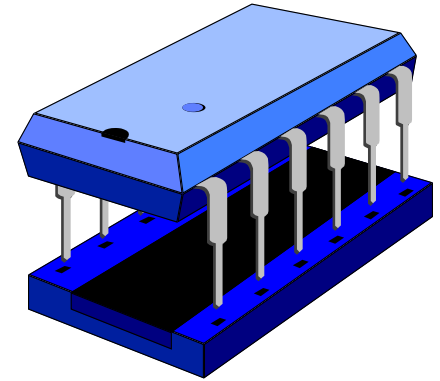


BASIC CIRCUITS AND MEMORY



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Bernhard Kainz (with thanks to **A. Gopalan**, **N. Dulay** and **E. Edwards**)

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Digital Circuits

- Basic Circuits
 - Half Adder [Assignment Project Exam Help](#)
 - Full Adder <https://powcoder.com>
 - Latches [Add WeChat powcoder](#)

Adders

- A digital circuit that performs **addition** of numbers
- Not only used in arithmetic logic unit(s), but also in other parts of the processor, where they are used to calculate addresses, table indices, and similar operations
- Most common adders operate on binary numbers

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Half Adder

- Consider adding two 1-bit binary numbers together:

	0	0	1	1
+	0	1	0	1
	0	1	1	??

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- Input – 2 separate lines

Half Adder

- Consider adding two 1-bit binary numbers together:

	0	0	1	1
+	0	1	0	1
	00	01	01	10

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- Input – 2 separate lines
- Output – two bits – how do we represent this?
 - Use two separate lines (Sum and Carry)

Half Adder

- Can we now draw the circuit?

- What do we need? – Truth Tables

- One each for sum and carry

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Half Adder

- Recall

	0	0	1	1
	0	1	0	1
	00	01	01	10

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- Truth Table

A	B	A + B	Sum	Carry
0	0	0	0	0
0	1	1	1	0
1	0	1	1	0
1	1	2	0	1

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Half Adder

- Selecting Gates

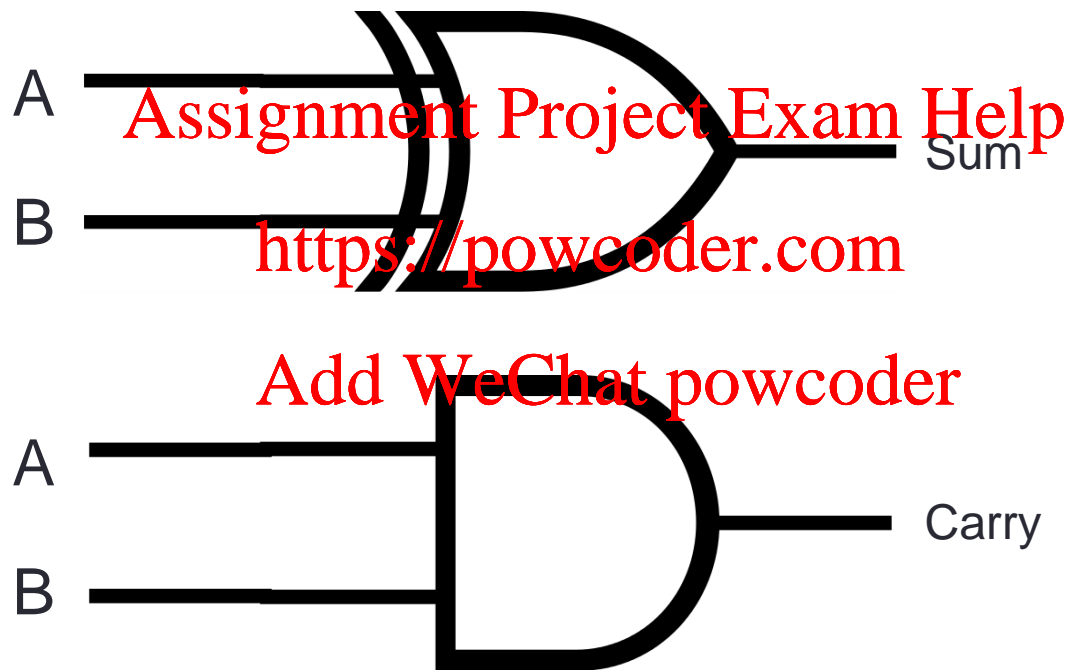
Sum	Carry	XOR	And
0	0	0	0
1	0	1	0
1	0	1	0
0	1	0	1

- Hence, we can build the expressions as:

