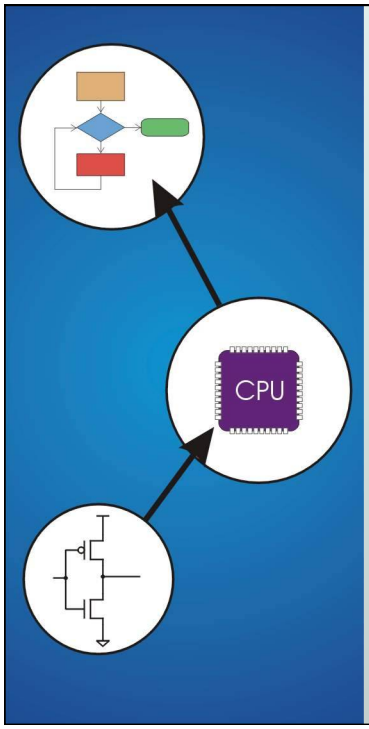
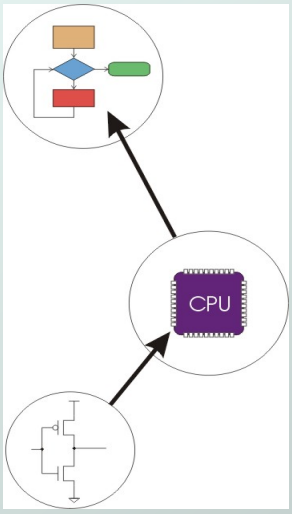


Chapter 3
Digital Logic Structures

Original slides from Gregory Byrd, North Carolina State University

Modified by Chris Wilcox, Sanjay Rajopadhye
Colorado State University

Computing Layers



Problems

Algorithms

Language

Instruction Set Architecture

Microarchitecture

Circuits

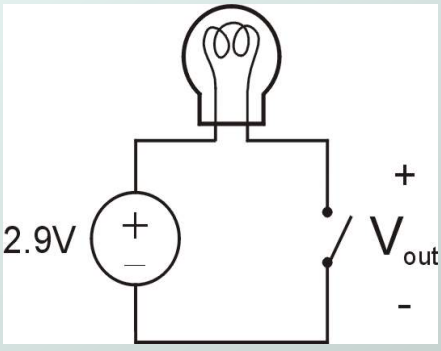
Devices

Transistor: Building Block of Computers

- Microprocessors contain billions of transistors
  - **Intel Pentium 4 (2000):** 48 million
  - **IBM PowerPC 750FX (2002):** 38 million
  - **IBM/Apple PowerPC G5 (2003):** 58 million

  Logically, each transistor acts as a switch
- Combined to implement logic functions (gates)
  - AND, OR, NOT
- Combined to build higher-level structures
  - Adder, multiplexer, decoder, register, memory, …
- Combined to build processor
  - LC-3

Simple Switch Circuit

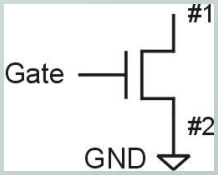


- Switch **open**:
  - Open circuit, no current
  - Light is **off**
  - V_{out} is **+2.9V**
- Switch **closed**:
  - Short circuit across switch, current flows
  - Light is **on**
  - V_{out} is **0V**

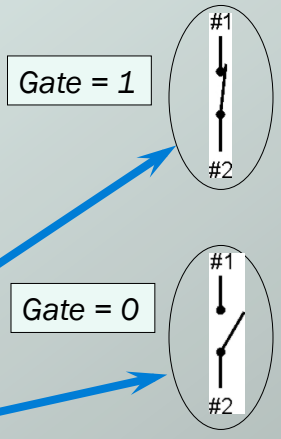
Switch-based circuits can easily represent two values: on/off, open/closed, voltage/no voltage.

n-type Transistor

- A transistor is an **electrically** controlled switch
- n-type
  - when Gate has positive voltage, short circuit between #1 and #2 (switch closed)
  - when Gate has zero voltage, open circuit between #1 and #2 (switch open)

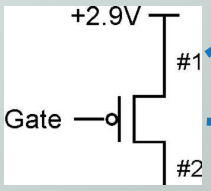


Terminal #2 is connected to GND (0V).

