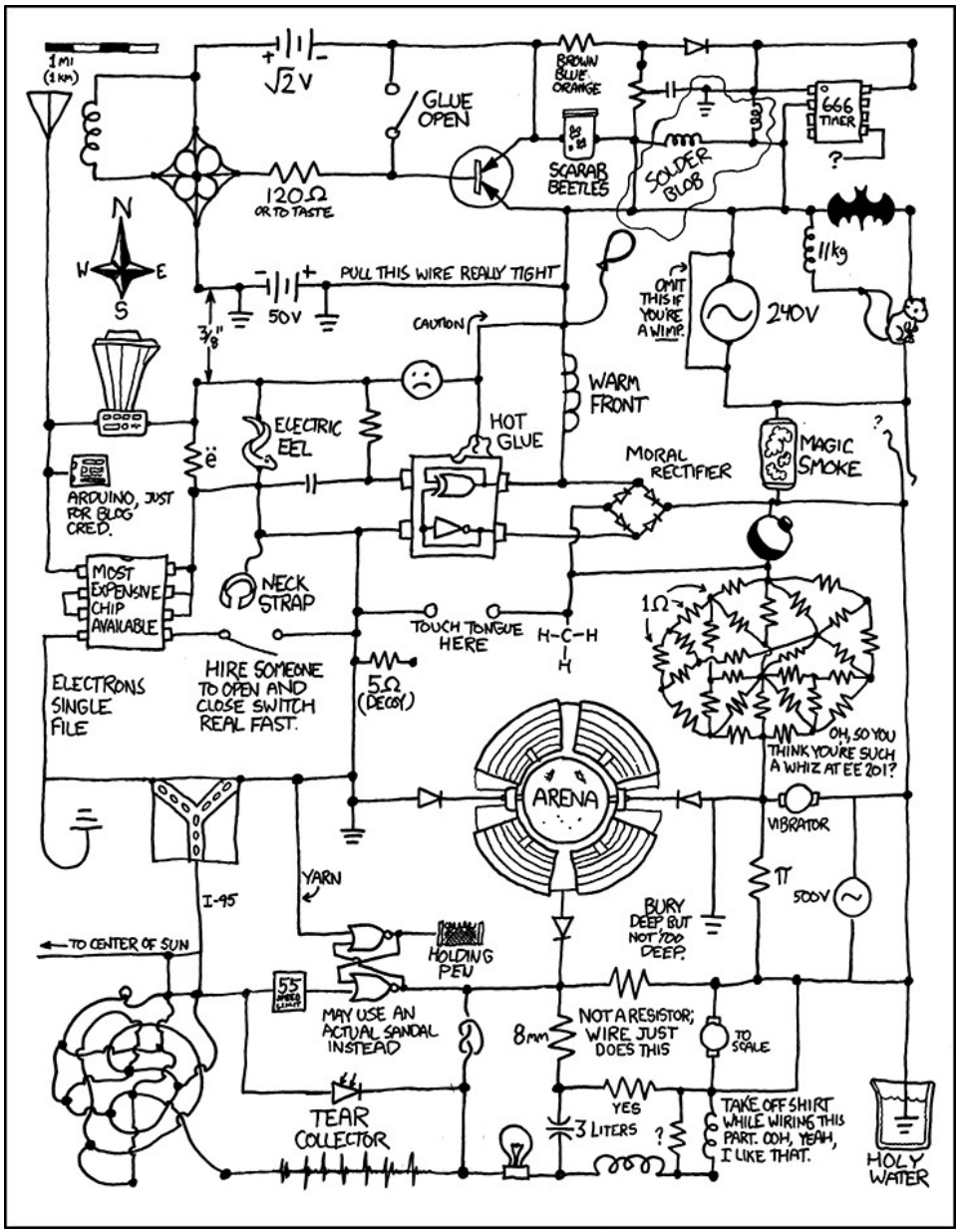
CS 261
Fall 2022

Mike Lam, Professor



Sequential Circuits

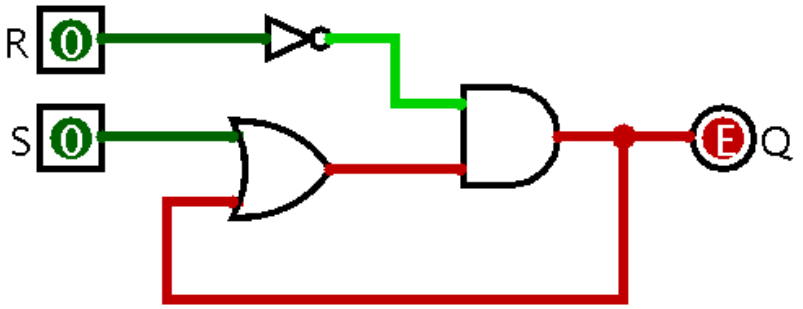
Circuits

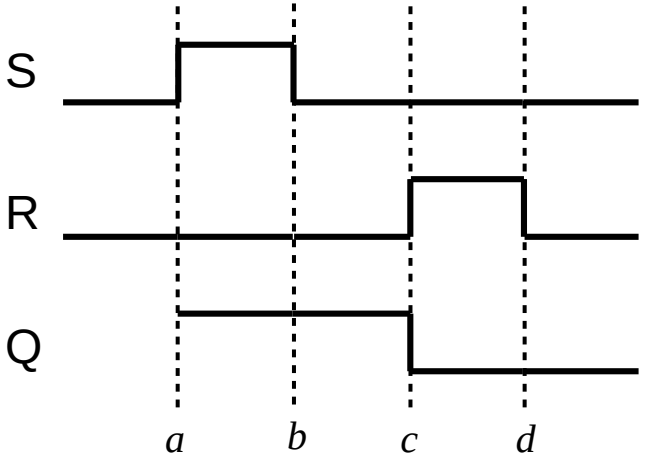
- Circuits are formed by linking gates (or other circuits) together
  - Inputs and outputs
    - Link output of one gate to input of another
    - Some circuits have multiple inputs and/or outputs
  - Combinational circuits: outputs are a boolean function of inputs
    - Not time-dependent
    - Used for computation
  - Sequential circuits: output is dependent on previous outputs
