Penn State Abington
CMPEN 271
Lecture Set #21
Memory and Programmable Logic

R. Avanzato © 2014-2015

Topics:

- Review Counters and State Machines — **Video part 1 of 5 ←**
- Memory Concepts — Video part 2 of
- Memory Decoding
- Programmable Logic Devices — Video part 3 of 5
- FPGA Technology
- Microprocessors and Microcontrollers — Video part 4 of 5
- Final Exam Info
- Review Questions — Video part 5 of 5

Sequential Circuit Review

- What is the count sequence of a **MOD-75 ripple counter**? How many FFs are required? On what count do you reset the flip-flops to zero?

- What is count sequence of a **MOD-5 ripple counter**? On what count do you reset the flip-flops to zero? Are there any glitches or spikes? If you implemented MOD-5 counter on a **synchronous 74163 MSI counter**, on what count would you reset?

- **Compare the following circuit designs**
  - 1) MOD-5 ripple (JK FFs) counter
  - 2) MOD-5 state machine (D FF) counter
  - 3) MOD-5 74163 IC counter.
  - Show state diagram for a MOD-5 state machine counter. What are the advantages of disadvantages of each design. Generalize to any MOD-N.

Sequential Circuit Review

- What is a **sequential circuit**? **Combinational** circuit?
- How would you characterize a **state machine**?
- What is difference between **synchronous and asynchronous circuits**?

Penn State Abington
CMPEN 271
Lecture Set #21
Memory and Programmable Logic

Topics:

- Review Counters and State Machines — Video part 1 of 5
- Memory Concepts — **Video part 2 of 5 🡐**
- Memory Decoding
- Programmable Logic Devices — Video part 3 of 5
- FPGA Technology
- Microprocessors and Microcontrollers — Video part 4 of 5
- Final Exam Info
- Review Questions — Video part 5 of 5

Memory Concepts

Example: 8 x 8 Memory device (8 locations with 8 bits of data stored at each location)

	ADDRESS	DATA
location 0 →	000 →	10011001
location 1 →	001 →	01111101
location 2 →	010 →	10101100
location 3 →	011 →	11001001
location 4 →	100 →	00000000
location 5 →	101 →	11111111
location 6 →	110 →	11111111
location 7 →	111 →	00000011

8x8 memory chip

Note: data is arbitrary

- At each address location, there are 8 data bits stored. (Note: diagram shows an arbitrary 8 bits of data; data could represent machine instructions, numerical data, ASCII characters, etc.)

- Each location has a unique binary 3-bit address, starting at 0.

- For 8 locations, a 3-bit address is necessary. This is same as saying 3 address lines are necessary. (A "line" is simply a "wire". A group or set of wires is often called a "bus".)

Memory Concepts

<u>Example</u>: **1K x 8 Memory device** (1024 locations, 8 bits at each location)

	ADDRESS binary	ADDRESS hex	DATA
location 0 →	0000000000	000	10011001
location 1 →	0000000001	001	01111101
location 2 →	0000000010	002	10101100
etc.	0000000011	003	11001001
	0000000100	004	00000000
	...	...	...
location 1023 →	1111111111	3FF	00000001

Note: data is arbitrary

This memory chip would require **<u>10 address lines</u>** (wires) to handle **<u>1024 locations</u>**.
Address values can be expresses in either binary or hex

Memory Concepts

- RAM = random access memory (volatile)
- SAM = sequential (serial) access memory (e.g. magnetic tape)
- SRAM = static RAM (SRAM; semiconductor; latch/flip-flop-based; fast)
- DRAM = dynamic RAM (DRAM; capacitor-based; needs refreshing)

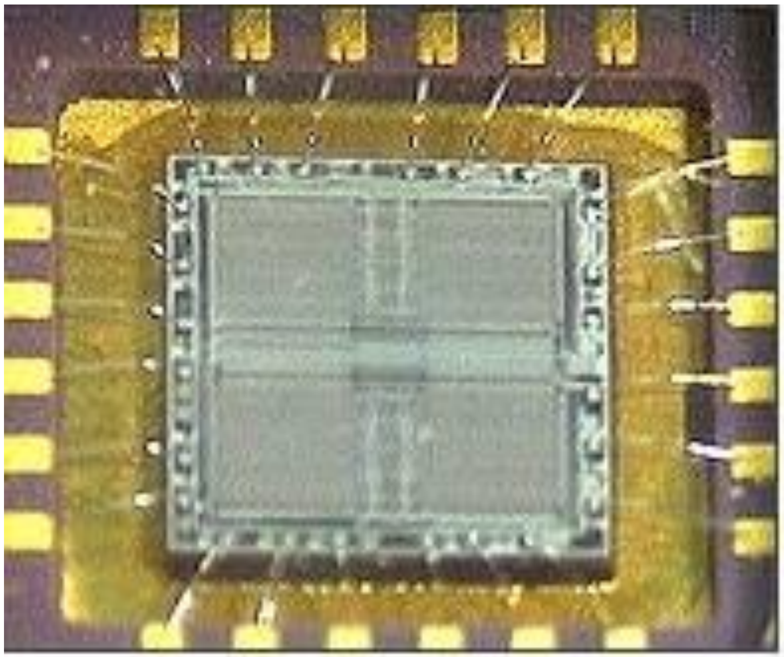
- ROM = read-only memory (also random-access; non-volatile)
- PROM = programmable read-only memory
- EPROM = erasable PROM (use UV light to erase)
- EEPROM = electrically-erasable PROM
- Flash memory (similar to EEPROM)

- Volatile memory - memory loss when no power
- Non-volatile memory - memory retained when no power

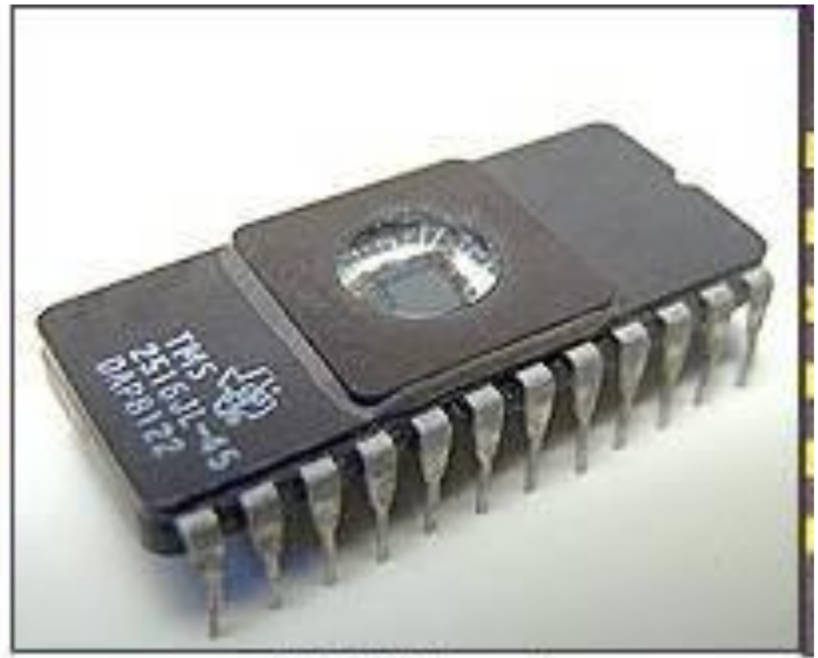
- Cache memory = fast RAM; (pronounced “cash”); fastest memory
- Access (read/write) time
- CD, DVD storage capacity

NOTE: read sections on "memory circuits" on www.howstuffworks.com

Memory Concepts (EPROM)