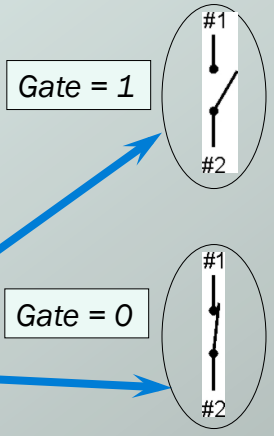


p-type Transistor

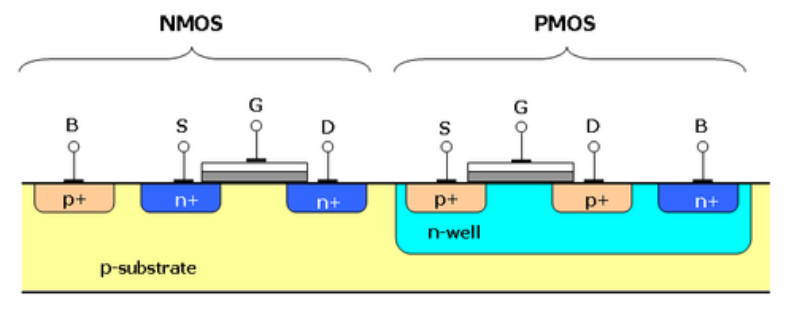
- p-type is *complementary* to n-type
  - when Gate has positive voltage, open circuit between #1 and #2 (switch open)
  - when Gate has zero voltage, short circuit between #1 and #2 (switch closed)



Terminal #1 is connected to +2.9V.



Physical Transistor



http://en.wikipedia.org/wiki/CMOS

Logic Gates

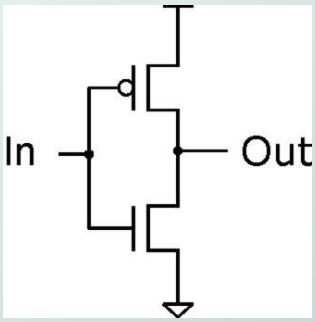
- Use switch behavior of MOS transistors to implement logical functions: AND, OR, NOT.
- Digital symbols:
  - recall that we assign a range of analog voltages to each digital (logic) symbol

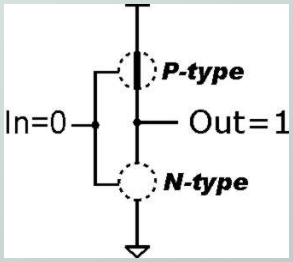
  - assignment of voltage ranges depends on electrical properties of transistors being used
    - typical values for "1": +5V, +3.3V, +2.9V
    - from now on we'll use +2.9V

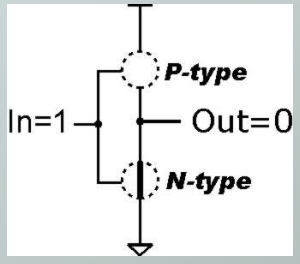
CMOS Circuit

- Complementary MOS
- Uses both n-type and p-type MOS transistors
  - p-type
    - Attached to + voltage
    - Pulls output voltage UP when input is zero
  - n-type
    - Attached to GND
    - Pulls output voltage DOWN when input is one
- **For all inputs, make sure that output is either connected to GND or to +, but not both!**

Inverter (NOT Gate)





