Basics

Chapter 2

Digital Logic

Topics

- Voltage And Current
- Transistor
- Logic Gates
- Symbols Used For Gates
- Interconnection Of Gates
- IC Chips
- Combinatorial Circuits
- Flip-Flops
- Binary Counters
- Clocks

Topics

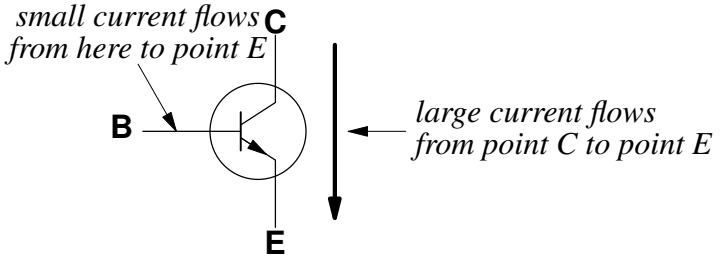
- Demultiplexor
- Feedback Concepts
- Iteration vs Replication
- Chip Engineering Aspects
  - Gate & chip minimization
  - Spare gate utilization
  - Power & heat dissipation
  - Clock Skew
- Process Technologies
- Physical Size Of IC's

Voltage And Current

- Voltage
  - potential force measured between two points
  - units is volts
  - measuring device is voltmeter
- Current
  - flow of electrons along a path
  - units is amps
- Ground
  - point that is assumed to be 0 volts

Transistor

- A semiconductor device that is used to control flow of electrical current; a miniature switch
- 3 connections in a transistor
  - 2 for current flow
  - 1 for controlling flow



- Symbol
- What do you do with a transistor in digital circuits and computer architecture?

Logic Gates

- Basic boolean functions
  - *and, or, not*
- Truth tables

A	B	A and B
0	0	0
0	1	0
1	0	0
1	1	1

A	B	A or B
0	0	0
0	1	1
1	0	1
1	1	1

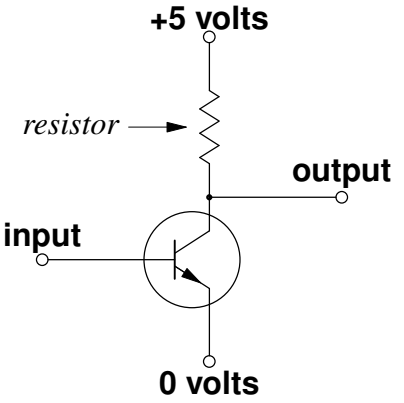
A	not A
0	1
1	0

- A table consisting of output result for each possible set of inputs

Logic Gates

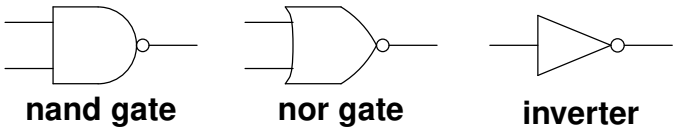
- What do you do with a transistor in digital circuits and computer architecture?
  - Transistors can be used to implement boolean functions.
  - Boolean functions are used in building digital circuits
- All digital systems at lowest level composed of transistors
- 0 is *false*, 1 is *true*.
- In transistor voltage, 0V is boolean 0 and 5V is boolean 1

Example Of How Transistors Can Be Used To Build Boolean Gates



- Not gate implementation using a transistor and a resistor
- Boolean circuits are called logic gates.
- Manufacturers sell IC chips that contain all circuitry for gates

Symbols Used For Gates



- Symbols

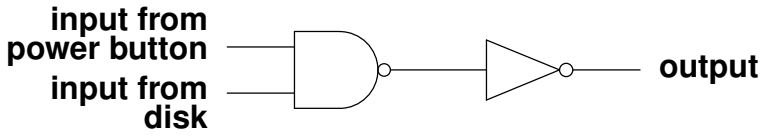
A	B	A nand B
0	0	1
0	1	1
1	0	1
1	1	0

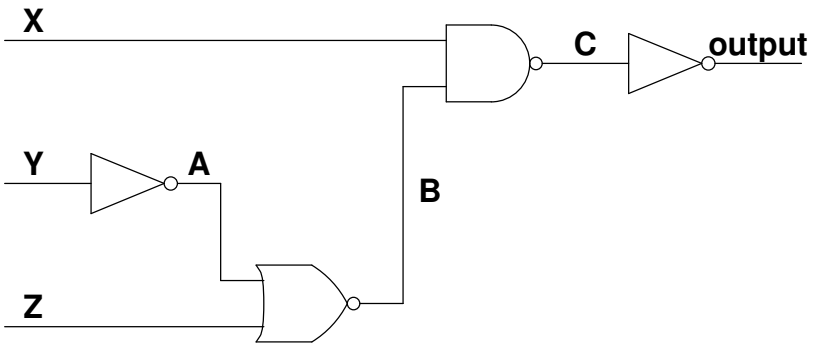
A	B	A nor B
0	0	1
0	1	0
1	0	0
1	1	0

- Truth tables for nand and nor

Interconnection Of Gates

- Gates can be connected together to obtain a combinatorial circuit
  - Transistor output of a gate is connected to input transistors in other gates