Quartz window close-up



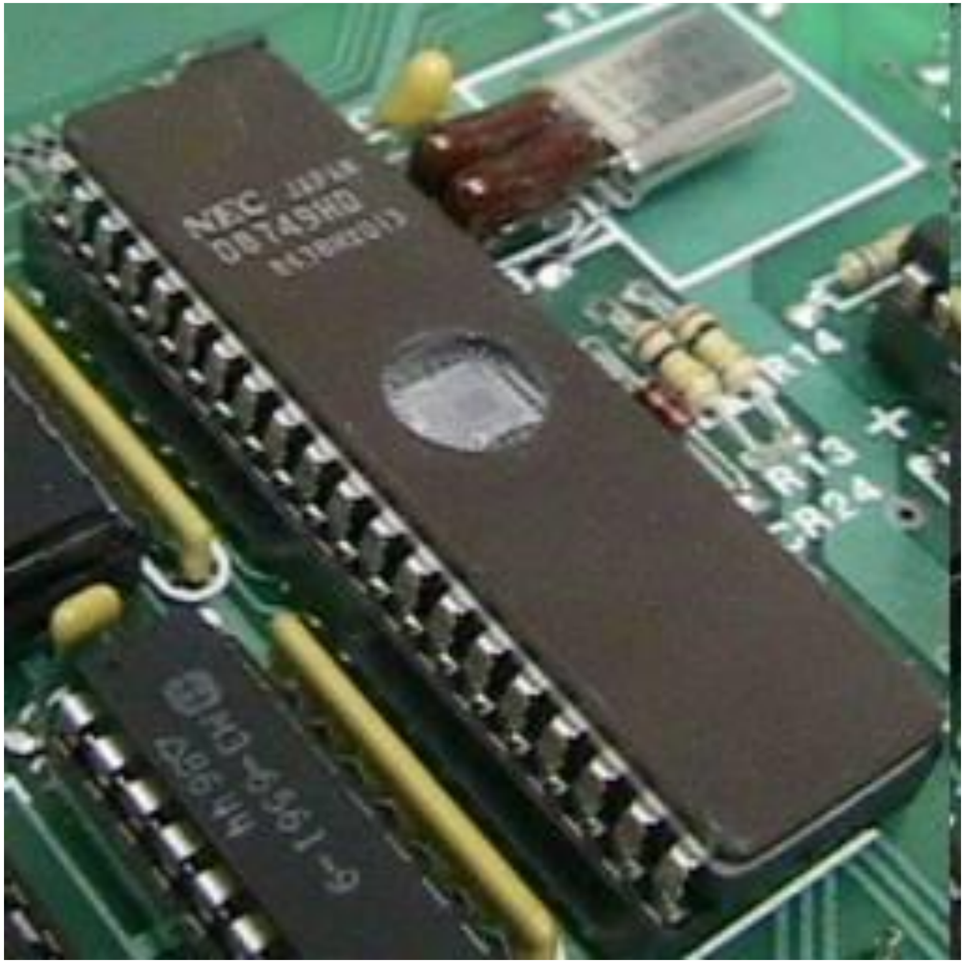
TMS-2516 version

Ref: http://images.google.com/imgres?imgurl=http://www.old-computers.com/history/images/Timeline_Eprom2716_1.jpg&imgrefurl=http://www.old-computers.com/history/detail.asp%3Fn%3D21%26t%3D3&usg=__E3tMAD-CRlQp7HuF_2bRrq5_Pg8=&h=286&w=431&sz=27&hl=en&start=1&sig2=VjePo3RamcqNXksGIXgFZQ&um=1&tbnid=lLRzyNJL_43LuM:&tbnh=84&tbnw=126&prev=/images%3Fq%3DEPROM%26hl%3Den%26sa%3DX%26um%3D1&ei=Vk0gS4vTIIeQNvLuiMUC

Memory Concepts (EPROM)

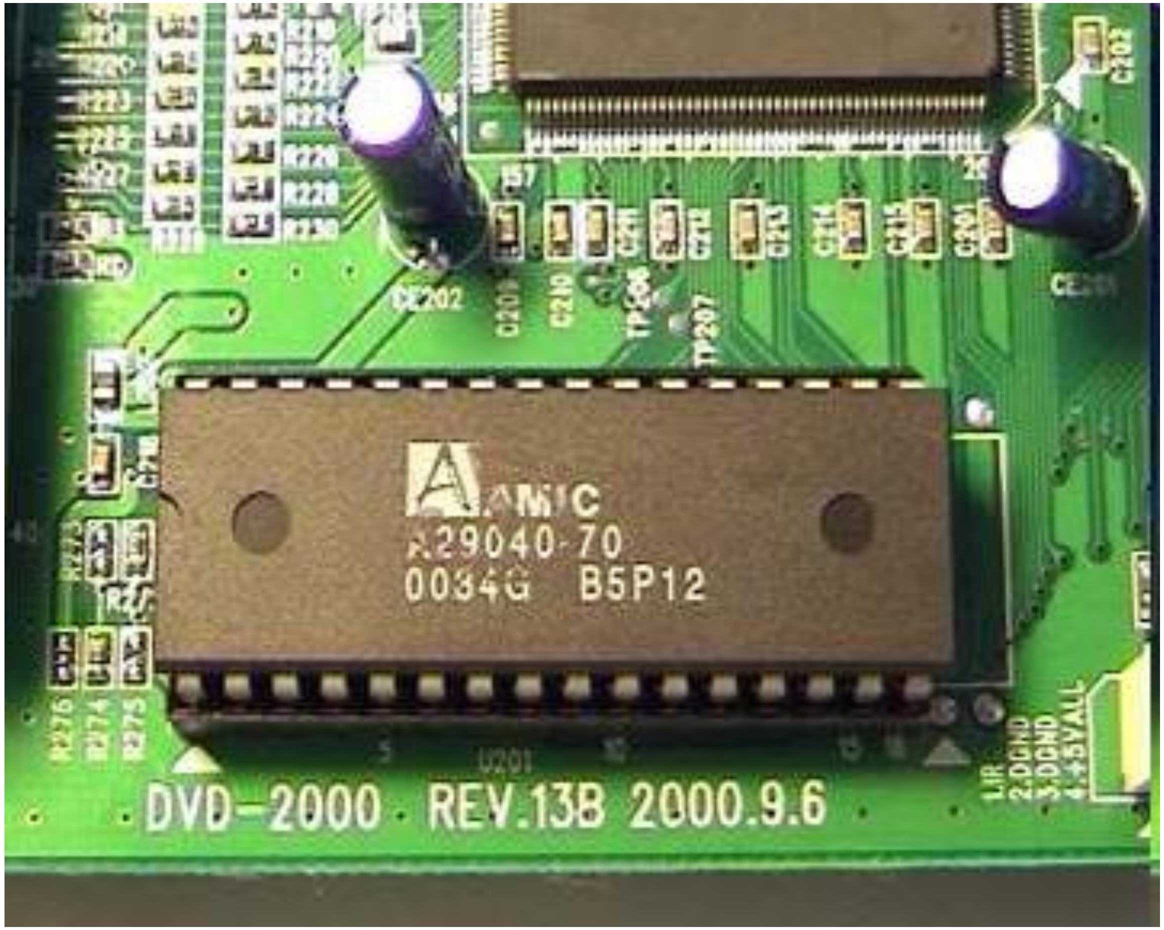
http://www.7-forum.com/modelle/e32/eprom_tausch_egs/eprom-11.jpg

Memory Concepts (EPROM)



http://lions-wing.net/lessons/hardware/eprom.png

Memory Concepts (EEPROM)