- $\text{Sum} = A \oplus B$
- $\text{Carry} = A \cdot B$

Half Adder

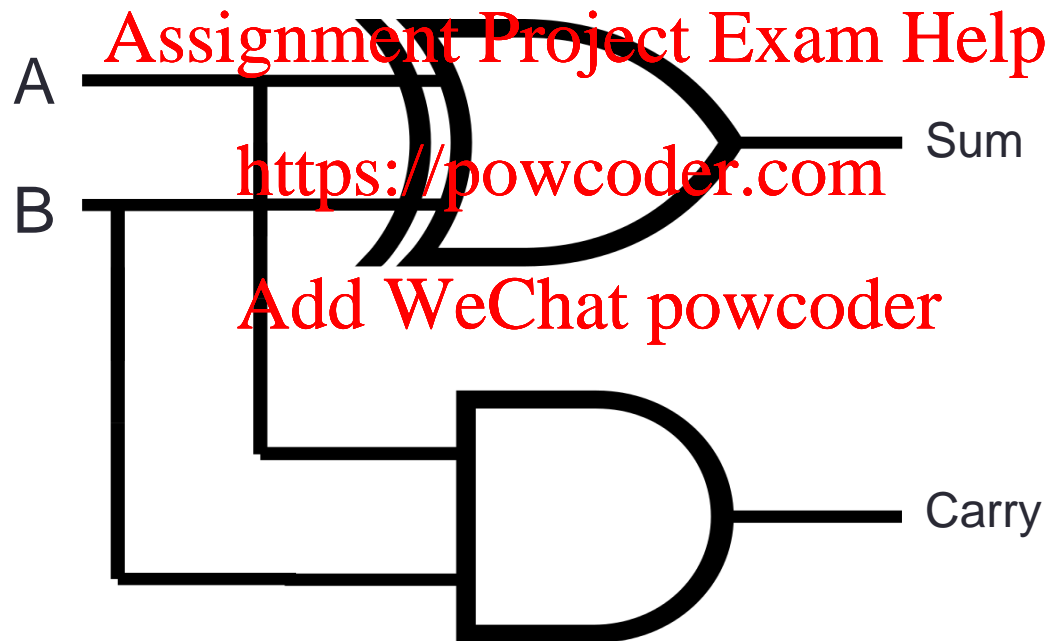
- Circuit



Is this Correct?

Half Adder

- A more concise and better version 😊



Full Adder

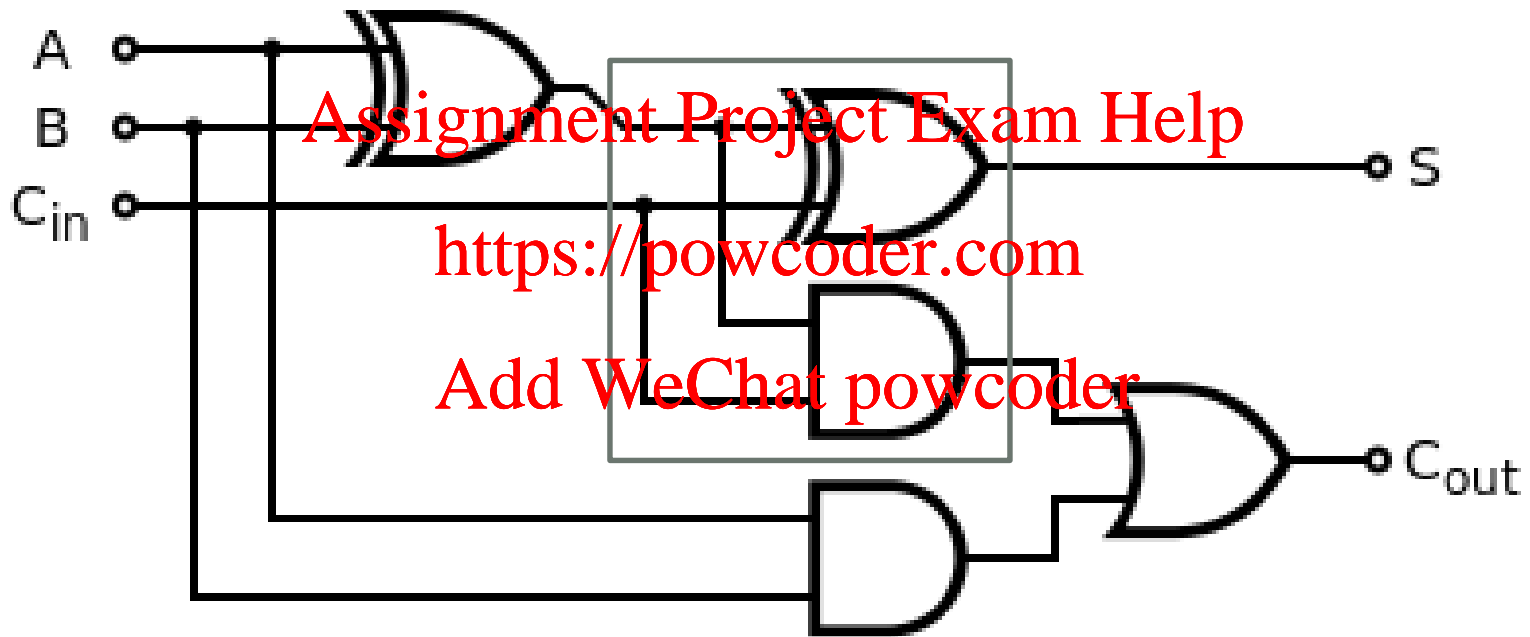
- Half-adders have a major limitation
 - Cannot accept a carry bit from a previous stage → they cannot be chained together to add multi-bit numbers
- Full-adders can accept three bits as input
 - Third bit is the carry-in bit
- Can be cascaded to produce adders of any number of bits by daisy-chaining the carry of one output to the input of the next

