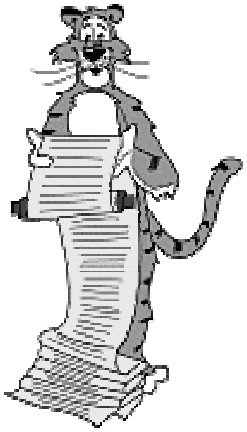
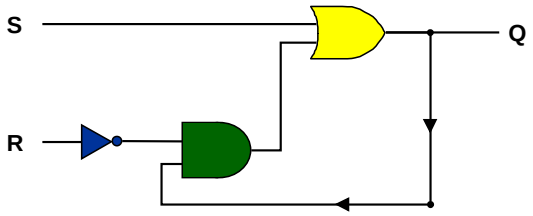
Lecture A5: Sequential Circuits





Overview

Lecture A1 – A3: TOY machine.

Lecture A4: Boolean logic and combinational circuits.

- In principle, we could build X-TOY computer with one gigantic combinational circuit.
- Each circuit element used (at most) once.

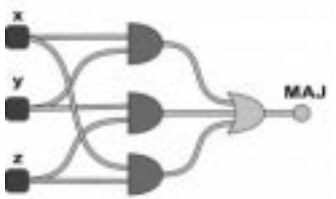
Today: reuse circuit elements by storing bits in "memory."

Next time: glue components together to make X-TOY computer.

Sequential vs. Combinational Circuits

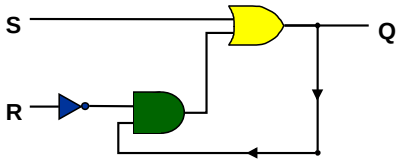
Combinational circuits.

- Output determined solely by inputs.



Sequential circuits.

- Feedback loop.
- Output determined by inputs and previous outputs.



Flip-Flop

Flip-flop.

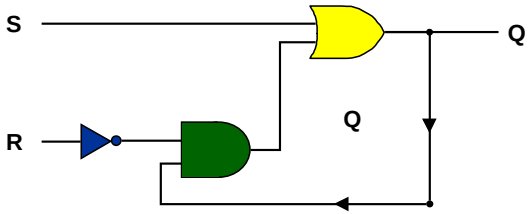
- A small and useful sequential circuit.
- "Remembers" one bit.

We will consider several flavors.

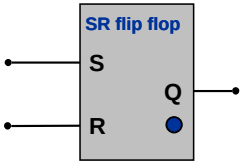
SR Flip-Flop

SR Flip-Flop.

- Pulse on S (set) ⇒ Flips "bit" on.
- Pulse on R (reset) ⇒ Flips "bit" off.
- S = R = 0 ⇒ Status quo.
- S = R = 1 ⇒ Not allowed.



Implementation



Interface

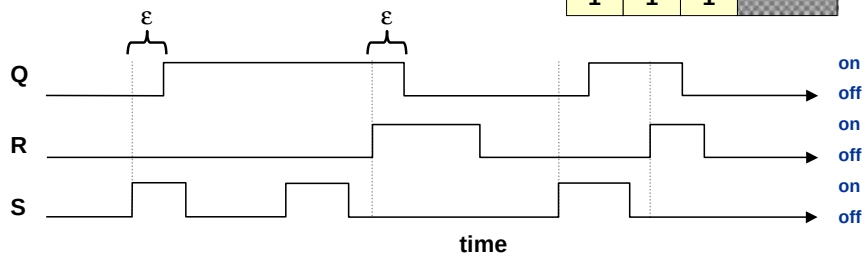
Truth Table and Timing Diagram (for SR Flip-Flop)

Truth table.

- Values vary over time.
- S(t), R(t), Q(t) denote value at time t.

SR Flip Flop Truth Table			
S(t)	R(t)	Q(t)	Q(t+ε)
0	0	0	0
0	0	1	1
0	1	0	0
0	1	1	0
1	0	0	1
1	0	1	1
1	1	0	
1	1	1	

Sample timing diagram.



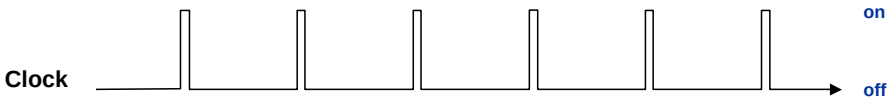
time

Clock

Clock.

- Fundamental abstraction.
  - regular on-off pulse
- External analog device.
- Synchronize operations of different circuit elements.
- 800 MHz clock means 800 million pulses per second.

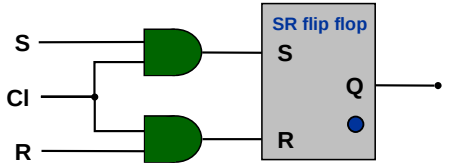
cycle time



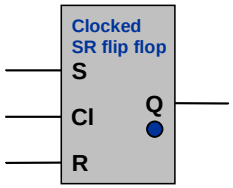
Clocked SR Flip-Flop

Clocked SR Flip-Flop.

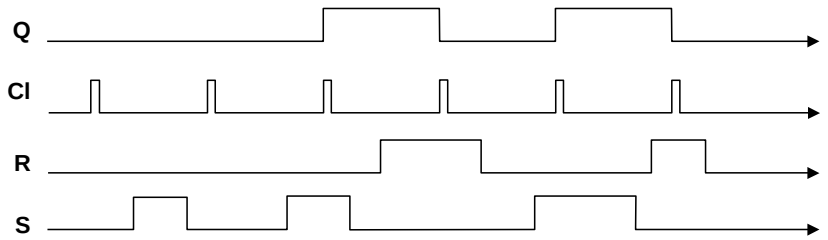
- Like SR flip-flop but S and R only work if clock is on.



