| Computer Science 210 s1 Computer Systems 1 |
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| Lecture Notes |
| Chapter 3 |
| Digital Logic Structures |
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## Transistor: Building Block of Computers

- Microprocessors contain millions of transistors $\qquad$
IBM PowerPC 750FX (2002): 38 million
IBM/Apple PowerPC G5 (2003): 58 million
Intel Core ${ }^{\text {™ }}$ P Processor (2008): 410 million
Intel@ Xeon Phi" coprocessor 5110 P (2012): 5 billion $\qquad$
-Logically, each transistor acts as a switch
-Combined to implement logic functions $\qquad$
- AND, OR, NOT
-Combined to build higher-level structures - Adder, multiplexer, decoder, register, ..
-Combined to build processor
- LC-3

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## Simple Switch Circuit



Switch-based circuits can easily represent two states: on/off, open/closed, voltage/no voltage.
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## n-type MOS Transistor

-MOS = Metal Oxide Semiconductor

- two types: n-type and p-type
-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 must be connected to GND (OV).


## p-type MOS Transistor

- p -type is complementary to n -type $\qquad$
- 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)

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$\qquad$
Terminal \#1 must be
connected to +2.9 V



## Logic Gates

Use switch behavior of MOS transistors to implement logical functions: AND, OR, NOT.

## Digital symbols: <br> - recall that we assign a range of analog voltages to each digital (logic) symbol


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


## CMOS Circuit

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Complementary MOS $\qquad$
Uses both n-type and p-type MOS transistors

- p-type
- Attached to + voltage
- n-type
$\qquad$
- Attached to GND

For all inputs, make sure that output is either connected to GND or to + but not both!
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Inverter (NOT Gate)

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NAND Gate (AND-NOT)


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Basic Logic Gates $\qquad$

$\qquad$
NOT $\qquad$


OR

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## More than 2 Inputs?

$\qquad$
AND/OR can take any number of inputs.

- AND $=1$ if all inputs are 1 .
$\qquad$
$-\mathrm{OR}=1$ if any input is 1 .
- Similar for NAND/NOR $\qquad$
Can implement with multiple two-input gates, or with single CMOS circuit. $\qquad$

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## DeMorgan's Law

Converting AND to OR (with some help from NOT)
Consider the following gate: $\qquad$
$B-\int-\overline{\bar{A}} \cdot \bar{B}$
Shows that you can write an expression like "not (A or B)" as "(not A) and $(\operatorname{not} B)$ ". Similarly, "not (A or B)" can be written as "(not A) and (not B)"

| $A$ | $B$ | $\bar{A}$ | $\bar{B}$ | $\bar{A} \cdot \bar{B}$ | $\overline{\bar{A} \cdot \bar{B}}$ |
| :---: | :---: | :---: | :---: | :---: | :---: |
| 0 | 0 | 1 | 1 | 1 | 0 |
| 0 | 1 | 1 | 0 | 0 | 1 |
| 1 | 0 | 0 | 1 | 0 | 1 |
| 1 | 1 | 0 | 0 | 0 | 1 |

Watch this video
http://youtu.be/tKnS3s8fOu4
Therefore, you can implement
any truth table using only
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NAND (or NOR) gate

## Summary

MOS transistors are used as switches to implement logic functions.

- n-type: connect to GND, turn on (with 1) to pull down to o
- p-type: connect to +2.9 V , turn on (with 0 ) to pull up to 1

Basic gates: NOT, NOR, NAND

- Logic functions are usually expressed with AND, OR, and - Logic

DeMorgan's Law

- Convert AND to OR (and vice versa)
by inverting inputs and output
- Means we may only need to use NOT and AND to implement any logic circuit

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