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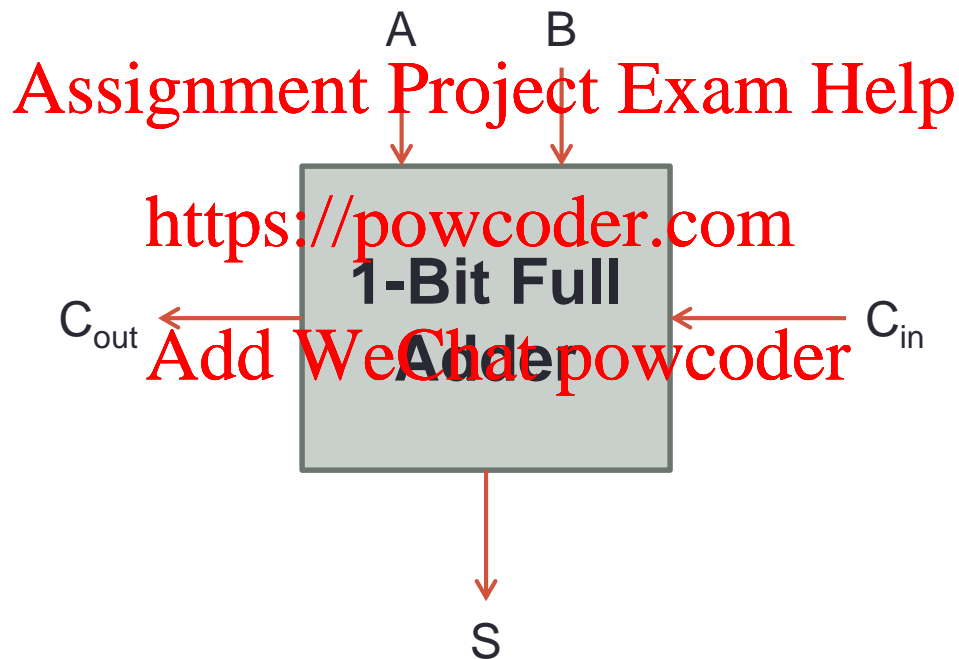
Full Adder



$$S = A \oplus B \oplus C_{in}$$
$$C_{out} = (A \cdot B) + C_{in} \cdot (A \oplus B)$$

Full Adder

- Conceptually



Ripple-Carry Adder

- Consists of several full adders connected in a series so that the carry must propagate through every full adder before the addition is complete
- Require the least amount of hardware of all adders, but they are the slowest
- Carry-Lookahead Adder (homework)

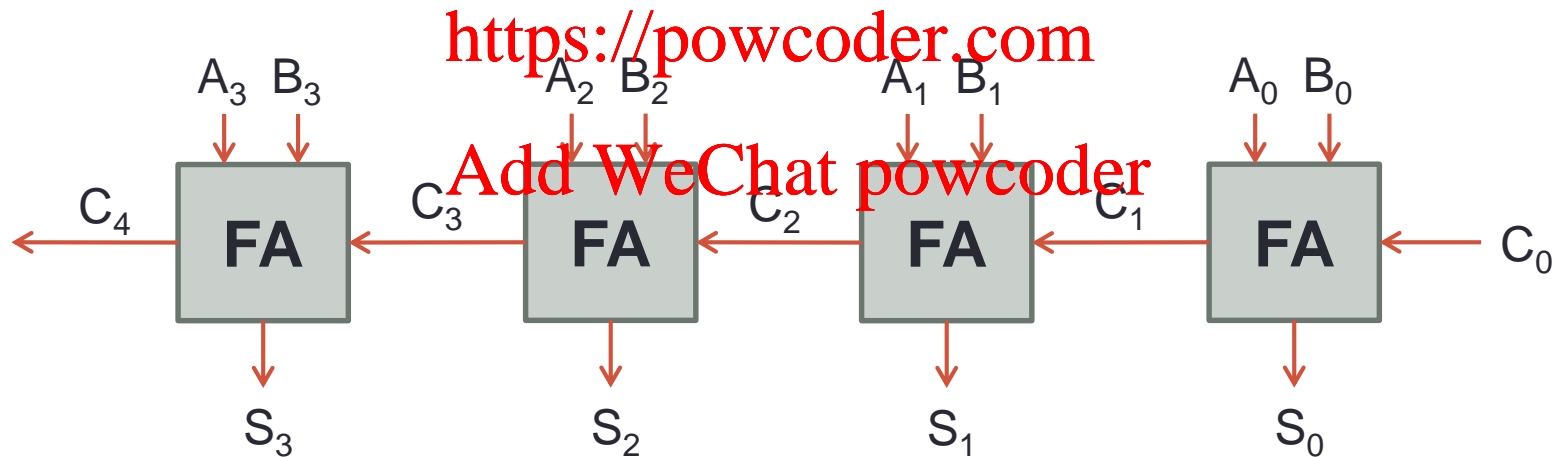
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Ripple-Carry Adder

- The following diagram shows a four-bit adder, which adds the numbers A and B, as well as a carry input, together to produce S and the carry output.



