Lecture A4: Sequential Circuits

Overview

Lectures A1 – A2: TOY machine behavior.

Lecture A3: Boolean logic and combinational circuits.
   • Basic abstraction = controlled switch.
   • In principle, we could build 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 TOY computer.

Sequential vs. Combinational Circuits

Combinational circuits.
   • Output determined solely by inputs.
   • Can draw solely with left-to-right signal paths.

Sequential circuits.
   • Feedback loop.
   • Output determined by inputs and previous outputs.
   • Need loops to draw.

Flip-Flop

Flip-flop.
   • A small and useful sequential circuit.
   • Abstraction that "remembers" one bit.
   • Basis of important computer components:
     – memory
     – counter

We will consider several flavors.
SR Flip-Flop

What is the value of Q if:
- $S = 1$ and $R = 0$ ? $\Rightarrow$ $Q$ is surely 1.
- $S = 0$ and $R = 1$ ? $\Rightarrow$ $Q$ is surely 0.
- $S = 0$ and $R = 0$ ? $\Rightarrow$ $Q$ is possibly 0 . . . or possibly 1.
- While $S = 0$ and $R = 0$, $Q$ "remembers" what it was the last time $S$ or $R$ was 1.

SR Flip-Flop

- $S = 1$, $R = 0$ (set) $\Rightarrow$ Flips "bit" on.
- $S = 0$, $R = 1$ (reset) $\Rightarrow$ Flops "bit" off.
- $S = R = 0$ $\Rightarrow$ Status quo.
- $S = R = 1$ $\Rightarrow$ Not allowed.

Truth Table and Timing Diagram

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

Sample timing diagram for SR flip-flop.

Clock

Clock.
- Fundamental abstraction.
  - regular on-off pulse
- External analog device.
- Synchronizes operations of different circuit elements.
- 1 GHz clock means 1 billion pulses per second.
Frequency is inverse of cycle time.

- Expressed in hertz.
- Frequency of 1 Hz means that there is 1 cycle per second.
- Hence:
  - 1 kilohertz (kHz) means 1000 cycles/sec.
  - 1 megahertz (MHz) means 1 million cycles/sec.
  - 1 gigahertz (GHz) means 1 billion cycles/sec.
  - 1 terahertz (THz) means 1 trillion cycles/sec.

Heinrich Rudolf Hertz
(1857-1894)

Clocked SR Flip-Flop

- Same as SR flip-flop except S and R only active when clock is 1.

Clocked D Flip-Flop

- Output follows D input while clock is 1.
- Output is remembered while clock is 0.

Fetch-Execute Cycle

- Need 1-bit counter.
1-bit counter ("edge-triggered").
- Circuit that oscillates between 1 and 0.
1-bit counter ("edge-triggered").
- Circuit that oscillates between 1 and 0.

1-Bit Counter

- Master Slave Clocked D flip flop
- Interface