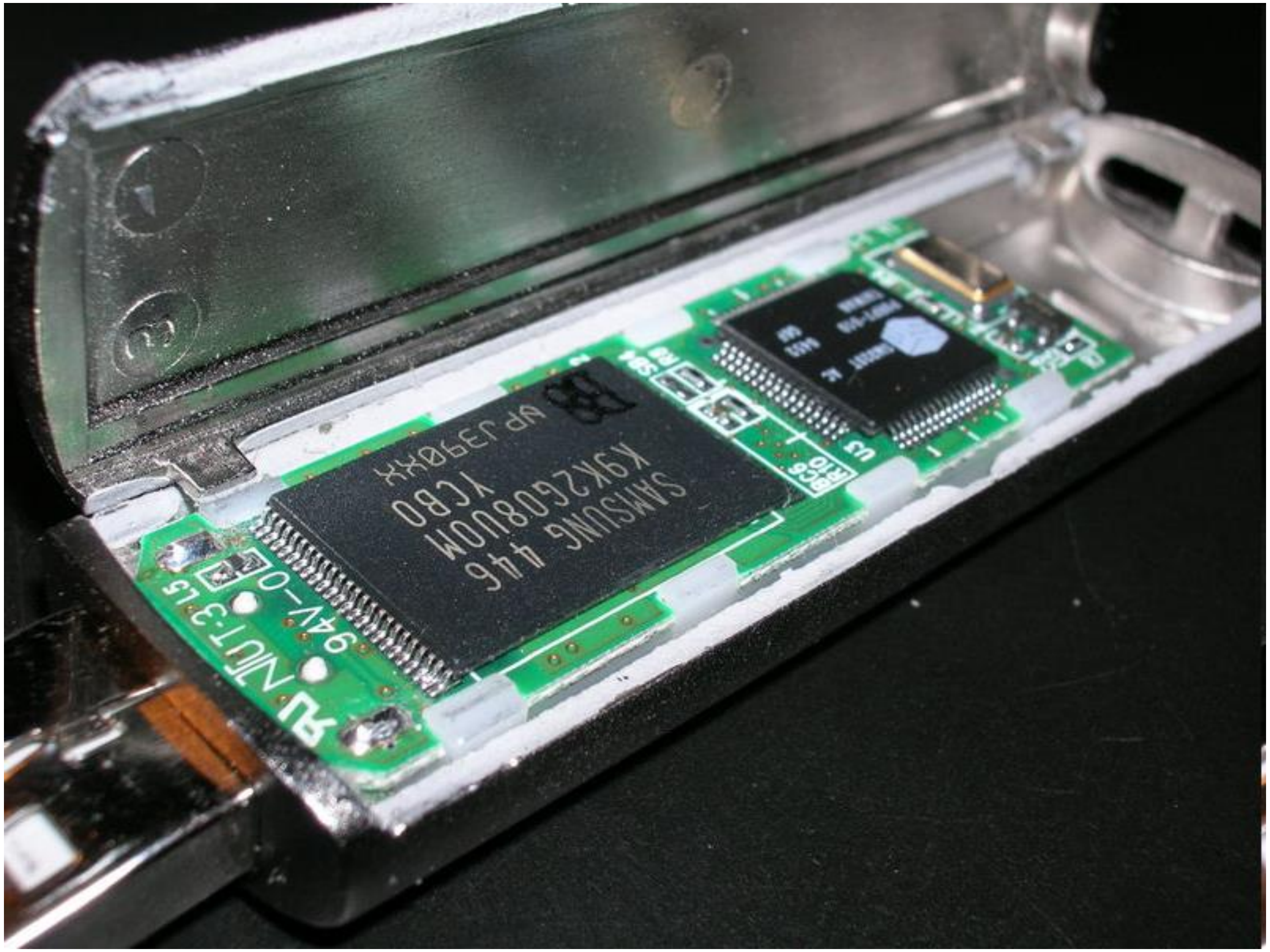


http://lions-wing.net/lessons/hardware/eprom.png

Memory Concepts (ROM)

http://www.novopc.com/wp-content/uploads/2008/10/rom.jpg

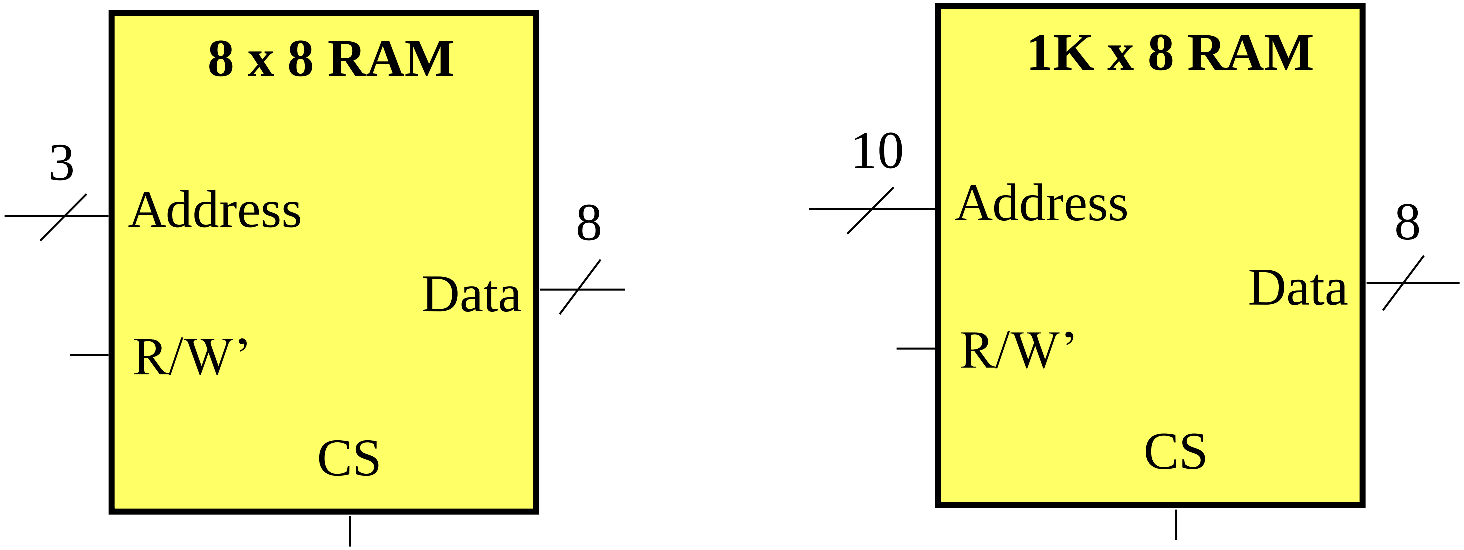
Memory Concepts (Flash memory)



Flash memory has advanced beyond EEPROM

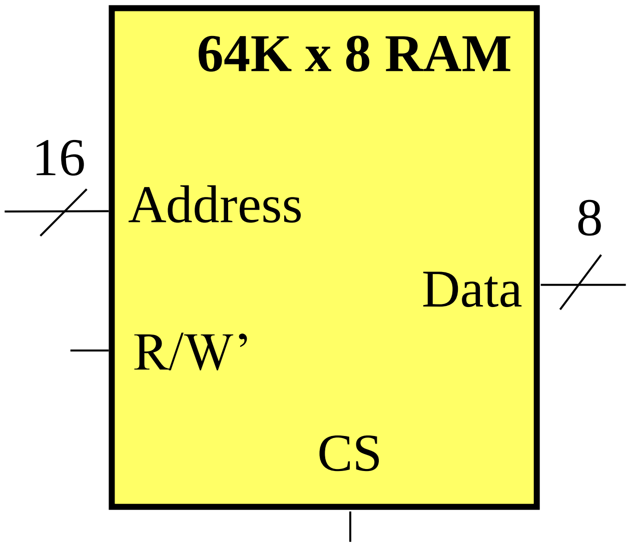
http://www.gogetbuy.com/images/article/usb_flash_memory.jpg