Gates

- Building blocks for combinatorial circuits
 - Output depends only on current input
- All gates can be built out of NAND and NOR gates
- What if we would like to store values?
 - Use a *feedback* mechanism where the output values depend indirectly, on themselves

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Latches

- Building blocks to sequential circuits

- Can be built from gates

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- Able to remember 1-bit of information ☺

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- Useful web-page

- <http://www.play-hookey.com/digital/sequential/>

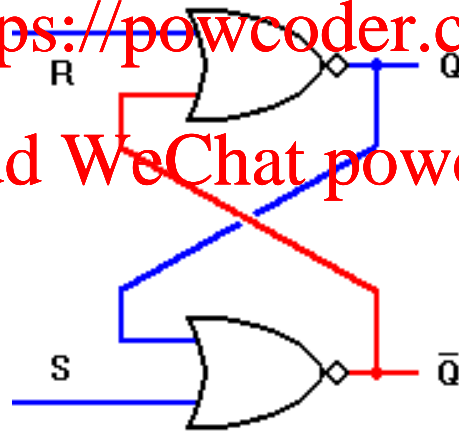
Latches

- SR-latch
 - S = Set
 - R = Reset

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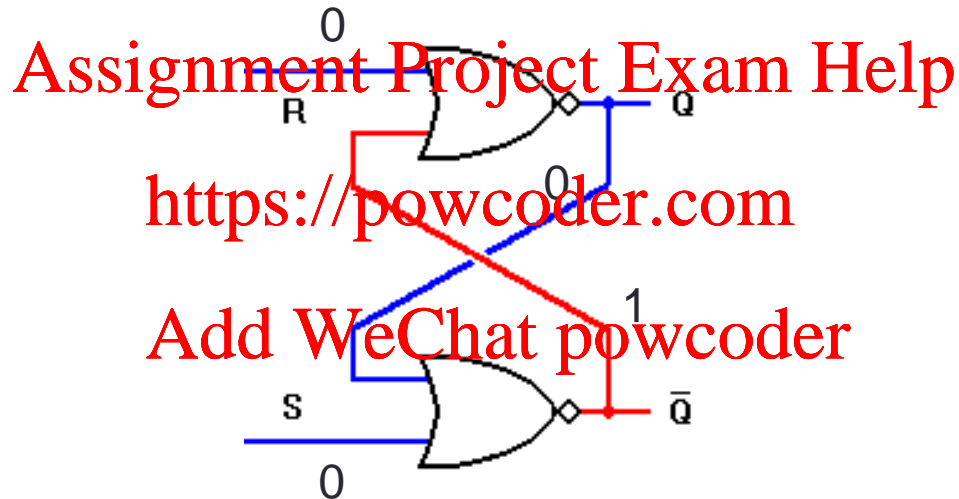
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Latches

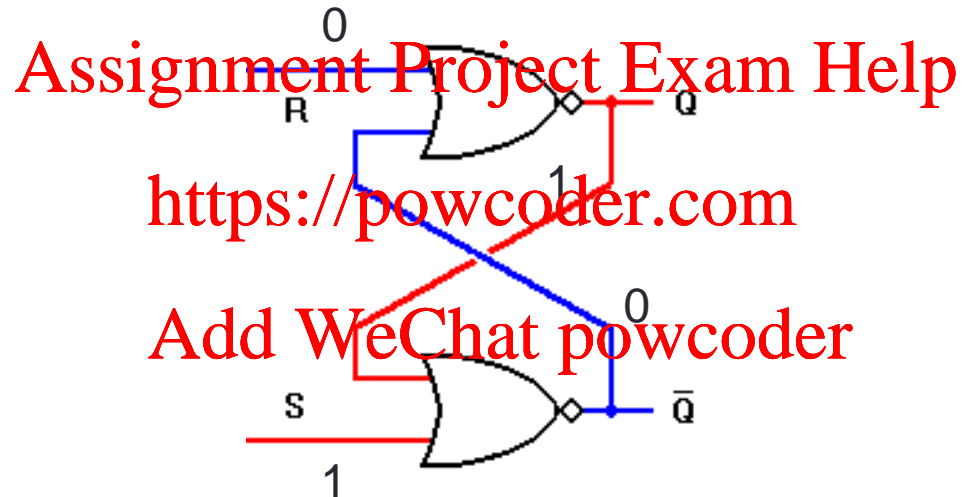
- $S = 0, R = 0$



- Value of Q does not change → value is 'remembered'
 - Sometimes called the *latch* state