    - Time-dependent
    - Used for memory

Circuit memory

- Question: How do we make a circuit “remember” something?
  - Answer: Create a feedback loop!
  - Creates a “storage” circuit, often called a latch
  - Truth table must include previous state
  - Alternatively, draw a timing diagram
    - Shows how input/output signals change with respect to time
    - Given input signals in diagram, we can determine output signals

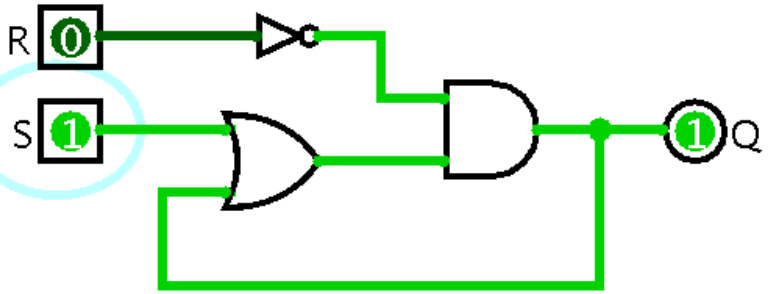
SR AND-OR latch



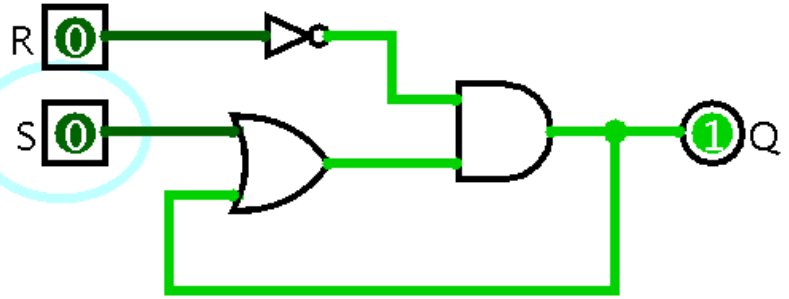


S = “set” R = “reset”