Implementation



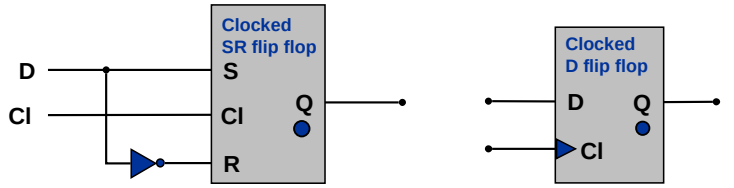
Interface



Clocked D Flip-Flop

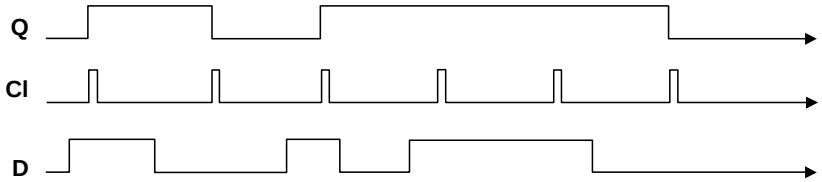
Clocked D Flip-Flop.

- Output follows D input when clock is high.
- Output is remembered when clock is low.



Implementation

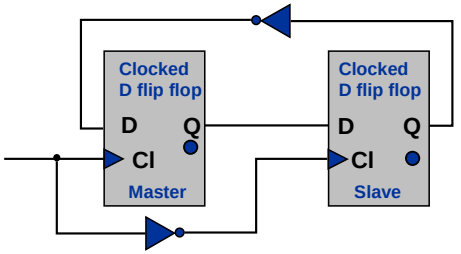
Interface

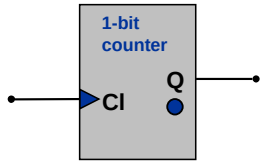


1-Bit Counter

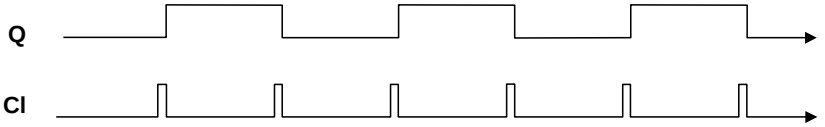
1-bit counter (falling edge-trigger).

- Circuit that oscillates between on and off.





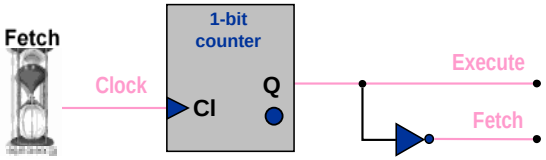
Interface

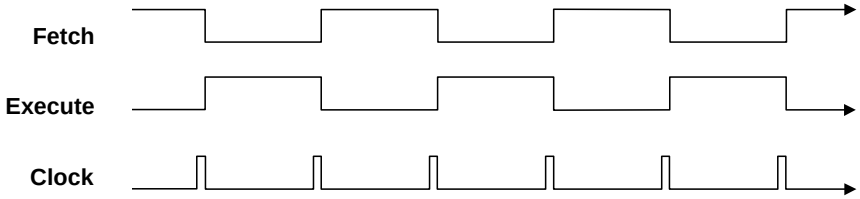


Fetch-Execute Cycle

Fetch-execute cycle.

- Use 1-bit counter.





Memory Overview

Computers have many types of memory.

- PC.
- Registers.
- Main memory.

We implement 1 bit of memory with clocked D flip-flop.

Need mechanism to organize and manipulate groups of related bits.

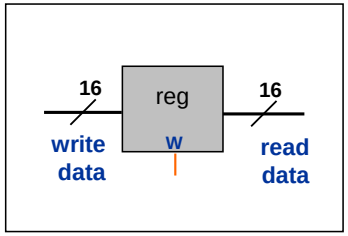
- X-TOY has 16-bit words.
- Memory hierarchy make architecture cleaner.

Stand-Alone Register

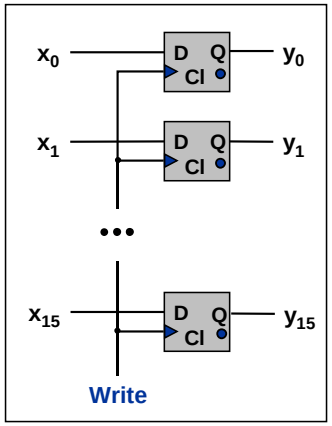
k-bit register.

- Stores k bits.
- Register contents always available on output.
- If write enable is asserted, k input bits get copied into register.

Ex: PC, 16 TOY registers, 256 TOY memory locations.



16-bit Register Interface



16-bit Register Implementation

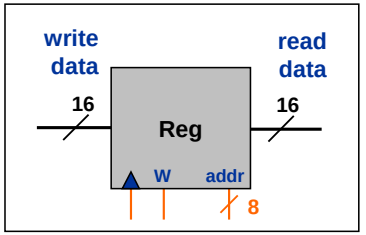
Register File Interface

n x k register file.

- Bank of n registers; each stores k bits.
- Read and write information to ONE of n registers.
  - address inputs specifies which one
  - how many bits needed to specify address?
- Addressed bits always appear on output.
- If write enable and clock are asserted, k input bits get copied into addressed register.

Examples.

- X-TOY registers: n = 16, k = 16.
- X-TOY main memory: n = 256, k = 16.



256 x 16 Register File Interface

Register File Implementation

Implementation.

- Use n k-bit registers.
- Multiplexer and decoder used to select.