Sequential Logic
Most useful circuits include a combination of combinational and sequential logic blocks.

Observation:

- Multiple-input NAND or NOR gates are sufficient to build any combinational logic function.
- Any clocked flip-flop or storage element will be sufficient to add the sequential logic functionality to any system.
Memory Circuits / Elements

1) Latch

2) Flip Flop

3) Memory Cell
Latches:

Terminology

Transparency: Input to latch appears immediately on the latched output.

Opaque: Input to the latch does not appear at the output while in the opaque state.

Edge Triggered: Input to the latch at a control transition determines when the input is transferred to the latch output.
Example:

\[ \begin{align*}
  x_c & \quad \text{when } x_c \text{ is high, output tracks input} \\
  x_i & \quad \text{when } x_c \text{ is low, latch is opaque} \\
  c & \quad \text{very simple} \\
  \text{negative edge triggered.} \\
\end{align*} \]

Limitations:

- \( x_o \) can get no closer to \( VDD \) than \( VTN \)
- Leakage of charge will occur when \( x_c \) is low
- Any loads placed on \( x_c \) will further degrade
  \footnotesize{50 \text{ K\Omega}}
- rail to rail output
- leakage & loading problem
- more complexity
- removes loading problem
- removes the leakage problem.
- volatile
- load challenge
  load transistor must be stronger than the FB inverter.

6 - transistor solution -
Flip Flops

S-R
D
T
JK

\{ Master/Slave Version \}
S-R flip flop

Two cross-coupled NOR gates

Two cross-coupled NAND gates

R & S cannot be high at the same time.

If they are ever both simultaneously high, the state of the FF will be indeterminate.

Both go low will be indeterminate.

Level of logic:

Transistors:

😊
To obtain a clocked S-R flip-flop

R

\[ \bar{q} \]

\[ s \]

\[ 12 + \bar{8} = 20 \]

- Output will not change when \( \bar{q} \) is low
- Output is immediate when \( q \) is high

20 transistors
3 levels of logic
Master-Slave Flip Flop

Master-Slave Clocked S-R Flip Flop
triggered on negative edge \( \phi \)

40 transistors
6 levels of logic