Latches

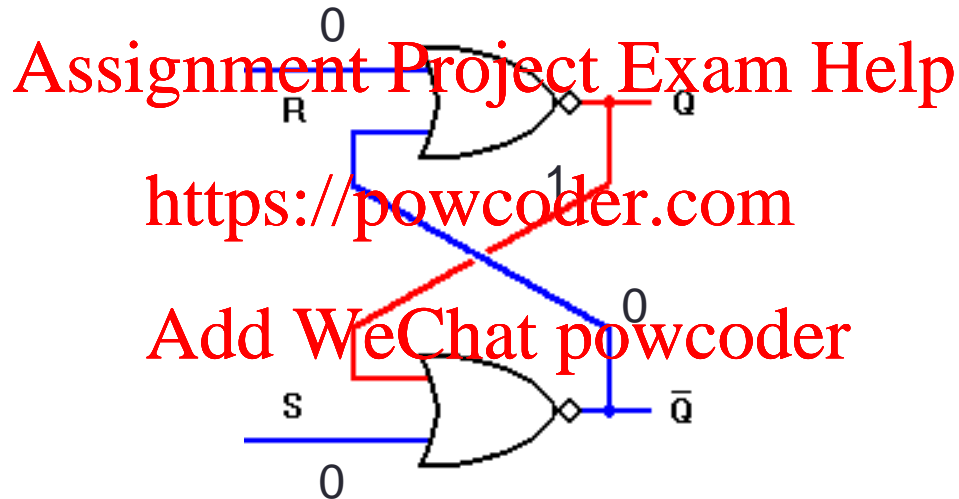
- $S = 1, R = 0$



- Set the value of Q

Latches

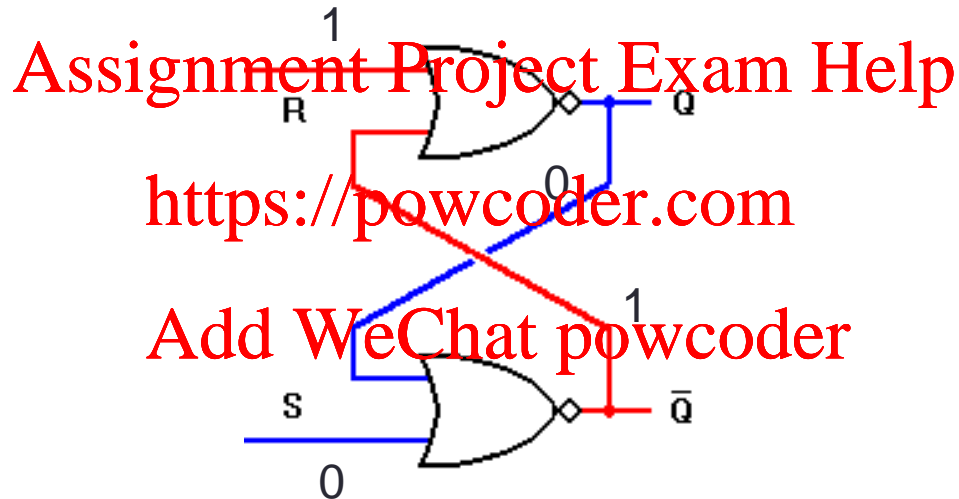
- $S = 0, R = 0$



- Value of Q stays the same – it ‘remembers’ 😊

Latches

- $S = 0, R = 1$



- Reset the value of Q to 0
- $S = 1, R = 1$ leads to undefined state

Latches

- SR-Latch: Truth table

S	R	Q	Q'
0	0	Latch	
0	1	0	1
1	0	1	0
1	1	Undefined	

Flip-Flops

- Latches are *asynchronous* → output changes very soon after the input changes

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- Most computers today, are *synchronous*
 - Outputs of all the sequential circuits change simultaneously to the rhythm of a global *clock signal*

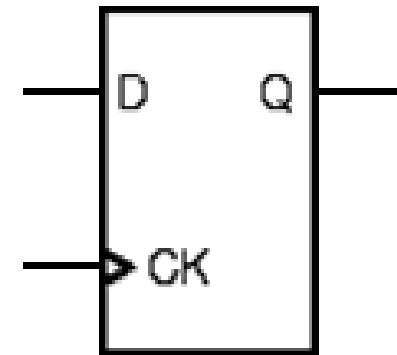
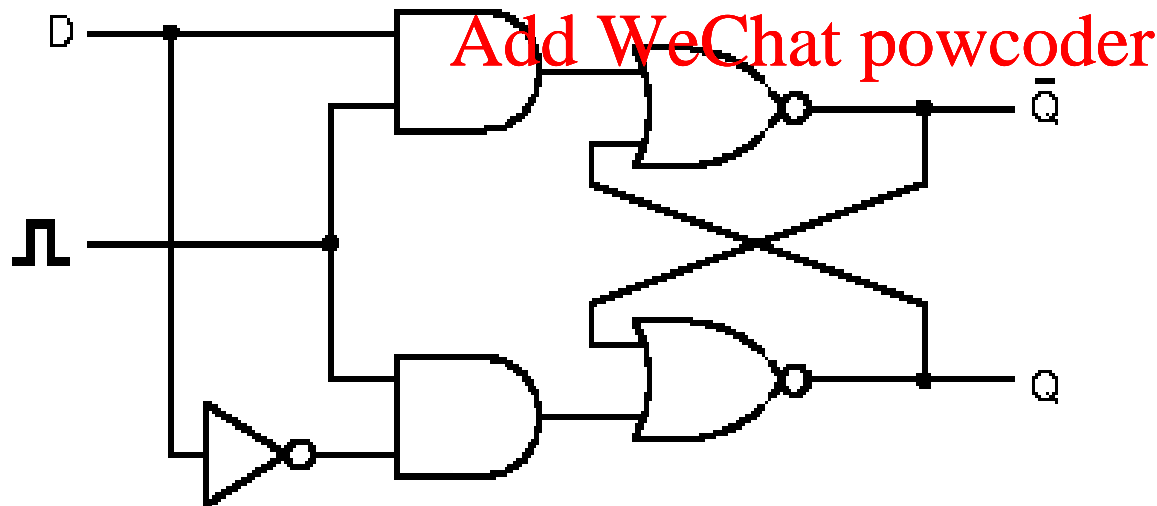
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- A *flip-flop* is a synchronous version of the latch

Memory

- Useful variation on the SR latch circuit is the Data latch, or D latch
- Constructed by using the inverted S input as the R input signal
 - Allows for a single input \rightarrow No race condition as input is inverted