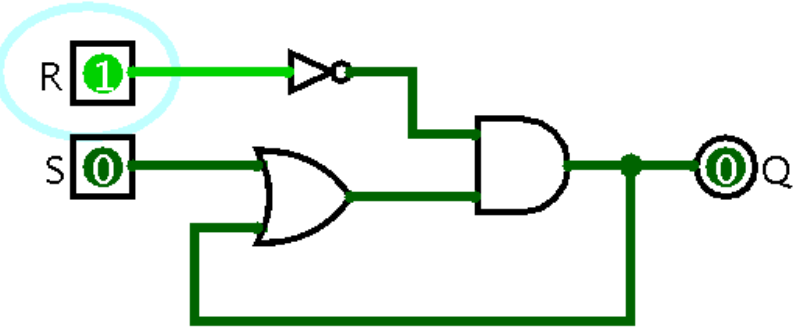
Event ***a*** *(S on)*



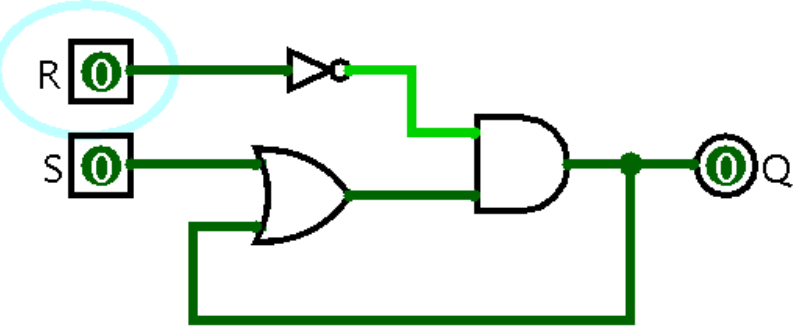
Event ***b*** *(S off)*



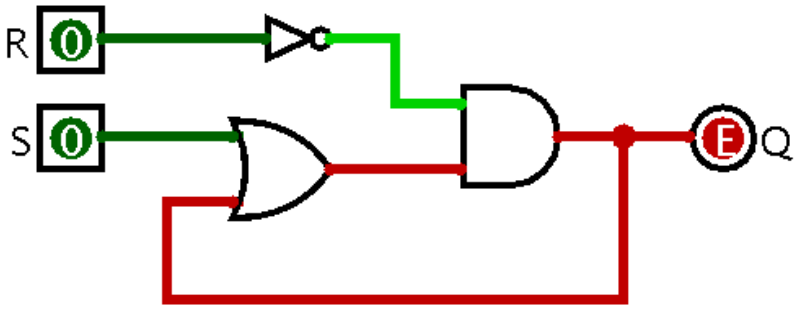
Event ***c*** *(R on)*

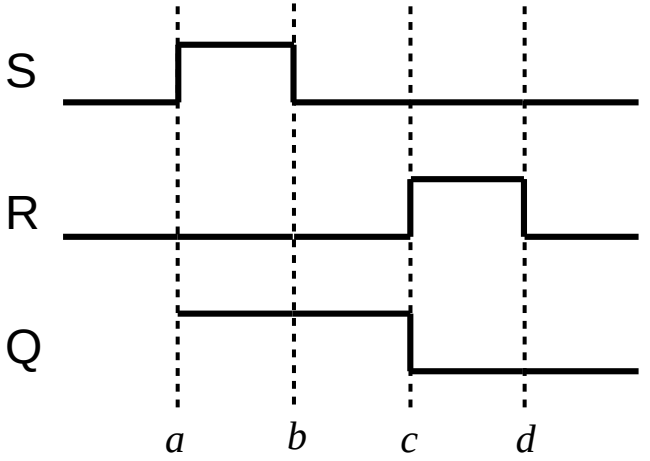


Event ***d*** *(R off)*



SR AND-OR latch

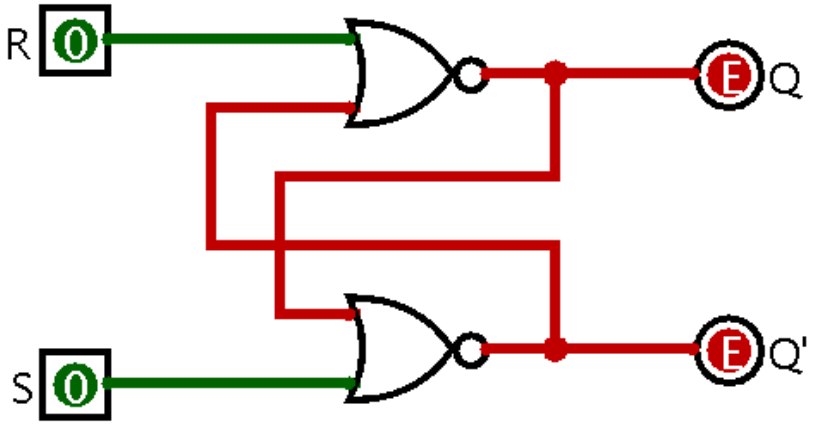




S = “set” R = “reset”

