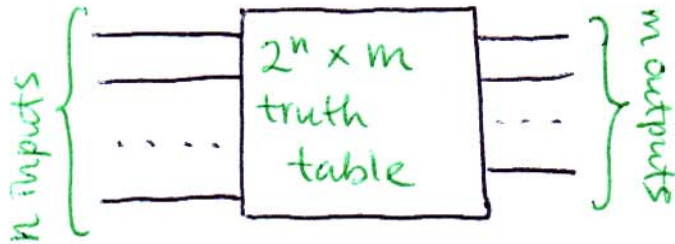


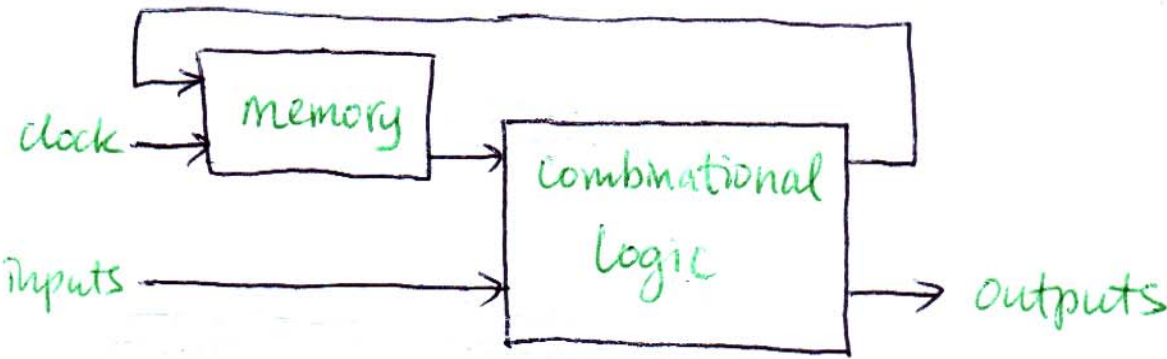
Lecture 27

Combinational Logic



— outputs depend only on present values of inputs

Sequential Circuit (simple example)



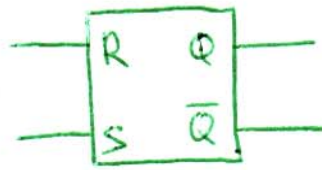
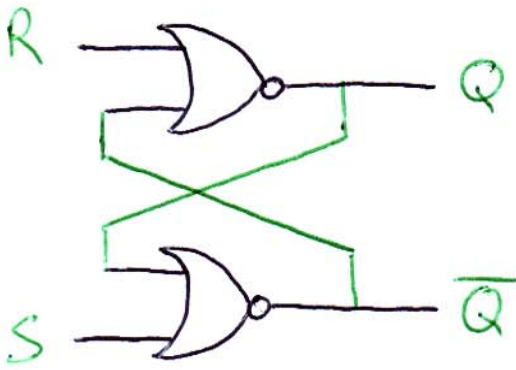
- outputs depend on both present and states of memory (past) elements
- clock determines when info stored in memory can change

RS latch



if  $A=0$ ,  $X = \overline{0+B} = \overline{B}$ ,  
 $\Rightarrow$  NOR becomes  $X = \overline{B}$

(2)



S	R	Q	$\bar{Q}$
0	0	1	0
0	0	0	1
0	1	0	1
0	0	0	1
1	0	1	0
0	0	1	0
1	1	0	0
0	0	?	?