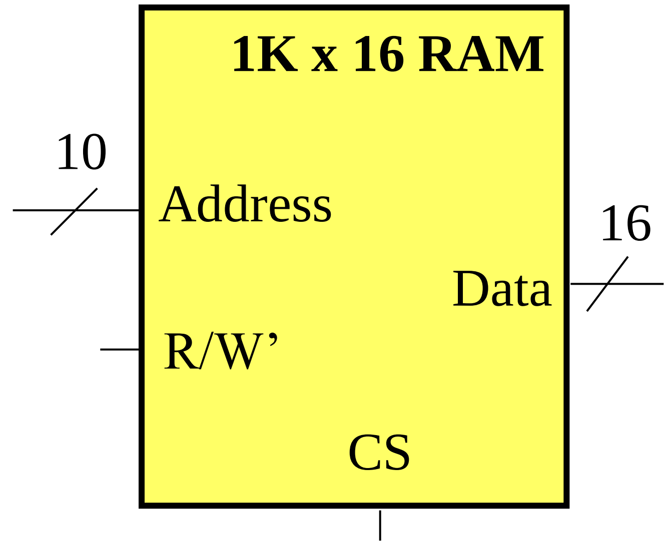
Memory Concepts



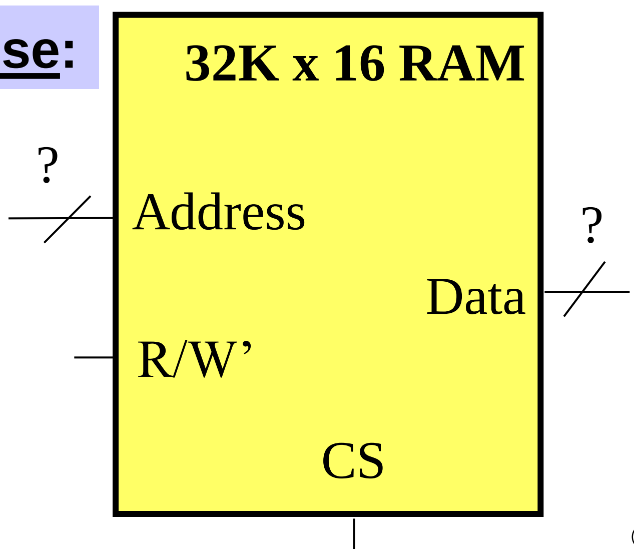
- **Block diagrams** for RAM memory modules (2 examples are shown above).
- Address lines and data lines shown on “**bus**” notation. Number of wires is displayed above slash.
- **R/W’ input** determines if the operation is a “Read” operation (information is retrieved from an address and placed on data bus), or is a “write” operation (data is taken from data bus and stored at a particular address).
- Data bus is **bi-directional** (can be used for input or output).
- “CS” means **“chip select**”. This is similar to an enable.
- Some memory modules use **“tri-state**” output logic to share a bus (i.e. outputs can be connected together as long as only one output is active.)

Memory Concepts - Exercises

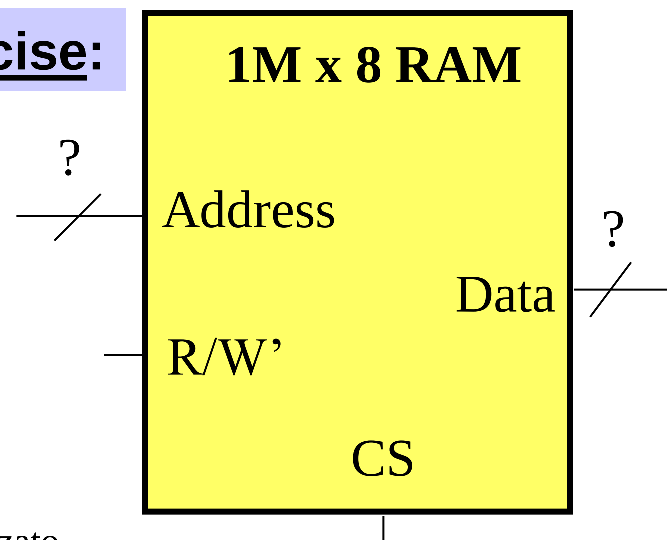




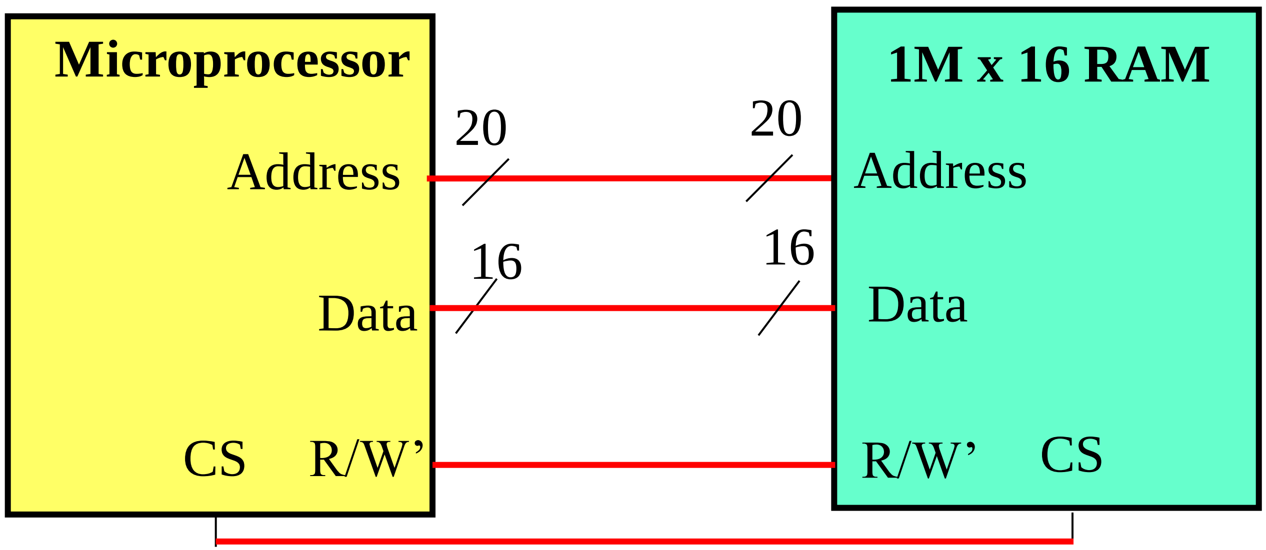
Exercise:



Exercise:

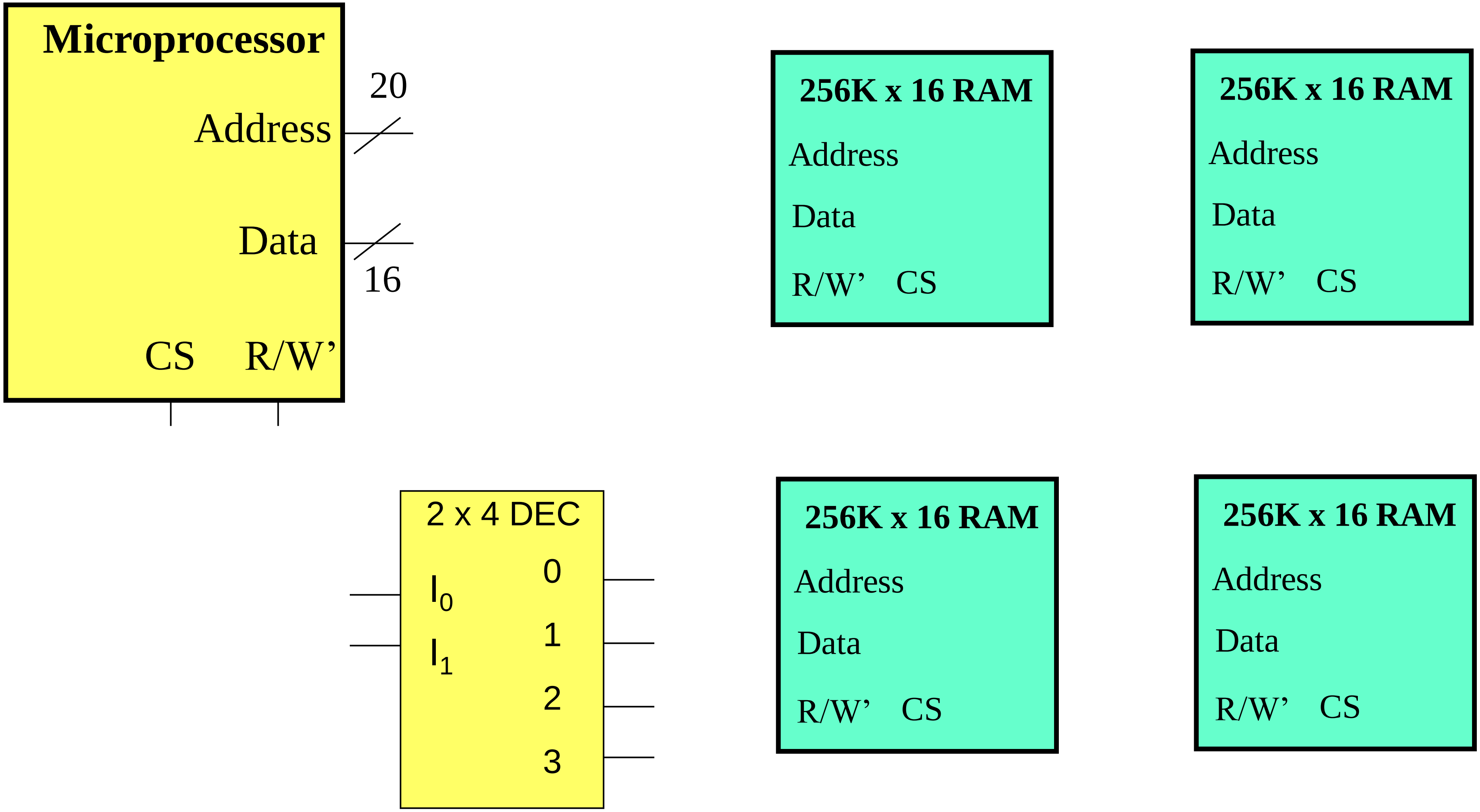


Memory Concepts - uP



In many microprocessor based systems, the memory modules exist in in sets of smaller component modules. For example, **1M x 16 might exist as four, 256K x 16 modules** connected together. Address lines are connected to a decoder, and the decoder "selects" the appropriate memory chip. All outputs are connected to the bus with tristate. This technique is called "**memory decoding**" - see references for additional information.

Memory Concepts - uP



memory decoding example

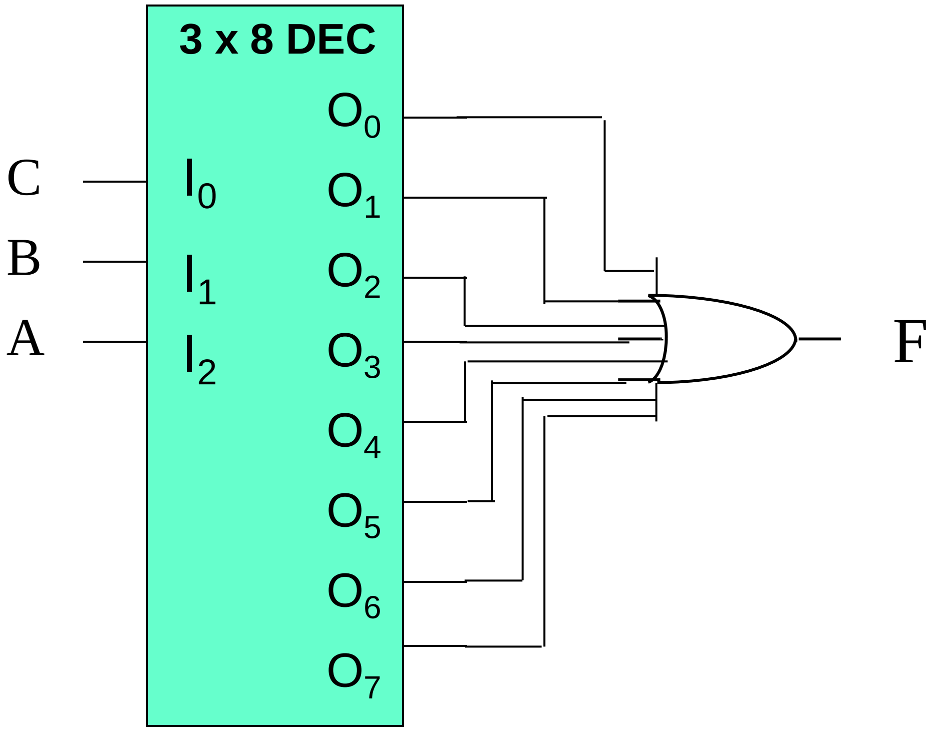
How does RAM memory work?

- **SRAM** uses a type of flip-flop
  - based on NAND gates
  - requires 6-8 transistors.

- **DRAM** uses one transistor and a capacitor
  - takes less space
  - slower than SRAM
  - less expensive than SRAM

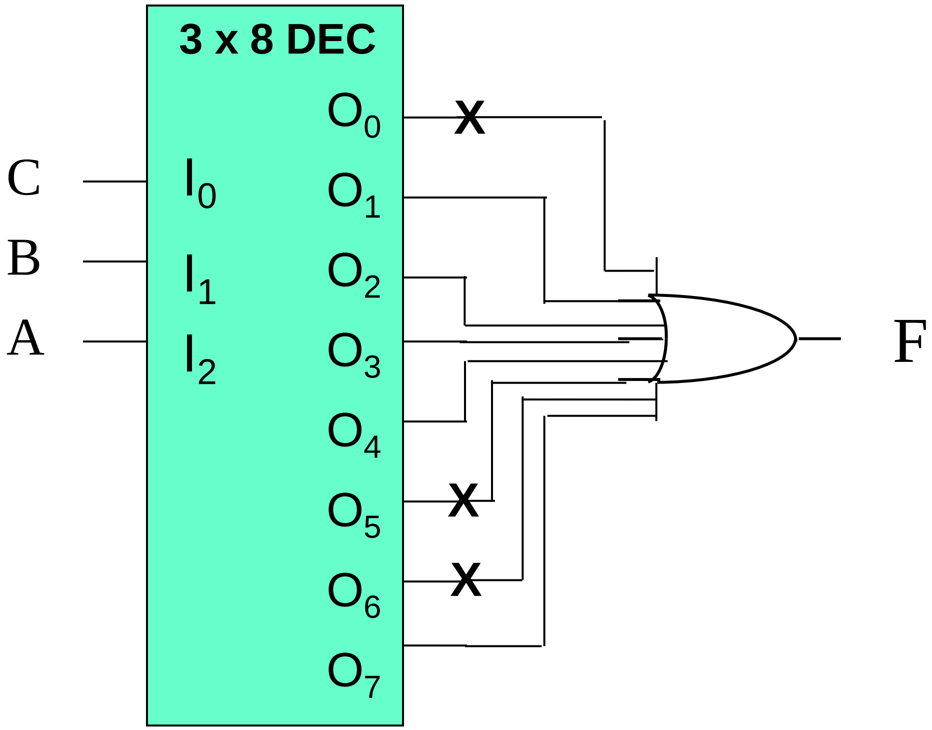
- Most **cache** memory is SRAM

How does ROM memory work?



What is F?

How does ROM memory work?



What is F?

X means break connection or blow fuse

Penn State Abington
CMPEN 271
Lecture Set #21
Memory and Programmable Logic

R. Avanzato © 2014-2015

Topics:

• Review Counters and State Machines	Video part 1 of 5
• Memory Concepts	Video part 2 of
• Memory Decoding	
• Programmable Logic Devices	**Video part 3 of 5 ←**
• FPGA Technology	
• Microprocessors and Microcontrollers	Video part 4 of 5
• Final Exam Info	
• Review Questions	Video part 5 of 5