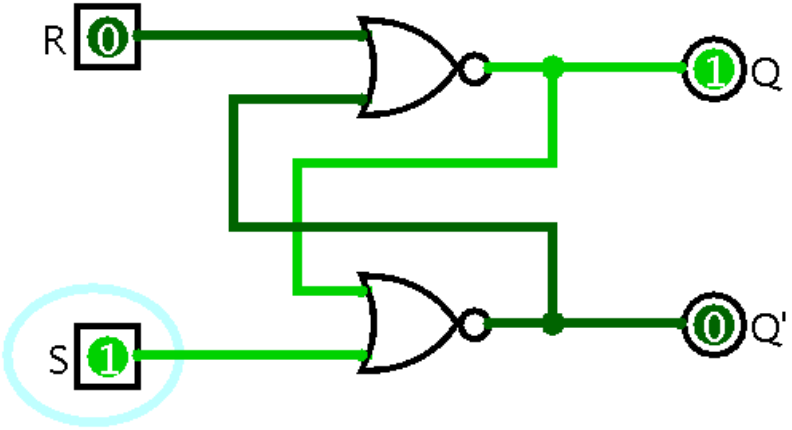
S	R	Q (old)	Q (new)	
0	0	0	0	
0	0	1	1	
0	1	0	0	
0	1	1	0	← **“reset”**
1	0	0	1	← **“set”**
1	0	1	1	
1	1	0	0	
1	1	1	0	← **the R “overrides” the S in this circuit**

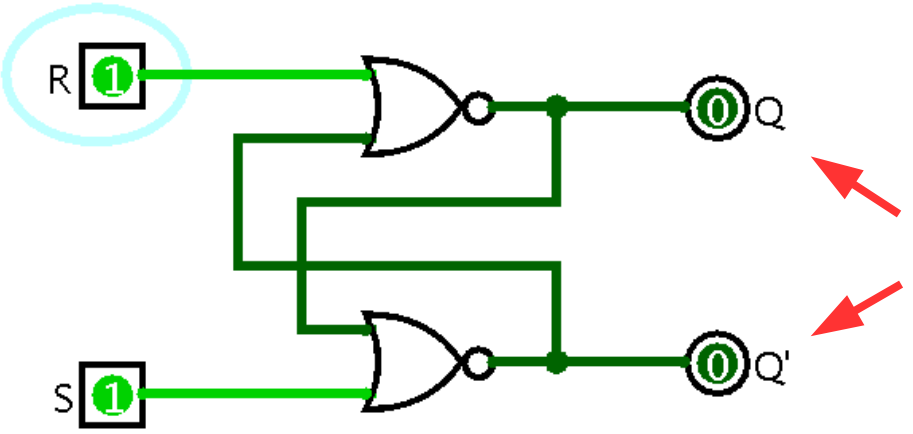
SR NOR latch



Works similarly to AND-OR, but requires one fewer gate (and it is a universal gate!)

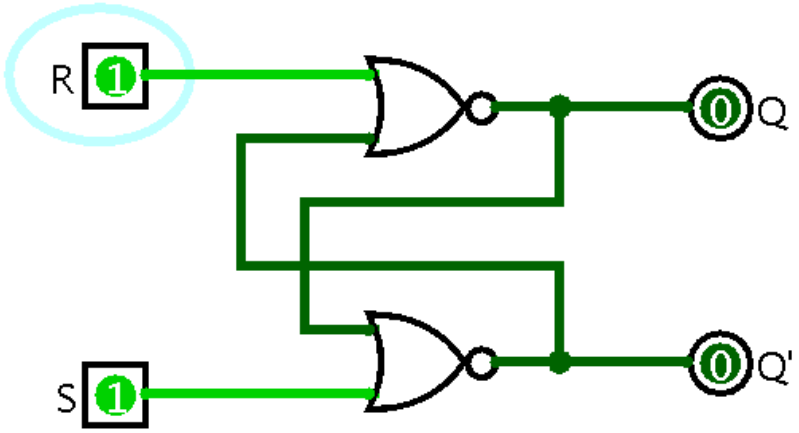
Question: What happens if we turn both R and S on at the same time?





