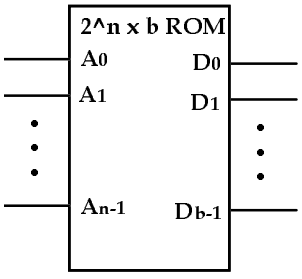
Outline

- Last time:
  - SR latch
  - D latch
  - Flip-Flops
  - Edge-triggered, Master-Slave
  - Shift Registers
  - Simple Counters
  - Serial-Parallel Conversion
  - LFSR Counters
- This lecture:
  - ROM, RAM
  - Bussing, Tri-state, multi-porting
  - Switch De-bouncing
  - FSM Design With ROMs

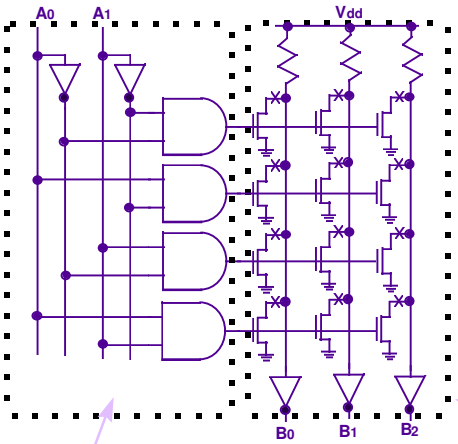
Read-Only Memory (ROM)

- A *Read-Only Memory* (ROM) is a combinational circuit with *n* address-line data inputs (A0, A1, ... An-1) and *b* (D0, D1, ... Db-1) data outputs. A ROM literally store the truth-table (minterms) of an n-input, b-output combinational circuit.



- A ROM is *nonvolatile* memory. That is, its contents are preserved even if no power is applied.

Read-Only Memory



- Often NOR decoder is used (see PLA), but in ROM all minterms must be decoded.
- ROM is often used to implement "table look-up" functions (multiplier, most significant bits (MSBs) of exponential or square-root).

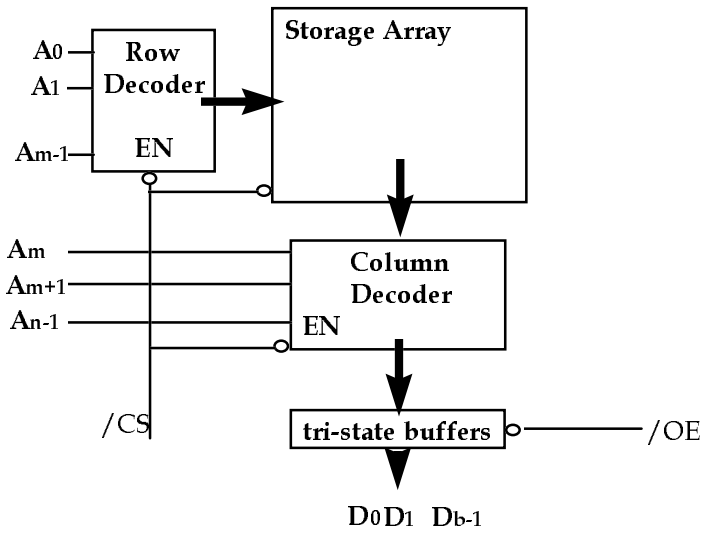
storage array

decoder (look-up array)

Classification of ROMs

- *Mask-programmable ROM*: Look-up array connections are programmed during semiconductor manufacture using a mask. Very fast (>5ns), very dense (~256Mbits), expensive ($20-50K+n*$0.50-20), 2-4week turn-around, low power.
- *Programmable ROM (PROM)*: Fuses (sometimes anti-fuses) to program once in the field, using PROM Programmer. Very fast, dense (~ 64Mbits), inexpensive ($2-100), 5min to write, low power.
- *Erasable Programmable ROM (EPROM)*: Fuses (sometimes anti-fuses) implemented using floating-gate MOSFETS to program 10K-100K times in the field, using EPROM Programmer. Fast (> 150ns), dense (~ 16Mbits), inexpensive ($2-30), 5min to write, low power, erased by flooding with UV light.
- *Electrically Erasable Programmable ROM (EEPROM, E2PROM)*: Same as EPROM, but specific bits may be erased selectively. Fast (> 150ns), dense (~ 16Mbits), inexpensive ($5-50), 5min to write, low power.
- *Flash Electrically Erasable Programmable ROM (Flash EEPROM, E2PROM)*: Same as E2PROM, but entire ROM may be erased electrically (no UV). Fast (> 100ns), dense (~ 64Mbits), inexpensive ($5-50), 5min to write, low power. Denser than E2PROM. *Very high growth in PCMCIA card/ portable electronics applications.*