Memory

- Two basic types of memory
- Static RAM (SRAM)
 - Bit-cell is a latch
 - Fast, not very dense (requires more transistors to implement)
 - Primarily used in Cache
 - Consumes less power
- Dynamic RAM (DRAM)
 - Bit-cell is a transistor and capacitor (which leaks information)
 - Storage has to be periodically refreshed
 - Primarily used in main memory
 - Cheaper than SRAM

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Memory

- Memories hold binary values
 - Data (e.g. Integers, Reals, Characters)
 - CPU Instructions (like Computer Programs)
 - Memory Addresses (Pointers to data or instructions)
- Contents remain unchanged unless overwritten with a new binary value
 - Some of them lose the content when power is turned off (volatile memory)

Memory – Examples

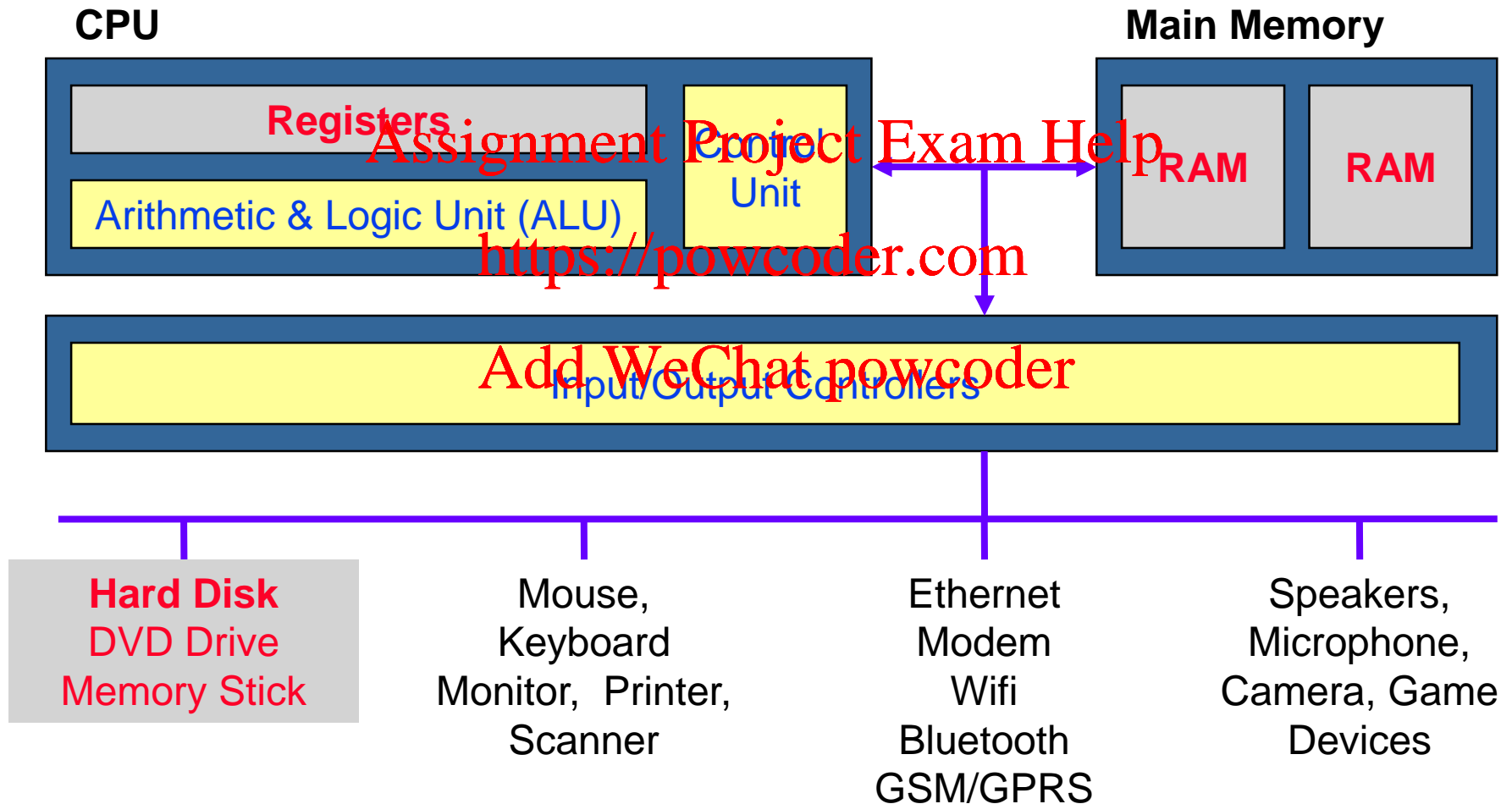
- CPU, Registers, Caches – L1, L2 [L3]
- Mainboard
 - RAM (Random Access Memory)
 - Caches
 - I/O Registers & Buffers
 - Video-card Memory
- Storage Devices
 - Hard Disks, CDs, DVDs, Tapes, Memory Sticks, Flashcards

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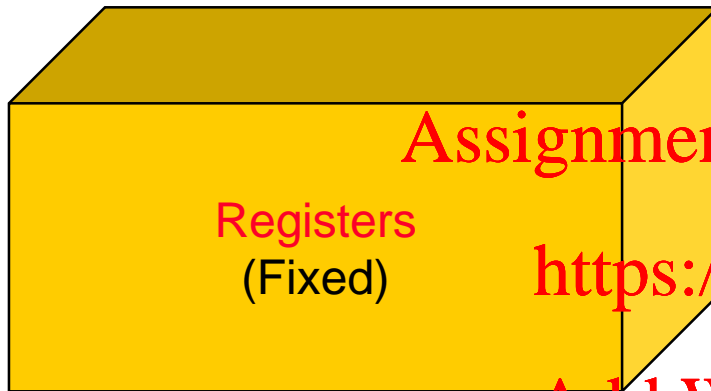
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Computer Architecture