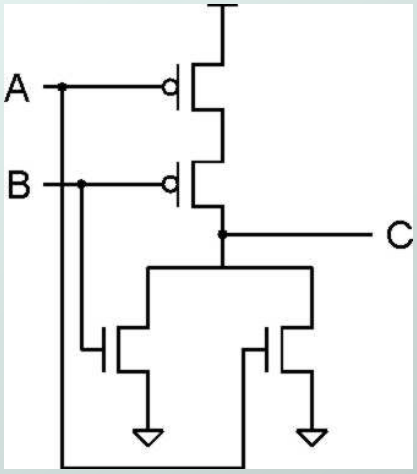


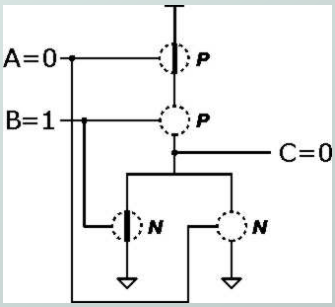
In	Out
0 V	2.9 V
2.9 V	0 V

In	Out
0	1
1	0

Truth table

NOR Gate



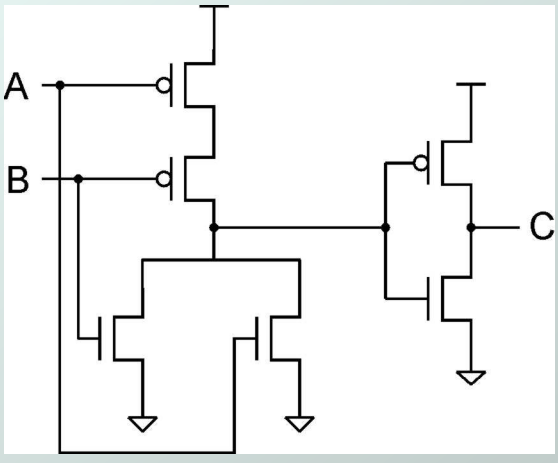


A	B	C
0	0	1
0	1	0
1	0	0
1	1	0

Truth table

Note: Serial structure on top, parallel on bottom.

OR Gate

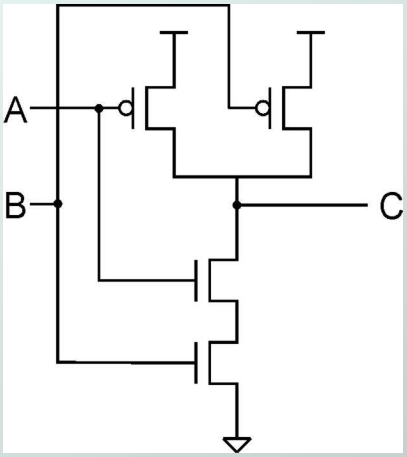


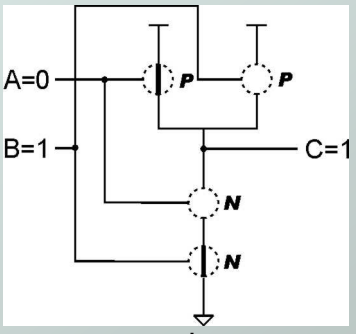
A	B	C
0	0	0
0	1	1
1	0	1
1	1	1

Truth table

Add inverter to NOR.

NAND Gate (AND-NOT)



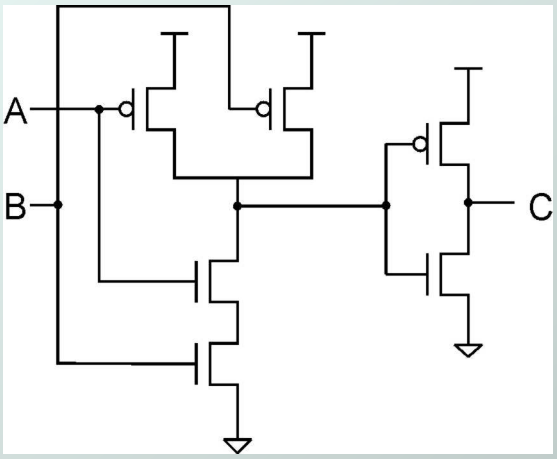


Truth table

A	B	C
0	0	1
0	1	1
1	0	1
1	1	0

Note: Parallel structure on top, serial on bottom.

AND Gate



A	B	C
0	0	0
0	1	0
1	0	0
1	1	1

Truth table

Add inverter to NAND.

