Computer Architecture
Sequential Circiuts

Cain Susko

Queen's University
School of Computing

March 15, 2022

Sequential Curcuits

within a sequential circuit there are:

- Outputs depend on the current and past values of input
- this implies that the use of some type of memory device to store the effects of past inputs
- It takes a sequence of inputs and generates a sequence of outputs

A sequential logic might remember previous inputs or it may just distill the previous inputs into states to remeber. Sequential circuits are widely used to implement computing and storage components of computer systems.

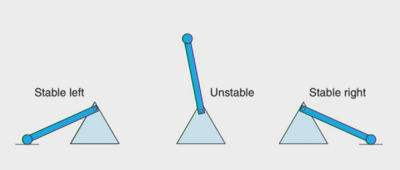
Devices there are different devices we can implement within sequential circuits:

- latches and flip-flops
- building blocks of sequential logic circuits - register, counter, shift register
- memory array and register file

these can be used to implement sometthing like a finite state machine

Single Bit Memory

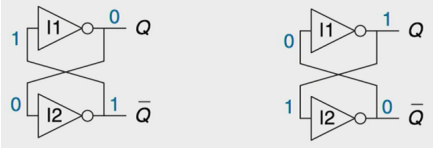
to have a on or off state, we must have what is known as a Bi-Stable Device. This is the fundamental building block of memory. This device must be stable at one of the 2 states, and must require an input to transition state. Examples of this device include a light switch or an inverted pendulum (see below) Another example is a coin flipping, where there are 2 states and to



change the state one must pick up and flip the coin. with many coins we could store more than $number of coins^2$ states as each coin is bi-stable.

Cross-Coupled Inverter Pair

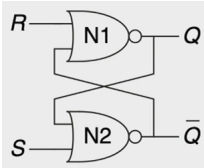
Within circuits, we can represent a bi-stable device using cross-coupled inverter pairs:



However, Once the state is set it cannot be changed.

SR Latch

The SR Latch is the actual way we implement a bi-stable device within circuits. The SR latch stores a single bit, and it;s value can be set by the `S` (set) and `R` (reset) terminals. The disign is derived from the Cross coupled inverter pair.



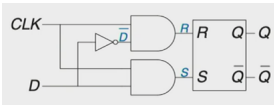
S	R	Q	$\bar{Q}$
0	0	Q_{prev}	$\bar{Q}_{prev}$
0	1	0	1
1	0	1	0
1	1	(avoid)	

D Latch

A D (data) Latch is a addition to the SR latch and has:

- a `D` (data) input
- a `CLK` (clock) input

these are to get inuput and control the timing of the input.



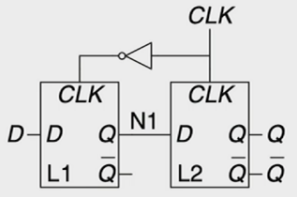
CLK	D	$\bar{D}$	S	R	Q	$\bar{Q}$
0	X	$\bar{X}$	0	0	Q_{prev}	$\bar{Q}_{prev}$
1	0	1	0	1	0	1
1	1	0	1	0	1	0

the `CLK` is a sequence on pulses such that it passes the value in `D` at a high voltage (at a specified interval).

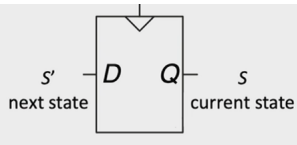
Flip Flop

A Flip Flop stores a single bit of information. It has a `D` (data) and `CLK` (timing). It will only accept the value in `D` at the high voltage (rising edge) of the `CLK` while 'remembering' its state at all other times.

It is implemented with 2 back to back D latches–specifically utilizing the delay intorduced by the `CLK` inverter (the `not` after the `CLK`):



The flip flop is going to remeber things and then is going to be able to execute things as the transitions within the flip flop. a D flip flop sybmol is:

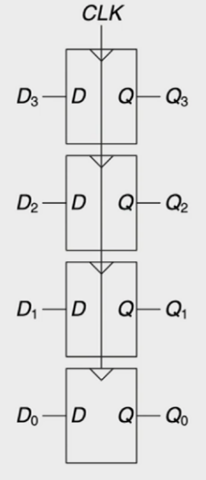


The D flip flop can be used to implement state machines. We also often use `S, S'` to label the current and next state. Some computers also have a 'watchdog' which resets the D flip flop to not look at the current state and only look at the future.

Circuits

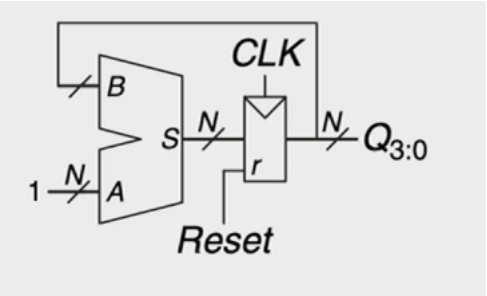
Now, with these devices there are many circuits we can make.

Registers An N-bit register is a bank of N flip flops sharing a common `CLK`. Registers are the key building block of sequential circuits.



Counter A counter is a very important device within computers. An N bit binary counter is a sequentail circuit with:

- clock and reset inputs
- an N-bit input



The counter implements an Adder, and a D Latch.

Shift Register A shift register takes an input and shifts it by a given ammount. An N-bit regiser has:

- a serial input S_{in}
- a serial output S_{out}
- N parallel outputs $Q_{N-1:0}$

on the risiing edge (high voltage) of the clock, a new bit is shifted in from S_{in} and all the subsequent contents are shifted forward. The last bit in the shift register is then available in S_{out}