- Example and output values

IC Chips

- TTL: Transistor-Transistor logic
  - electronics parts that implement gates
    - allows outputs of gate to be connected to gate(s) input.
- Multiple gates/IC
  - TTL 7400: 4 AND
  - TTL 7402: 4 OR
  - TTL 7404: 6 NOT
- 7400 family includes more sophisticated circuits as well (flip-flops, counters, multiplexors).

Combinatorial Circuits

- Circuits seen so far are called combinatorial
- Here, output changes only when input changes

- Beyond combinatorial circuits
  - How can digital logic perform a sequence of operations without requiring input values to change?
    * using more sophisticated circuits discussed soon
  - How can a circuit continue to operate even after input reverts to original state?
    * Example, user presses power button once and a sequence of operations are performed
    * Using clock

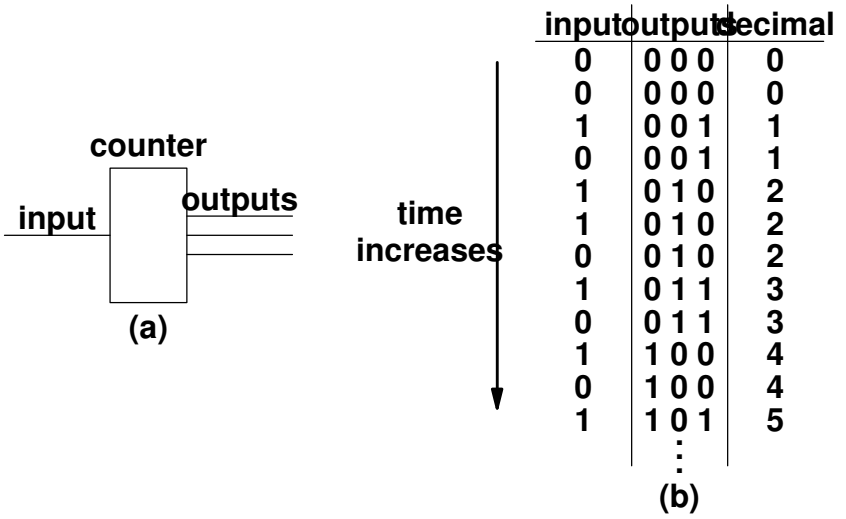
Flip-Flops

- Flip-flops are circuits that maintain state
  - Output depends on present as well as past inputs

- Transition diagram for flip-flop
- Output transition may occur on
  - leading edge (assume for now as default)
  - falling edge
  - both edges
- Some flip-flops have additional input called *reset* to set output to 0

Binary Counters

- Flip-flop has only two outputs 0/1
- Counter is the alternative
- Counter accumulates numeric total in binary

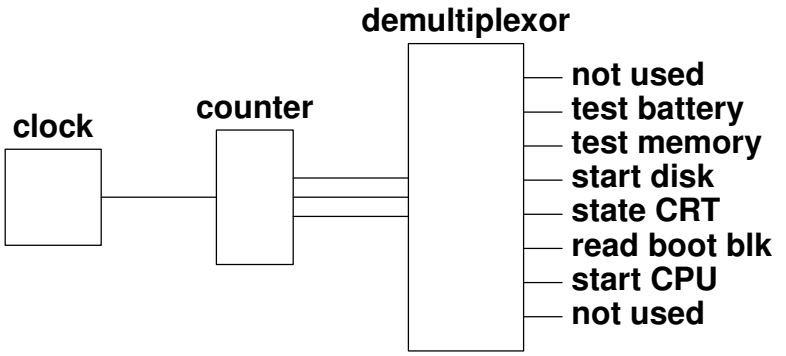


- Illustration of binary counter and sequence of input and output values

Clocks

- Recap: clock allows output to change without changing input.
- Clocks emits alternate 0 and 1
- Units is hertz
- Example usage of clock
  - How to perform sequence of operations without needing change of
    inputs in between the operations
  - Scenario: computer startup
    * test battery
    * power on and test the battery
    * start disk spinning
    * power up the CRT