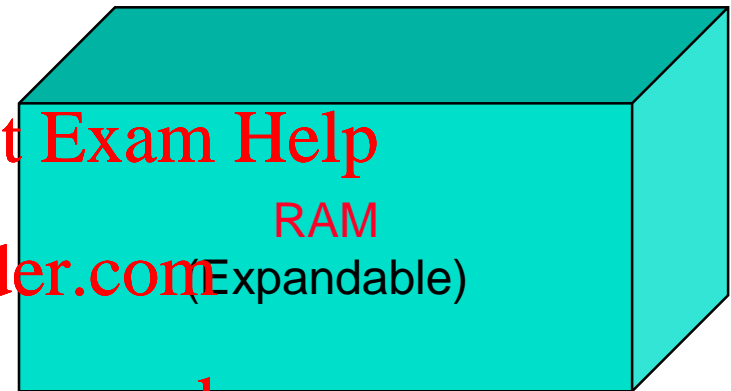


3 Types of Memory

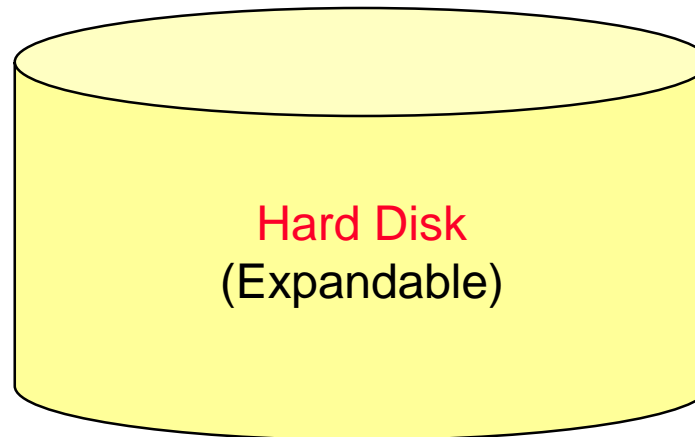
CPU



Main Memory



Storage
Device



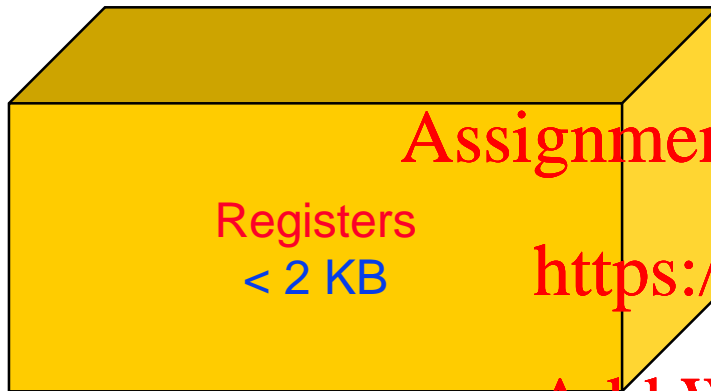
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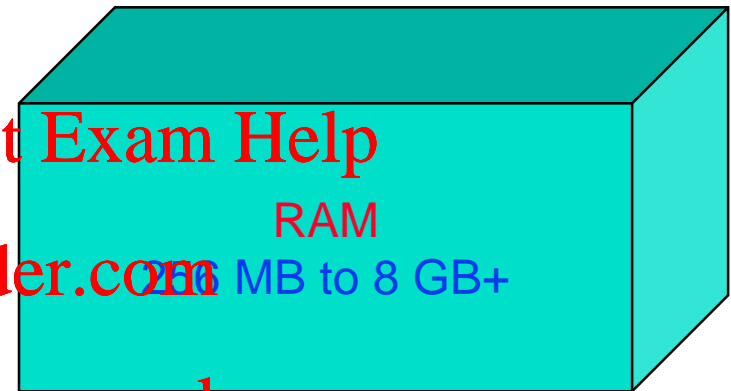
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Capacity