Disallow S=1, R=1 because Q' ≠ !Q

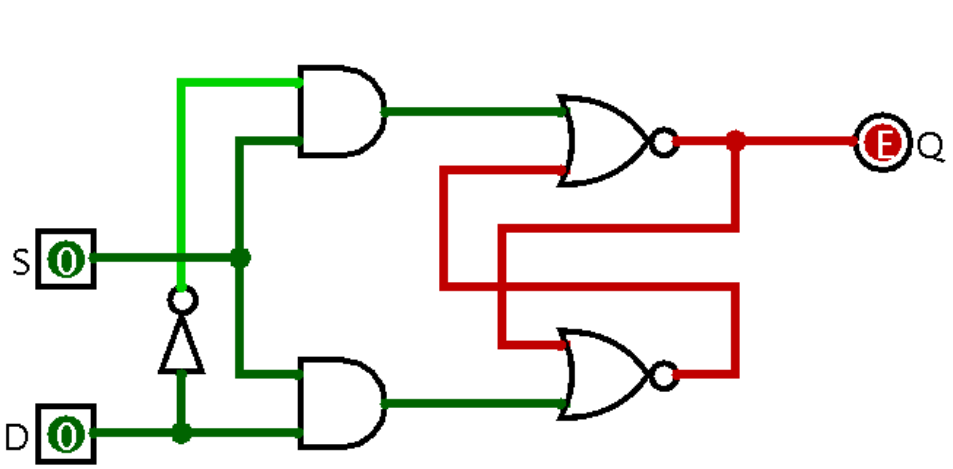
Aside: oscillation

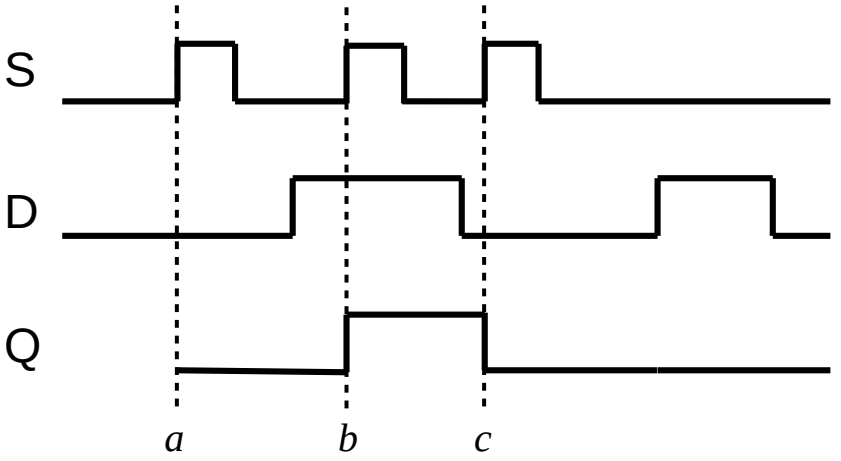


Question: What happens if we turn both R and S off at the same time (from the position previously disallowed)?

The circuit will be unstable; it begins to oscillate back and forth as quickly as possible, generating heat and eventually melting the connection and destroying the circuit

D latch



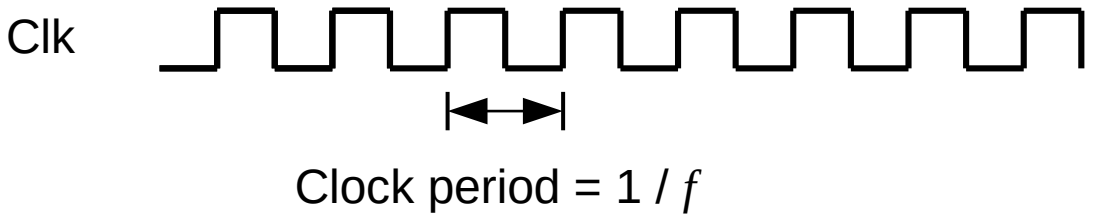


From “Code” book: S = “Save that bit!”

- As long as S is on, Q reflects the value of D.
- When S turns off, Q is "frozen" and retains its previous value.
- D can change while S is off with no change in Q

Clocks

- Provide oscillating signal
- Often used as “set” signal for latches
- Keeps computation and memory in sync
- Clocked latches are called flip-flops
- The clock period is the inverse of the frequency (measured in *hertz*)
- The length of a clock period determines the minimum time an instruction takes to execute