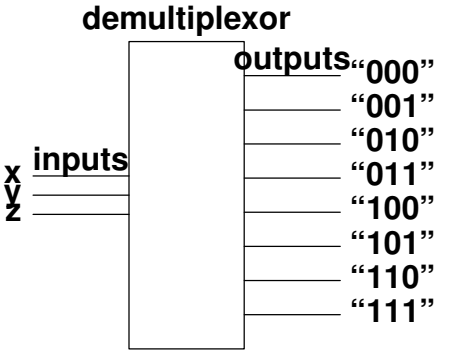
* read boot sector from disk into memory
* start CPU



- Illustration how a clock can be used to create a circuit that performs a sequence of six steps without changes to input

Demultiplexor

- Takes binary value as input and chooses a single output
- If input represents value *i* in binary, *i'th* output is selected



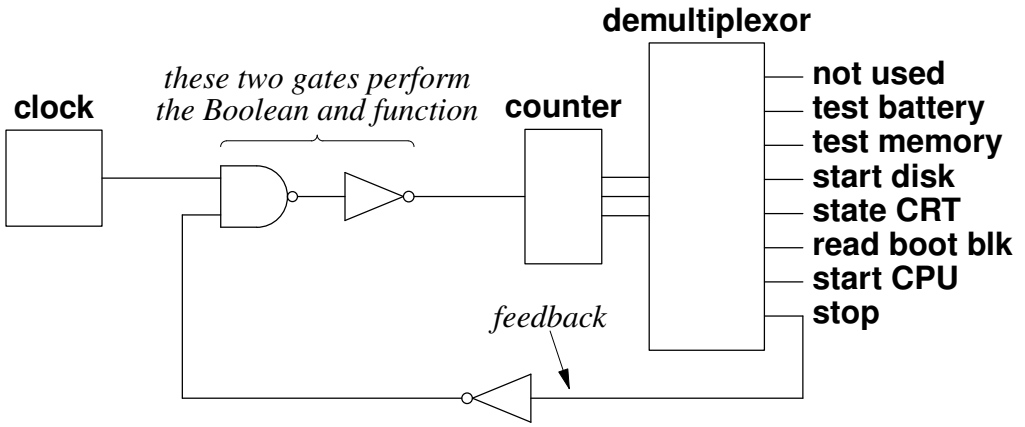
- Demultiplexor with three inputs and eight outputs

Feedback Concepts

- Clocks run forever, in previous example, same operations will be repeated after maximum value is reached.
- How do you control operations?
  - start or stop a sequence ?
  - use feedback, output affects the way circuit behaves.

Feedback

- Stopping a sequence
  - when maximum value is reached, feedback enables circuit to stop.



- Illustration of feedback to stop processing after one pass through each output

Feedback

- Starting a sequence
  - use reset button to set output of demultiplexor to 000, feedback inverter provides 1 as input,

Iteration vs Replication

- How do you handle operations applied to multiple items?
  - software experts says iteration
  - hardware experts says replication
- A fundamental paradigm/difference !!
- Replication
  - makes hardware more elegant
  - simultaneous operations speeds up execution
- Iteration
  - smaller code, example *for* loops

Chip Engineering Aspects

- Gate & chip minimization
  - minimizing gates
    - reduce boolean equations mathematically
    - example *x and 1 = x; x or 0 = x*
  - minimize IC
    - 4 *nand* gates better than 2 *nand* gates and 1 *not* gates
    - reason, 2 IC chips vs 1

Chip Engineering Aspects

- Spare gate utilization
  - assume need 1 *nand* and 1 *not*, note 7400 has 4 *nand* gates
  - use a spare *nand* gate, avoid need for IC 7402 *not* chip
  - 1 *nand* x = *not* x
- Power & heat dissipation
  - less chips is better, lower power used, so less heat generated
  - heat dissipation, primary concern in industry

Chip Engineering Aspects

- Timing
  - gate takes time to settle
  - signals take time to propagate
  - clock skew
    * clock signal reaches different parts of a large circuit at different times due to propagation delay
    * delay ~1ns/feet
    * solution: use several clocks instead of single global clock
    * downside: clock synchronization

Process Technologies

- Multiple gates/IC
  - SSI boolean gates
  - MSI counters
  - LSI small processors
  - VLSI complex processors
- ASIC: Application Specific Integrated Circuit ASIC

Physical Size Of IC's

- Moore's Law (Gordon Moore, Intel)
  - Density of silicon circuits (transistors/inch^2) doubles every year (revises to 18 months in 70's).

Class Exercises

- Basic laws: commutative, associative, distributive, AND-OR duality
- Writing a truth table for a circuit
- Drawing a circuit for a boolean expression
- Writing a boolean expression from a circuit
- Simplifying expressions