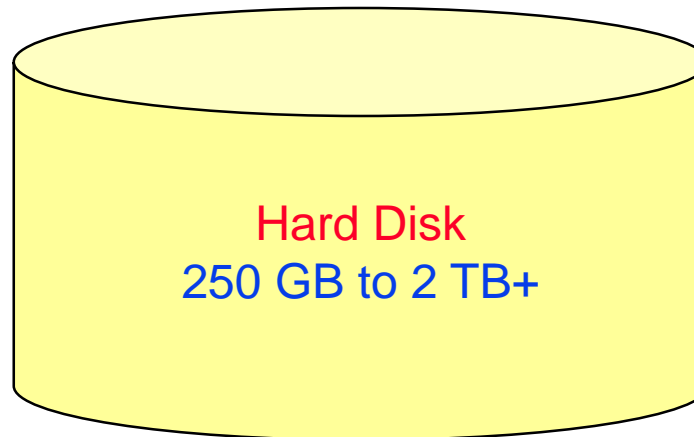
CPU



Main Memory



Storage
Device



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1 KB = 2^{10} bytes

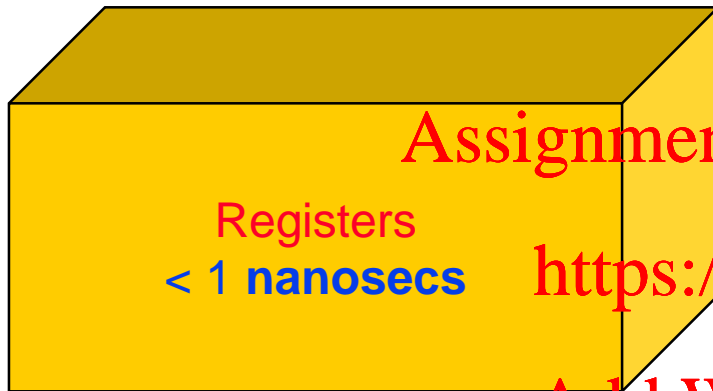
1 MB = 2^{20} bytes

1 GB = 2^{30} bytes

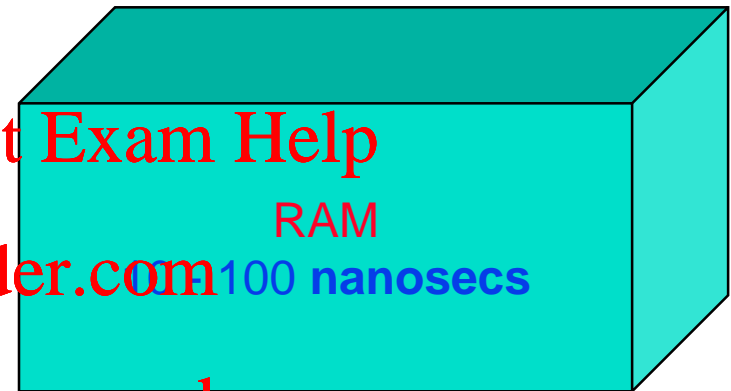
1TB = 2^{40} bytes

Speed (Access Time)

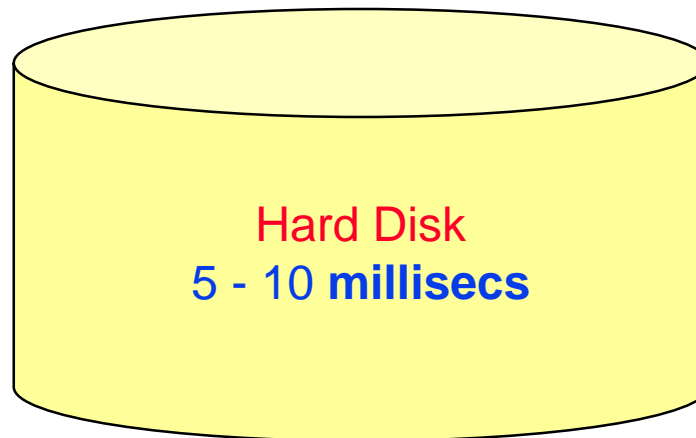
CPU



Main Memory



Storage
Device



milli = 10^{-3}
micro = 10^{-6}
nano = 10^{-9}

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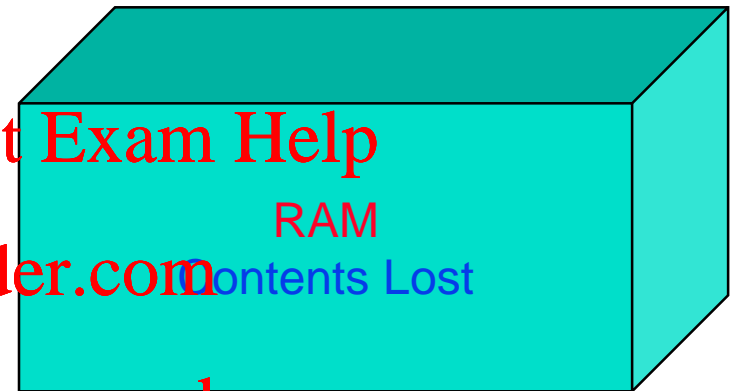
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Volatility

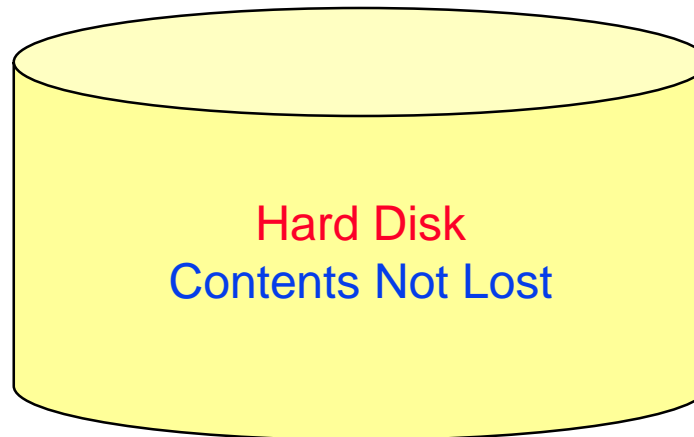
CPU



Main Memory



Storage
Device



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Summary