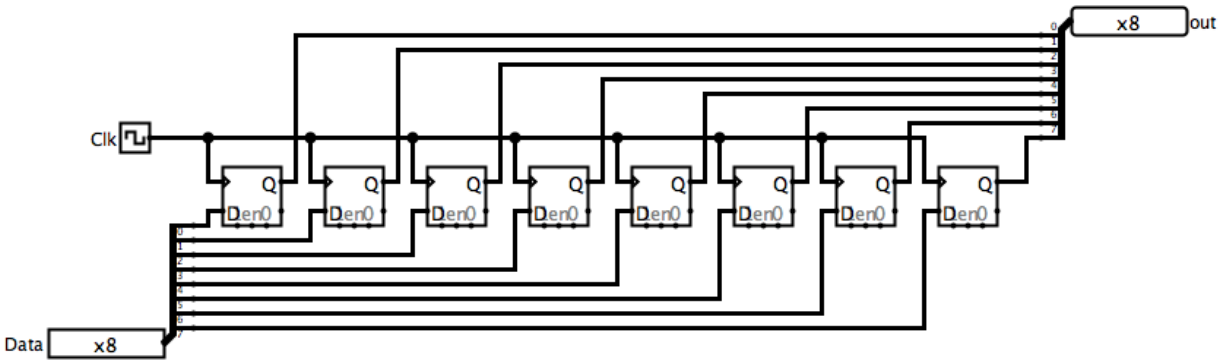


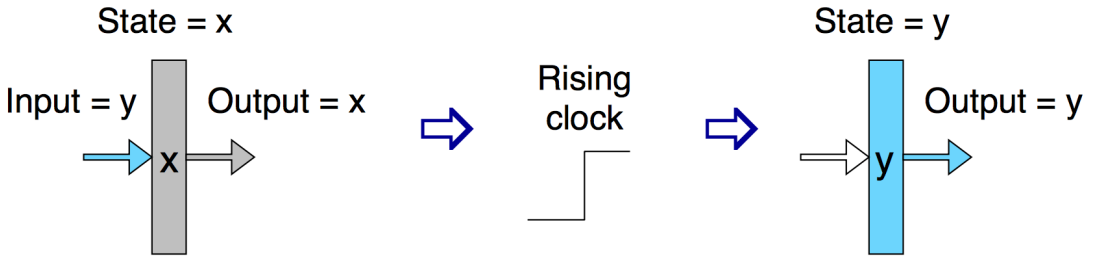
Flip-flop types

- SR: “set-reset”
- D: “data” bit + clock
- T: “toggle”
- JK: like SR + T (toggle when S=1, R=1)
  - J is S, K is R
- Any of these can be used to build the others
- Also can be built from basic logic gates in multiple ways

Registers

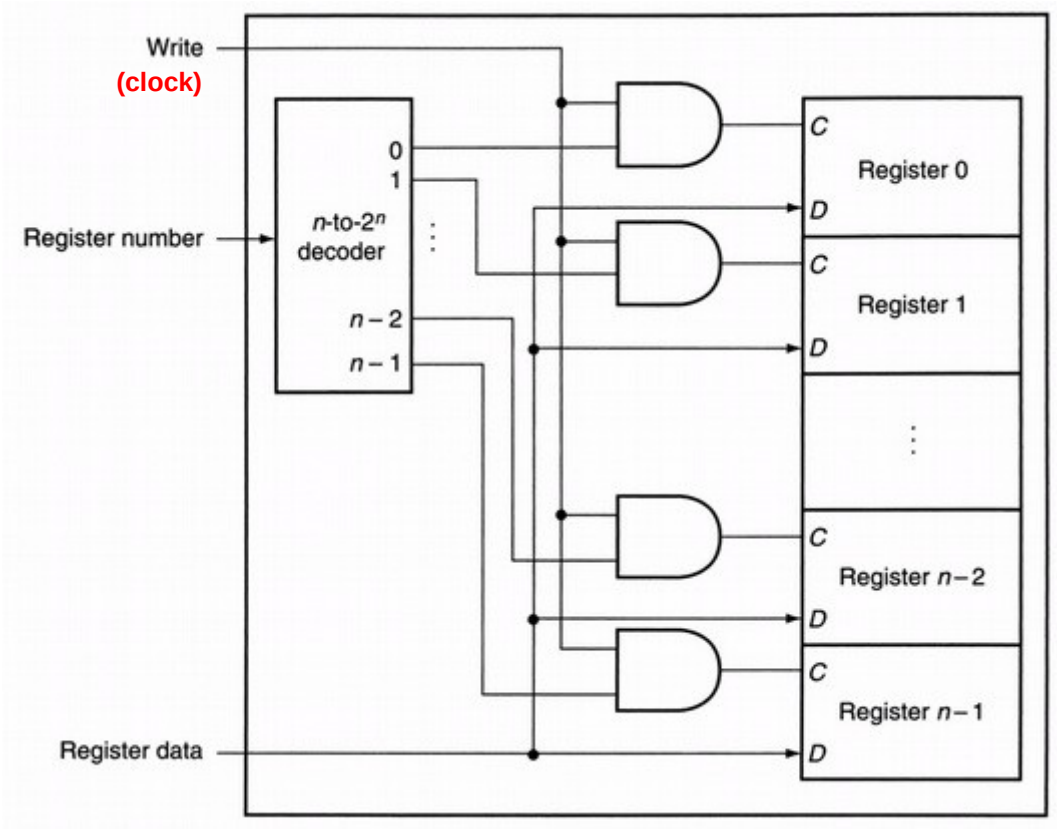
- Registers: arrays of flip-flops with a single set/clock input
- Connected by buses (groups of wires) to other components
- Edge triggering allows computation to stabilize before results are saved