Programmable Logic Devices

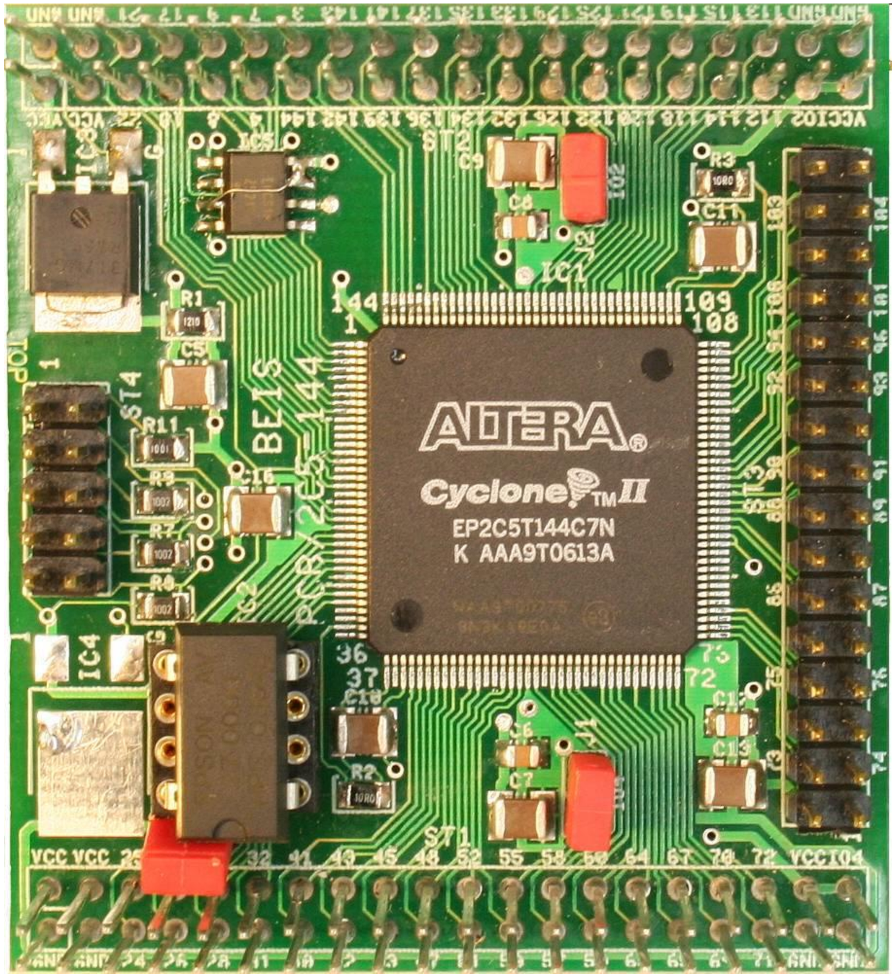
- **<u>Programmable Logic Device (PLD)</u>**
  - General term for reconfigurable hardware (logic circuits)
  - Early devices (PLAs, GALs, PALs) used a few hundred gates

- **<u>Complex Programmable Logic Device (CPLD)</u>**
  - equivalent to over 10,000 gates
  - mostly used for combinational circuits

- **<u>Field Programmable Logic Devices (FPGA)</u>** (most modern)
  - include flip-flops; more sophisticated than CPLD; uses look-up table

<u>NOTES</u>:
• PLDs require PC and software to program
• Some PLDs contain flip-flops, so you can implement state machines.
• PLDs are generally programmed in Verilog (C-like) or VHDL (ADA-like)
• CPLDs and FPGAs can contain tens (or hundreds) of thousands of gates (plus flip flops) which can be reconfigured into circuits by the user (using software tools) to solve a problem.

FPGA



- Altera is a manufacturer of CPLDs and FPGAs

FPGA

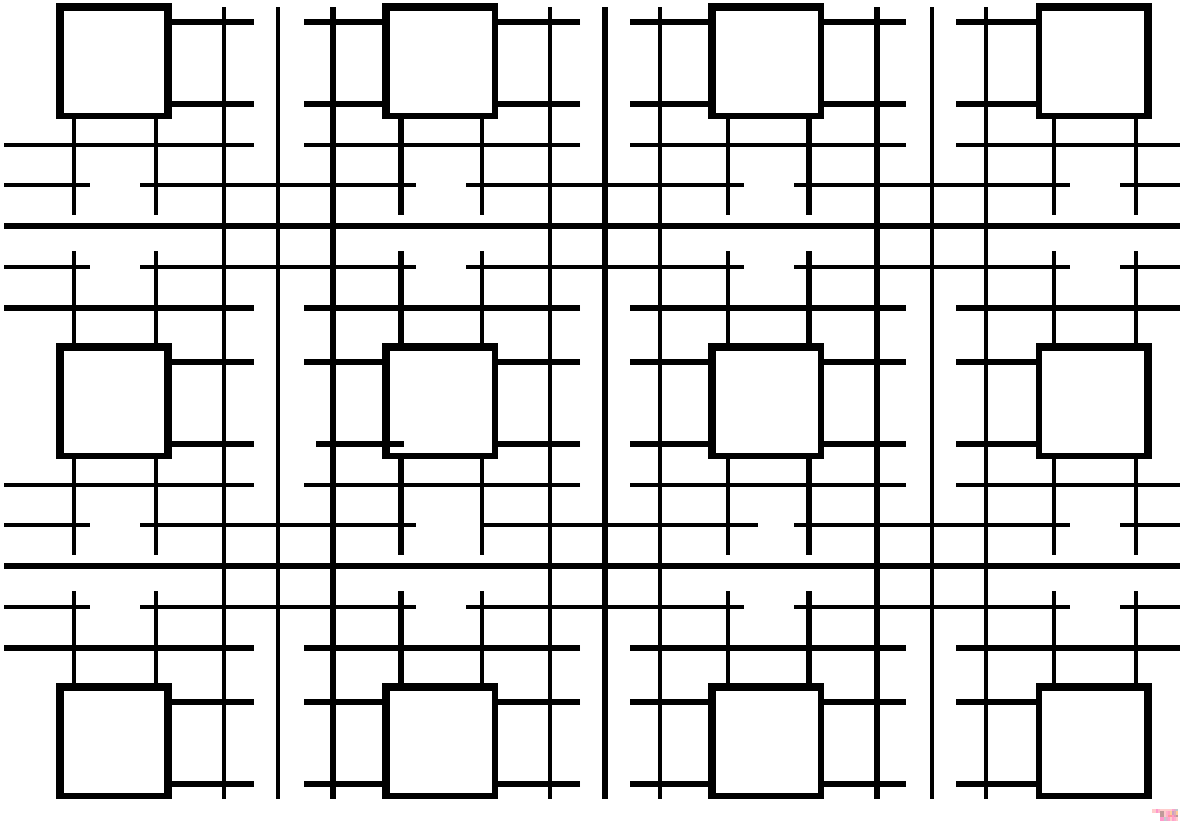
- Xilinx is a manufacturer of CPLDs and FPGAs

FPGA (Digilent NEXYS 3)

We have one in our Rydal lab. Try it.

