Sequential Logic

1

Combinational vs. Sequential

- Combinational: output depends completely on the value of the inputs.
  - time doesn't matter.
- Sequential: output also depends on the *state* a *little while ago*.
  - can depend on the value of the output some time in the past.

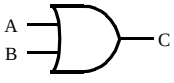
2

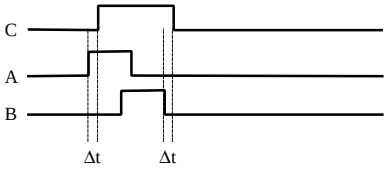
Memory

- Think about how you might design a combinational circuit that could be used as a single bit *memory*.
- Use your *memory* to recall that the output of a gate can change whenever the inputs change.

3

Gate Timing

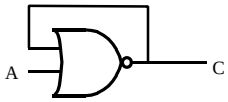




4

A	B	A nor B
0	0	1
0	1	0
1	0	0
1	1	0

Feedback



What happens when A changes from 1 to 0?

–Try connecting the microphone input to the earphone output on your PC.
–Try holding a mirror in front of you while you are looking in a mirror.
–Try using google.com to search for the term "google".

Caution: the above experiments may result in opening a worm hole in your immediate surroundings!

5

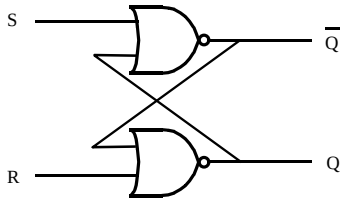
Feedback can be stable

- It is possible to use feedback in a circuit that is predictable and *stable*.
- It is harder to tell what is going on (when compared to combinational circuits), but it is possible:
  - figure out what the output is at some initial time.
  - use that output to determine the next output.
  - continue until the worm hole contracts…

6

A	B	A nor B
0	0	1
0	1	0
1	0	0
1	1	0

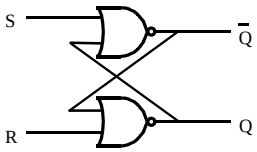
S-R latch



S stands for “Set” as in “Set to a 1”
R stands for “Reset” (set to a 0).

7

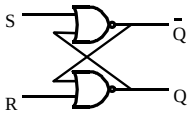
S-R latch Truth Table

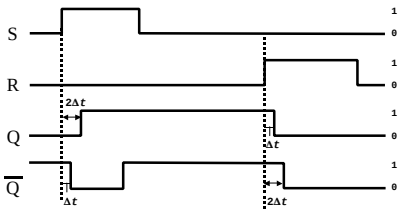


Q_t	S_t	R_t	Q_{t+1}
0	0	0	0
0	0	1	0
0	1	0	1
0	1	1	?
1	0	0	1
1	0	1	0
1	1	0	1
1	1	1	?

8

S-R latch Timing





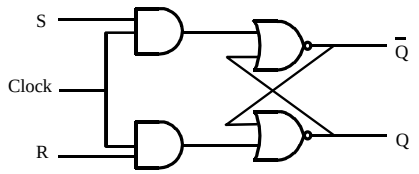
9

Clocked S-R Latch

- Inside a computer we want the output of gates to change only at specific times.
- We can add some circuitry to make sure that changes occur only when a *clock* changes (when the clock changes from 0 to 1).

10

Clocked S-R Latch



- Q only changes when the Clock is a 1.
- If Clock is 0, neither S or R *reach* the NOR gates.

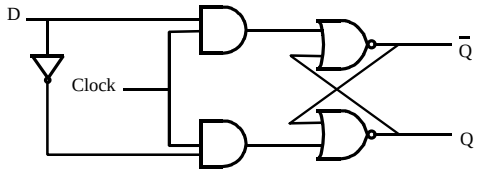
11

What if S=R=1?

- The truth table shows "?" when S=R=1.
- The value of Q is undetermined.
  - The circuit is not *stable*.
- We can make sure that S=R=1 now that we have a clock.

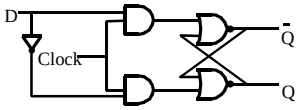
12

Avoiding S=R=1: D Flip-Flop



13

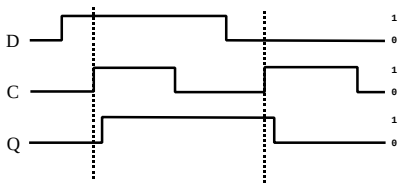
D Flip-Flop



- Now have only one input: D.
- If D is a 1 when the clock changes from 1 to 0, the circuit will *remember* the value 1 (Q=1).
- If D is a 0 when the clock changes from 1 to 0, the circuit will *remember* the value 0 (Q=0).

14

D Flip-Flop Timing



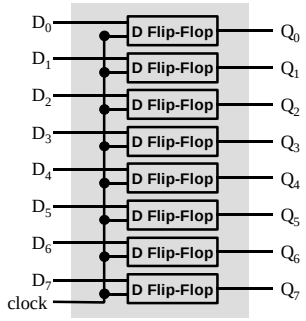
15

8 Bit Memory

- We can use 8 D Flip-Flops to create an 8 bit memory.
- We have 8 inputs that we want to *store*, all are *written* at the same time.
  - all 8 flip-flops use the same clock.

16

8 Bit Memory



17