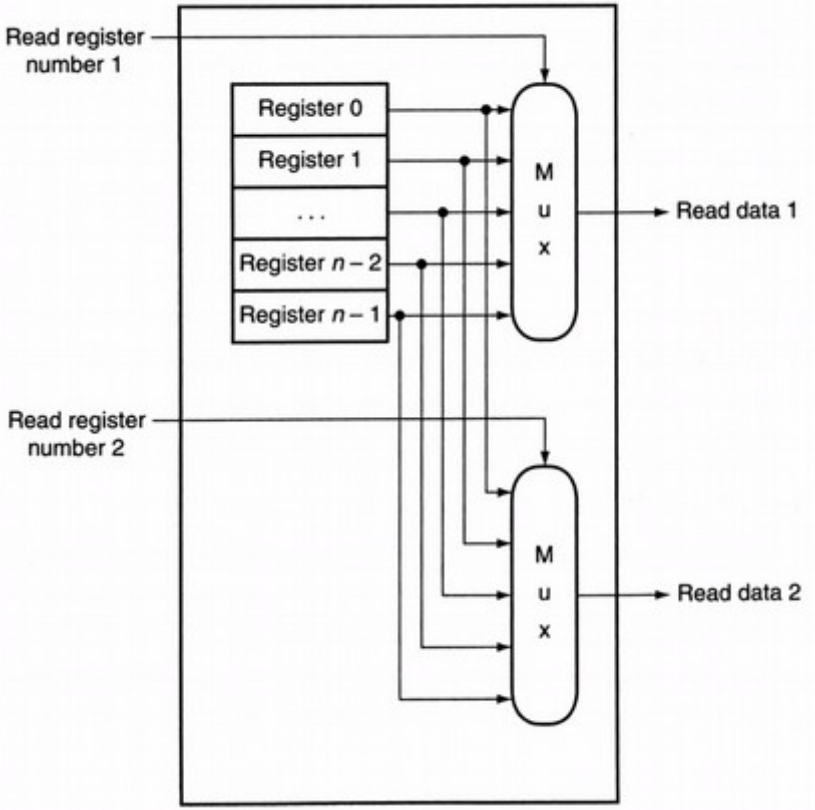




Register files

- Register files: multiple registers w/ read/write ports
  - Use multiplexors and decoders to differentiate





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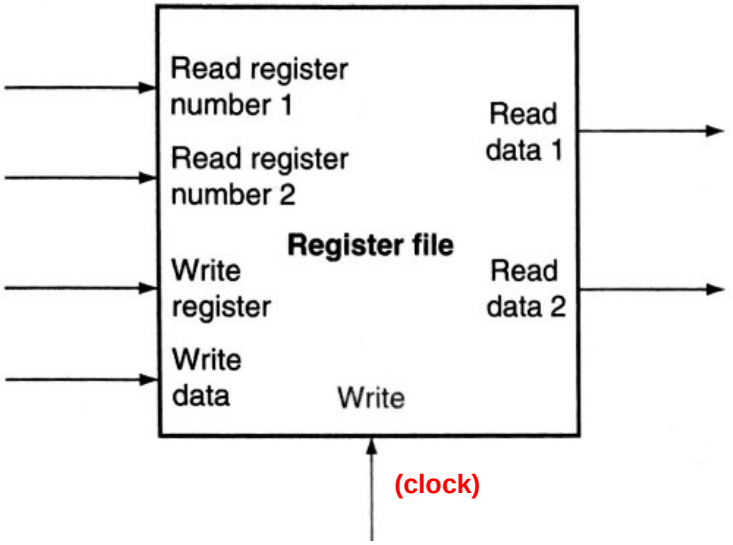
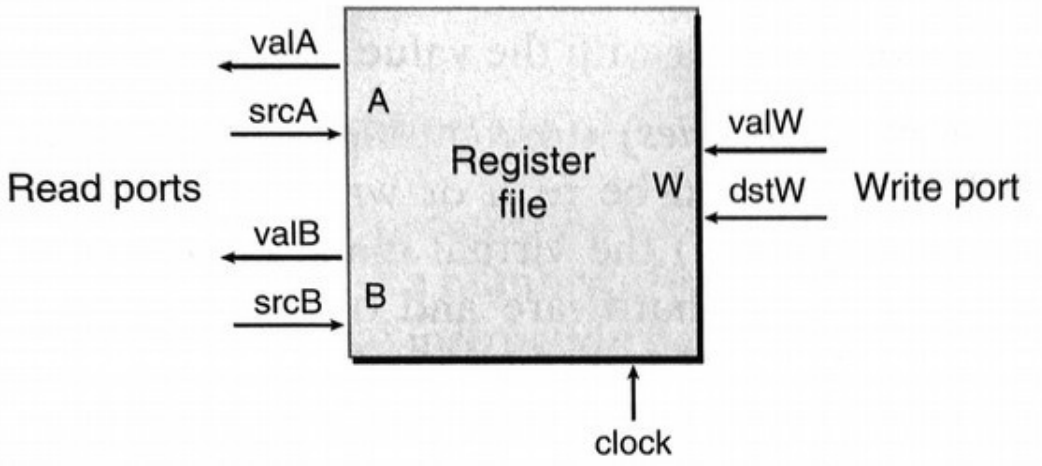