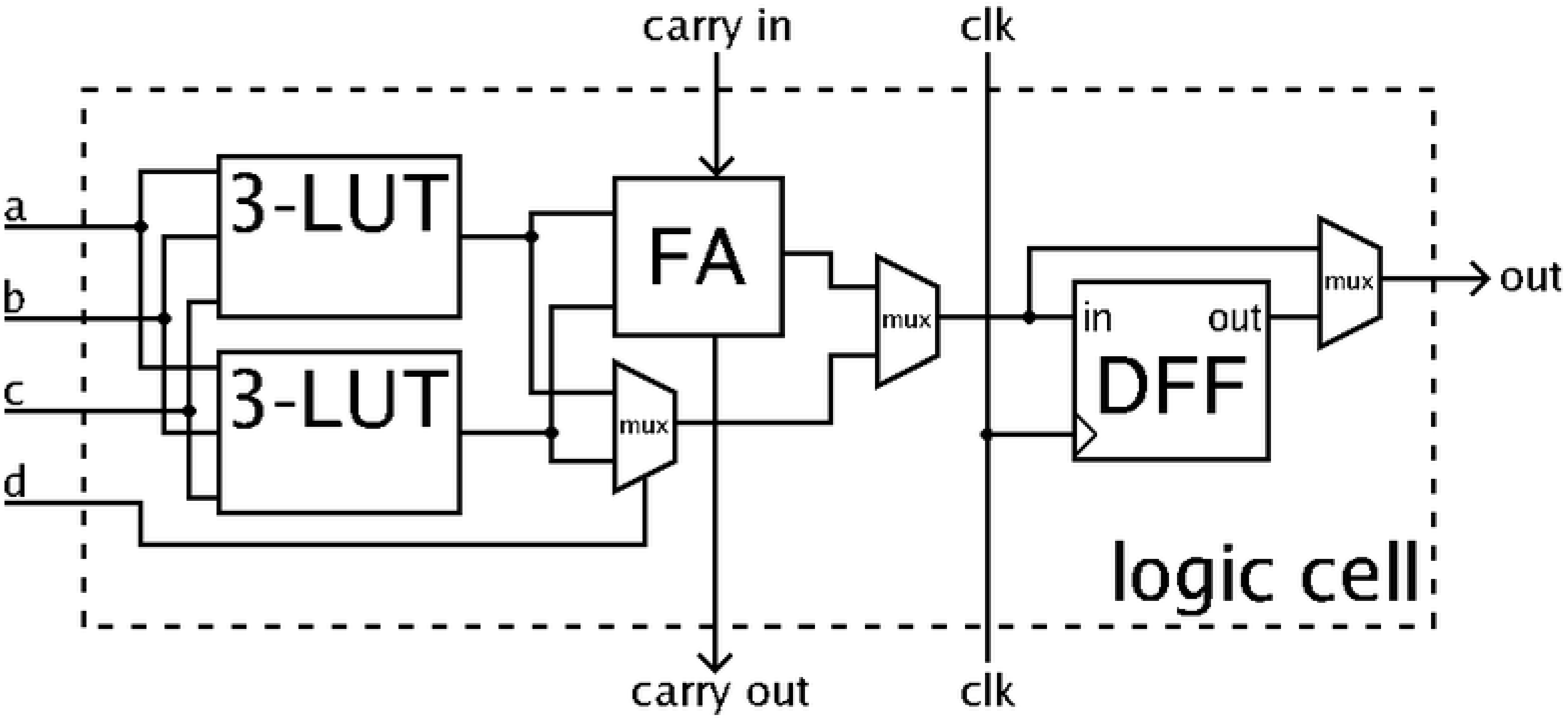
- http://www.digilentinc.com/Products/Detail.cfm?NavPath=2,400,897&Prod=NEXYS3&CFID=83606&CFTOKEN=30899869

FPGA Array (reconfigurable)



Notes:
1) Large array of combinational logic and FFs (logic cells)
2) Connections can be reconfigured using software tools

FPGA Logic Cell Example

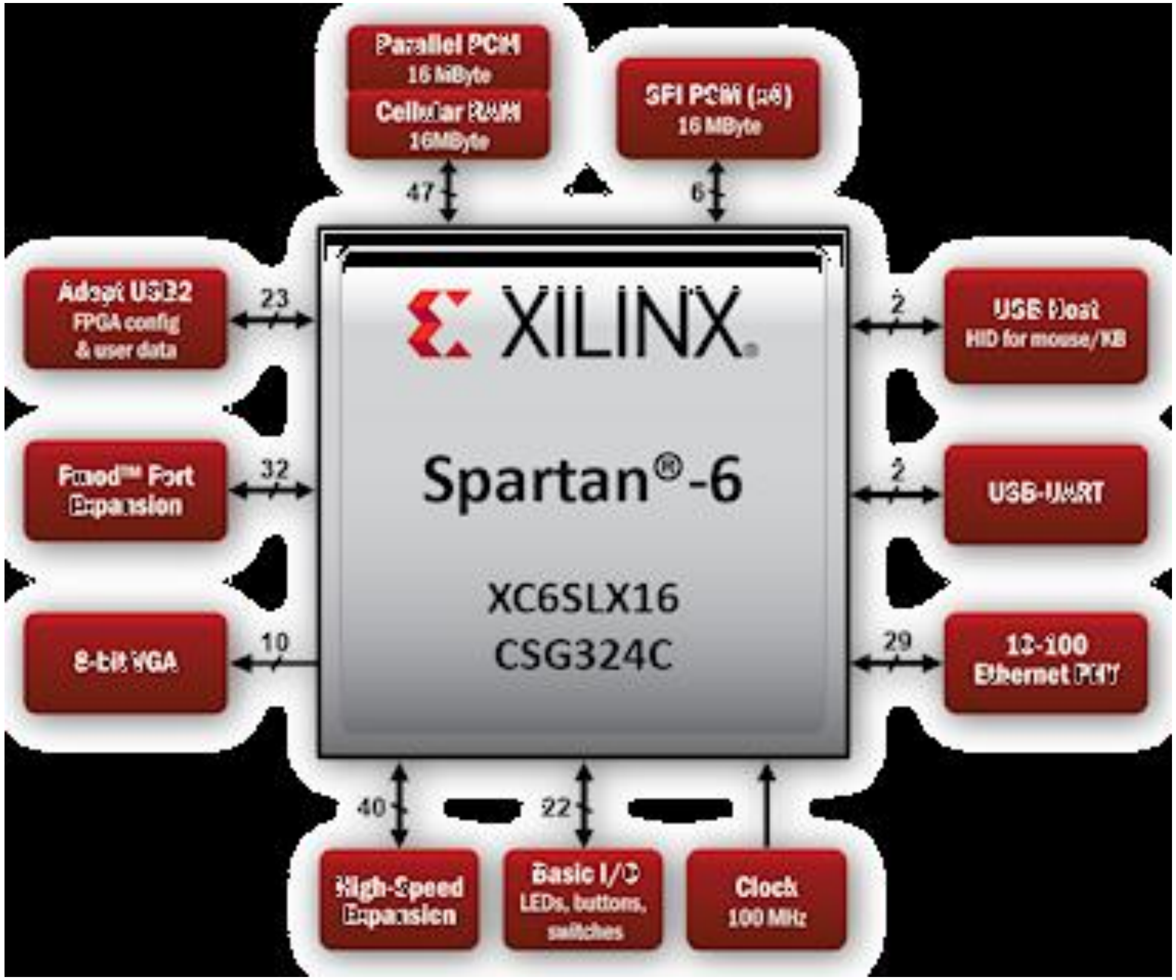


Notes:
1) LUT → Look up Table (used to implement combinational logic)
2) FA → Full adder
3) MUX → multiplexer
4) DFF → D flip flop

You will be learning more about FPGAs in future courses. For this course, understand the basic definition of a FPGA and the basic features and applications

- Ref: Wikipedia

FPGA



USB

VGA

Ethernet

Basic

Clock

- http://www.digilentinc.com/Products/Detail.cfm?NavPath=2,400,897&Prod=NEXYS3&CFID=83606&CFTOKEN=30899869

Penn State Abington
CMPEN 271
Lecture Set #21
Memory and Programmable Logic

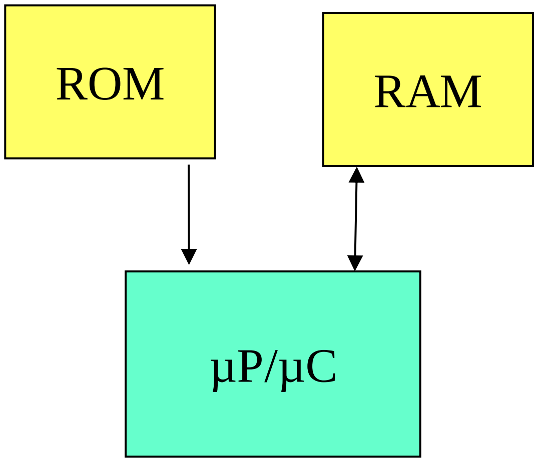
R. Avanzato © 2014-2015

<u>Topics:</u>

• Review Counters and State Machines	Video part 1 of 5
• Memory Concepts	Video part 2 of 5
• Memory Decoding	
• Programmable Logic Devices	Video part 3 of 5
• FPGA Technology	
• Microprocessors and Microcontrollers	**Video part 4 of 5 ←**
• Final Exam Info	
• Review Questions	Video part 5 of 5

Microprocessor (μP) Approach

- **<u>2 general type of microprocessors</u>**
  - General purpose (example: Intel i7) – laptops, desktops
  - Embedded applications (6811/6812, PIC, Arduino) – phones, microwave ovens, robots, toys, cars, home appliances
- **<u>Microprocessors for embedded applications are often called microcontrollers (μCs)</u>**
  - Microcontrollers are low cost, low power, low speed, have lots of i/o; ADCs, etc.
  - Programs for μCs is usually stored in ROM and is called <u>firmware</u>



What kind of microprocessor does a robot have? Clock speed? Memory?