} two stable states

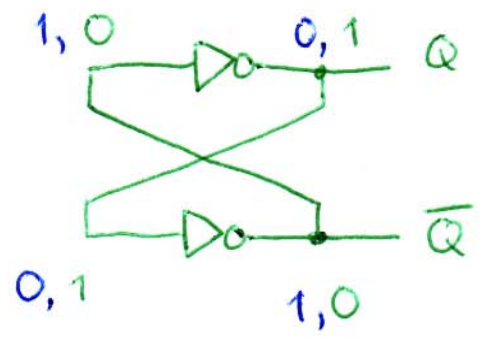
reset

after  $S=0, R=1$

set

after  $S=1, R=0$

← contrary to the names ( $Q=\bar{Q}$ ?)



step 1)

2)

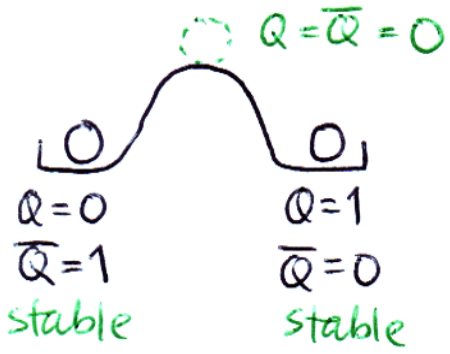
summary

S	R	Q	$\bar{Q}$
0	0	no change	
0	1	0	1
1	0	1	0
1	1	not allowed	

- latch has asynchronous response, i.e. output changes whenever the input changes
- contrary to "flip-flop", which requires a clock.

two stable states

(3)



- similar to ball analogy, need a strong enough force to send the latch from one stable state into another
- there exists a min pulse length needed for switching (typically ~10's ns)

Flip-flop (i.e. clocked or synchronized clock)

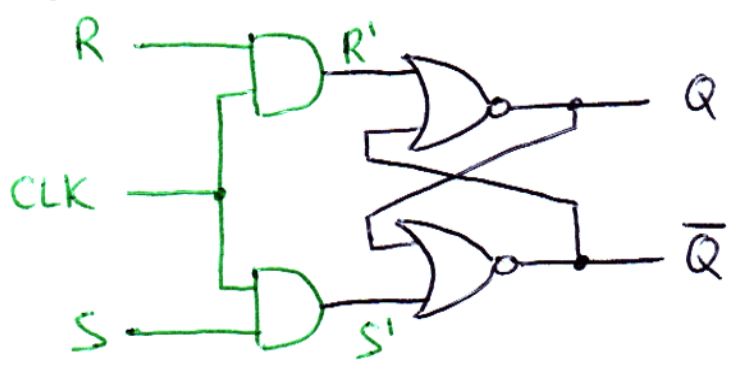
problems with latches: asynchronous circuits  
hard to combine/integrate

E.g. sequence of operations depends on exact values of prop. delays between gates

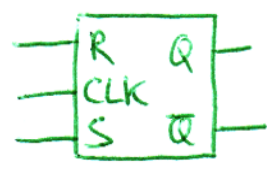
Synchronous circuits (= clocked) are usually preferred  
Inputs/outputs change @ well-defined times