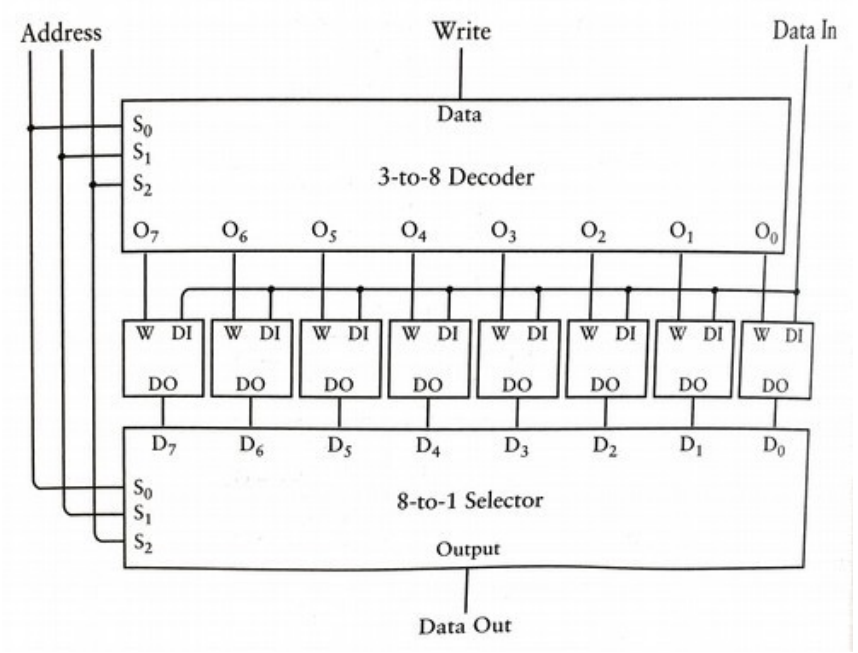
Canvas PDF version



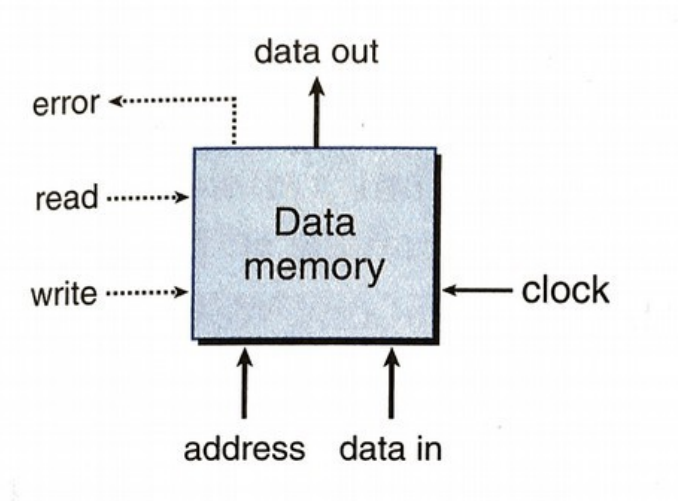
CS:APP version

Memory

- Memory: multiple flip-flops w/ address input
  - Random access memory (RAM) - can access any address at any time
  - Use decoder (translates n-bit number to 2^n "set" signals) to write data
  - Use selector (multiplexor) to read data



Single 8-element RAM array (3-bit addresses)



Abstraction of multiple RAM arrays

CPUs

- Combine ALU with registers and memory to make CPUs

(next time!)