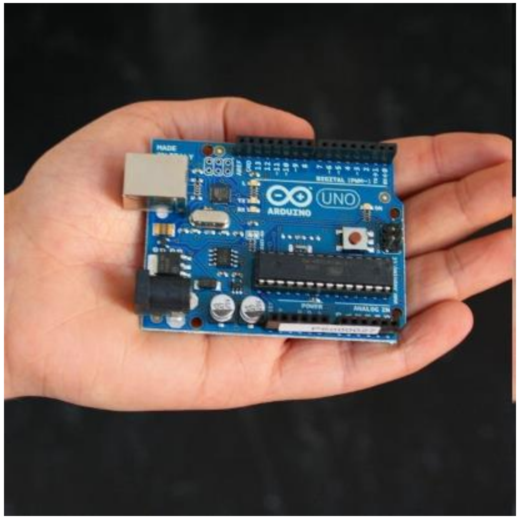
Microprocessor vs FPGA/ASIC

- **Microprocessors** (uPs) are used with memory device (RAM, ROM) to store data and software programs.
- uPs are more **general-purpose** than pure h/w (FPGA, CPLD, ASIC) - you can change the software!
- Pure **hardware** (FPGA, CPLD, ASIC) are generally **faster**; used for specific functions (e.g. moving data; HD controller, video accelerator card; etc.)
- Engineers must consider **trade-offs** between the 2 technologies (examples: price; performance; development time; future expansion; etc.)
- **Tradeoffs**
  - Software is serial processing (flexible and easy to change and update, but slower than dedicated hardware)
  - Hardware is parallel processing (fixed/dedicated but faster then software system)
- **Future technology** – reconfigurable hardware!
- Blurs **distinction** between software and hardware!
- FPGAs and microprocessors are all based on the concepts you learned in this **CMPEN 271 course.**

Microprocessors

- Investigate common microprocessors/microcontrollers
- PIC microcontroller http://www.microchip.com/
- Arduino (open source) http://www.arduino.cc/ (contains 10-bit A/D converters)
- RasberryPi (linux)
  - http://www.raspberrypi.org/
- BeagleBone (linux)
  - http://beagleboard.org/

/



You will be learning more about microprocessors and microcontrollers in future courses. For this course, understand the basic definition of a microprocessor and microcontroller and the basic features and applications

CMPEN 271 Big Ideas

- **Analog-to-digital converters** change analog (continuous) signals into digital (discrete) signals.
- **Digital systems** have advantages over analog systems in the areas of noise immunity and ability to integrate circuits onto ICs.
- **Numeric values and codes** can be represented in base 10, base 2, base 8, base 16.
- **Truth tables** can be used to represent inputs and outputs of combinational circuits.
- **Combinational circuits** can be implemented with AND, OR, NOT, NAND, etc gates.
- **XOR and XNOR** gates are often used for parity bit generation and error detection
- **Boolean algebra and K-Maps and s/w tools** can be used to minimize logic circuits to save space and cost.
- **MSI logic** devices such as multiplexers, decoders, encoders, demultiplexers, adders, magnitude comparators are used as building blocks to design complex combinational logic.
- A **flip-flop** stores 1 bit of information.
- **Sequential circuits** (circuits with FFs) can be used to design shift registers, ring counters, ripple counters, etc.
- **Finite State Machines** (FSMs) are special sequential circuits that can be designed to sequence through an arbitrary patterns of FF states. State diagrams and state tables are used when designing FSM.
- **MSI devices** such as counters, registers, and shift registers can be used as building blocks to design complex sequential circuits more efficiently.
- **Circuit simulation software tools** (e.g. Multisim, Pspice, VHDL, etc) are important tools used to design, simulate, and test digital circuits before they are constructed.
- **Memory devices** are used to store digital information.
- **FPGAs** are modern approaches to implementing combinational logic and FSMs to create high speed digital circuits.

Further Reading

- Mano, Kime, Logic and Computer Design Fundamentals, Prentice Hall, 2001, Chapter 6.
- "How Stuff Works" www.howstuffworks.com (see memory topics)
- www.xilinx.com (manufactures CPLDs, FPGAs and sells development software)
- www.altera.com (CPLDs and FPGAs)

Penn State Abington
CMPEN 271
Lecture Set #21
Memory and Programmable Logic

R. Avanzato © 2014-2015

Topics:

- Review Counters and State Machines — Video part 1 of 5

- Memory Concepts — Video part 2 of 5
- Memory Decoding

- Programmable Logic Devices — Video part 3 of 5
- FPGA Technology

- Microprocessors and Microcontrollers — Video part 4 of 5

- Final Exam Info
- Review Questions — **Video part 5 of 5 ←**

Final Exam Topics

- Final exam will be **comprehensive** (will cover topics over entire course)
- **Topics** include analog versus digital systems, base conversions, logic gates, Boolean algebra, XOR/XNOR gates, minimization, K-maps, parity bits, ASCII codes, MSI devices, decoders, multiplexers, adders, NOR/NAND latch, D flip-flops, JK flip-flops, ripple counters, shift registers, ring counters, state machines (with both D and JK flip-flops), registers, MSI shift registers, MSI counters, memory concepts.
- **Final exam will stress topics since last exam** – flip-flops, ripple counters, shift registers, ring counters, state machines (FSM) with both D and JK flip-flops, MSI counters and MSI registers. Memory concepts.
- **Review all sample review questions** from start of course until end of course.
- **Review results of exam** #1 and **exam** #2 and any **quizzes.**
- **The final exam will cover topics from the whole course**, but the focus will be on topics we covered since the last exam.

Memory Concepts Review (for final exam)

- Define RAM, ROM, SRAM, DRAM, PROM, EPROM, EEPROM, Flash, SAM, FPGA, microcontroller Provide real-world examples or applications for each.
- What is volatile memory? Non-volatile? Give examples of each.
- Is RAM volatile or non-volatile?
- Is ROM volatile or non-volatile?
- Is Flash volatile or non-volatile?
- How many address lines does a 4K x 16 memory module have?
- How many data lines does a 4K x 16 memory module have?
- How many bits are stored on a 32 x 8 memory module have?
- How many bytes are stored on a 32 x 8 memory module have?
- How many bits are stored on a 4K x 16 memory module have?
- What type of memory would you use to design a digital answering machine? What size memory module would be required?
- What type of memory is used in a portable MP3 player?
- What type of memory is used to store BIOS in a PC?
- What type of memory is used to store software for your anti-lock brakes?
- What type and size of memory is used a typical digital camera?

Review Questions

#1.- The term "RAM" means

a) random access memory b) radix arithmetic memory
c) random average memory d) raster access machine

#2.- How many address lines are required for a 1Kx8 memory module?

a) 8 b) 9 c) 10 d) 1024

#3.- How many data lines are required for a 1Kx8 memory module?

a) 8 b) 9 c) 10 d) 16

#4.- How many address lines are required for a 64x16 memory module?

a) 6 b) 8 c) 9 d) 16

Review Questions

#5.- The storage unit of SRAM consists of a(n)

a) flip-flop b) capacitor c) inductor d) electron

#6.- The storage unit of DRAM consists of a(n)

a) capacitor b) flip-flop c) inductor d) electron

#8.- FPGA technology is used in which of the following application areas?

a) Automotive (example lane changing warning system)

b) Aerospace and defense (example: missiles, satellites)

c) Consumer electronics (example: set top box)

d) Medical (example: portable ultrasound)

e) all of the above

#9.- What is a key advantage of FPGA technology?

a) is it very inexpensive

b) it can be reconfigured and still offer advantages of hardware

c) it is cheaper than an ASIC.