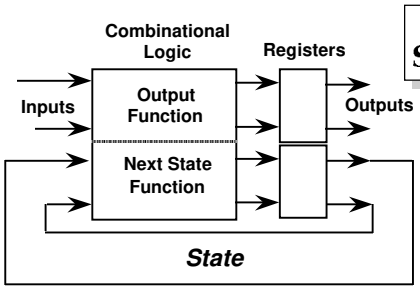
Internal ROM Structure



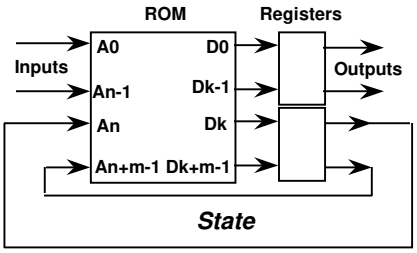
Read-Write Memory

- Static Random-Access Memory (SRAM): Storage Array implemented using flip-flops. Very fast (>3ns), dense (~16Mbits), relativel expensive. To write, Chip-select (/CS) and Write Enable (/WE) must be low. To read, /CS and Output Enable (/OE) must be low and /WE must be high.
- Dynamic Random-Access Memory (DRAM): Storage Array implemented using single transistor & a capacitor. Fast (>100ns), very dense (~64Mbits). Control signals are Row address strobe (/RAS), Column Address Strobe (/CAS) and Write-Enable (/WE).
- DRAMs use a destructive-read cycle, so the data must be written back after it is read.

Rom-Based FSM Design



Block Diagram for Synchronous Mealy Machine



ROM-based Realization

- **Inputs & Current State form the address**
- **ROM data bits form the Outputs & Next State**

Rom-Based FSM Design: Example

Example: BCD to Excess 3 Serial Converter

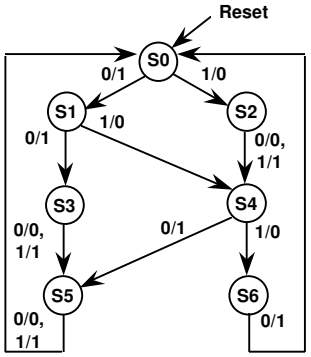
The bits are presented in bit-serial fashion starting with the least significant bit. There is a single input X, single output Z

BCD	Excess 3 Code
0000	0011
0001	0100
0010	0101
0011	0110
0100	0111
0101	1000
0110	1001
0111	1010
1000	1011
1001	1100

Rom-Based FSM Design: Example

Present State	Next State X=0	Next State X=1	Output X=0	Output X=1
S0	S1	S2	1	0
S1	S3	S4	1	0
S2	S4	S4	0	1
S3	S5	S5	0	1
S4	S5	S6	1	0
S5	S0	S0	0	1
S6	S0	--	1	--

State Transition Table

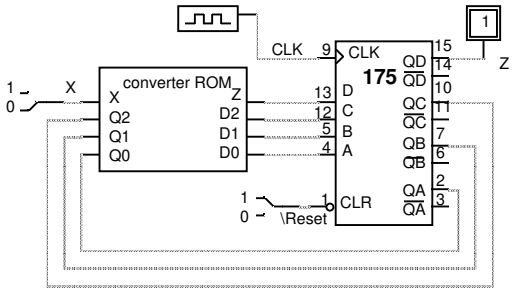


Derived State Diagram

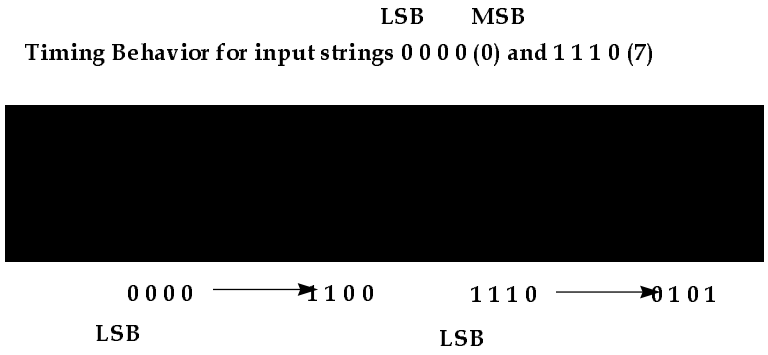
Rom-Based FSM Design: Example

ROM Address X	Q2	Q1	Q0	ROM Outputs Z	D2	D1	D0
0	0	0	0	1	0	0	1
0	0	0	1	1	0	1	1
0	0	1	0	0	1	0	0
0	0	1	1	0	1	0	1
0	1	0	0	1	1	0	1
0	1	0	1	0	0	0	0
0	1	1	0	1	0	0	0
0	1	1	1	X	X	X	X
1	0	0	0	0	0	1	0
1	0	0	1	0	1	0	0
1	0	1	0	1	1	0	0
1	0	1	1	1	1	0	1
1	1	0	0	0	1	1	0
1	1	0	1	1	0	0	0
1	1	1	0	X	X	X	X
1	1	1	1	X	X	X	X

Truth Table/ROM I/Os



Circuit Level Realization
74175 = 4 x positive edge triggered D FFs

In ROM-based designs, no need to consider state assignment

Rom-Based FSM Design: Example