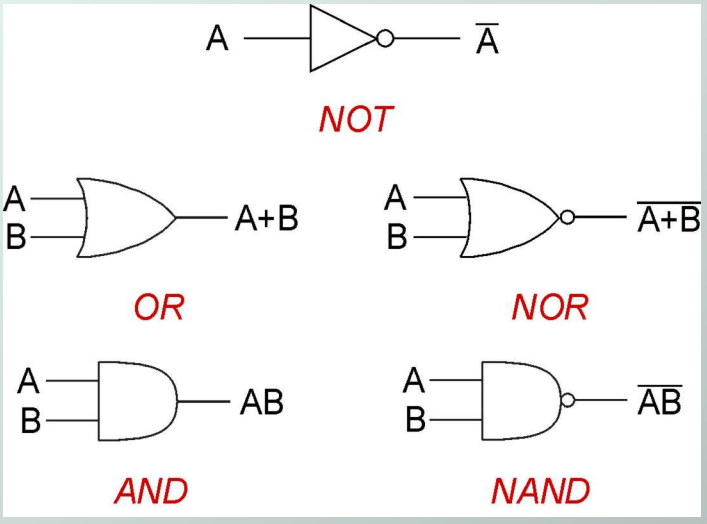
Series Parallel Circuits

- All transistors in an S-P circuit are of the same type (n or p)
- An SP circuit is constructed with the following rules
  - A wire is an SP circuit
  - A transistor is an SP circuit
  - Two or more SP circuits connected in **series** is an SP circuit
  - Two or more SP circuits connected in **parallel** is an SP circuit

Complement of an SP Circuit

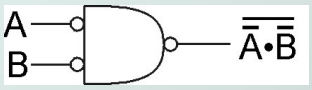
- Complement of an SP circuit consisting of a single transistor is the complementary type transistor (n becomes p and vice versa)
- To complement sub-circuits in series
  - Complement the sub-circuits
  - Connect them in parallel
- To complement sub-circuits in parallel
  - Complement the sub-circuits
  - Connect them in series
- Similar to De Morgan's Laws

Basic Logic Gates



DeMorgan's Law

- Converting AND to OR (with some help from NOT)
- Consider the following gate:



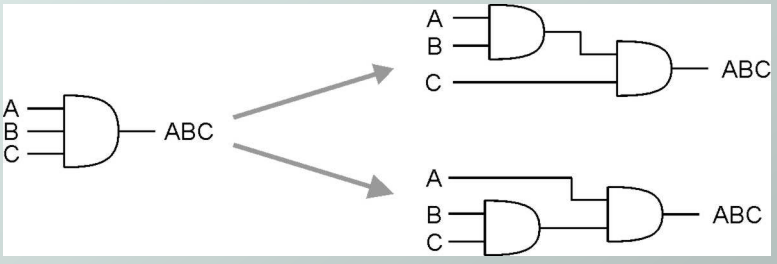
A	B	$\overline{A}$	$\overline{B}$	$\overline{A} \cdot \overline{B}$	$\overline{\overline{A} \cdot \overline{B}}$
0	0	1	1	1	0
0	1	1	0	0	1
1	0	0	1	0	1
1	1	0	0	0	1

Same as A OR B!

To convert AND to OR (or vice versa), invert inputs and output.

More than 2 Inputs?

- AND/OR can take any number of inputs.
  - AND = 1 if all inputs are 1.
  - OR = 1 if any input is 1.
  - Similar for NAND/NOR.
- Can implement with multiple two-input gates, or with single CMOS circuit.



Summary

- MOS transistors are used as switches to implement logic functions.
  - n-type: connect to GND, turn on (1) to pull down to 0
  - p-type: connect to +2.9V, turn on (0) to pull up to 1
- Basic gates: NOT, NOR, NAND
  - Logic functions are usually expressed with AND, OR, and NOT
- DeMorgan's Law
  - Convert AND to OR (and vice versa) by inverting inputs and output

Building Functions from Logic Gates

- ***Combinational Logic Circuit***
  - output depends only on the current inputs
  - stateless
- ***Sequential Logic Circuit***
  - output depends on the sequence of inputs (past and present)
  - stores information (state) from past inputs
- We'll
  - first look at some useful combinational circuits,
  - then show their limitations,
  - and how how to overcome them with sequential circuits

Announcements

Perficient will be in the CS building conference room, 2nd floor on Friday February 3 from 9:00 am – 12:00 noon critiquing resumes. Students are welcome to drop by during this time with a hard copy of their resume for review. They are also recruiting for full-time positions in consulting so this is also an opportunity for students to meet with this employer.

Many students still have a zero on Quiz 0. The score that you got will not be entered until you see Sanjay during office hours. If you missed doing it, you can still earn full credit.

Print it off the schedule page, do it and see Sanjay during office hours.