Improvements

1) clocked RS flip-flop

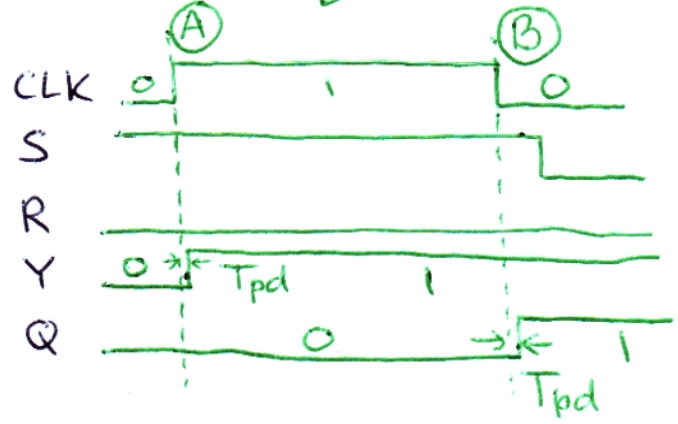
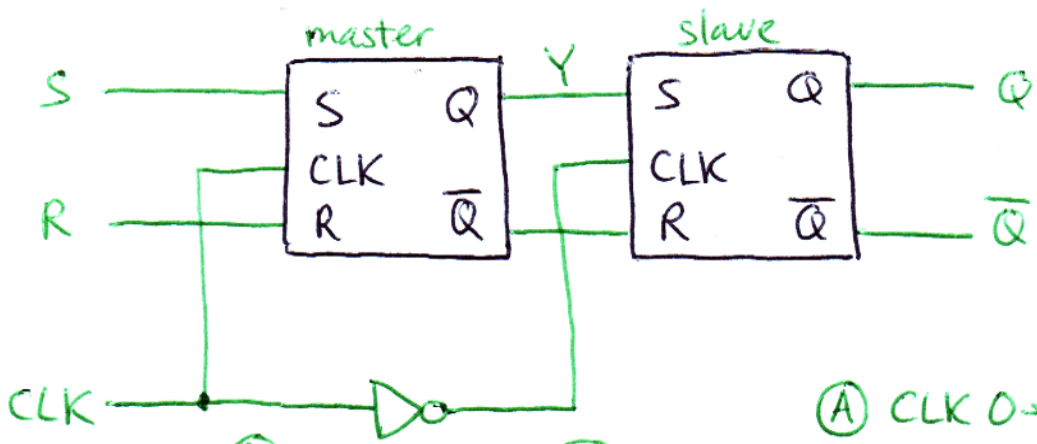


state can change only when CLK=1



2) triggering: level-sensitive or transition-sensitive (better)  
CLK (EN) = 1  
latch "transparent" when CLK  $\nearrow$  or  $\searrow$

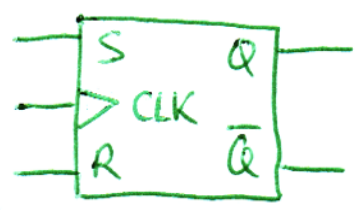
# Master-slave configuration



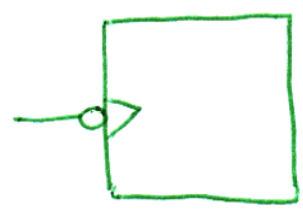
- Ⓐ CLK 0 → 1 master enabled & slave disabled
- Ⓑ CLK 1 → 0 master disabled & slave enabled

- Q ends up controlled by S, R when CLK  $\nabla$  only
- switch for multiple FF's can occur at the same time

## Symbol

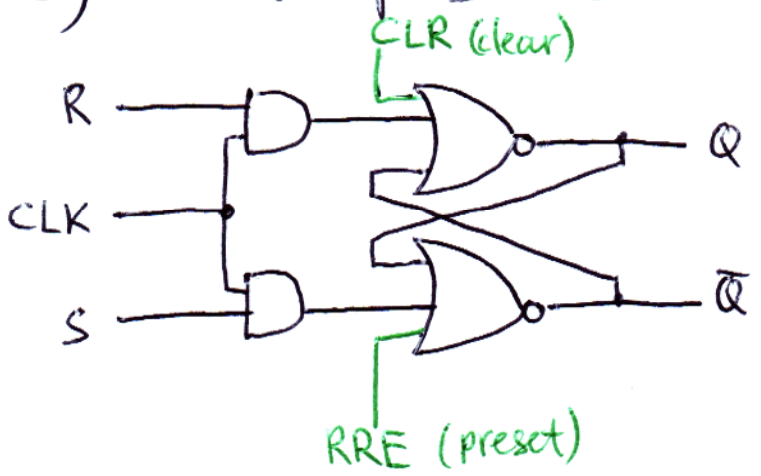


"+" edge  $\nabla$  triggered



"-" edge  $\nabla$  triggered

3) direct inputs : used to set FF state asynchronously (= force a state)



PRE → 1 : Q → 1 } regardless of CLK, S, R  
CLR → 1 : Q → 0 }