



Digital Design

Chapter 1: Introduction

Slides to accompany the textbook *Digital Design*, First Edition,
by Frank Vahid, John Wiley and Sons Publishers, 2007.
<http://www.ddvahid.com>

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Some Useful Information

- Where can I get help
 - www.cse.nd.edu/courses/cse20221/www/
 - TA's during lab time: M,T,W,T,F 2:20 – 5:20
 - email yoders1@nd.edu
 - 381 Fitzpatrick or 216 Stinson-Remick on Tues. & Thurs.
- What will make the lab easier
 - If there is a video for the lab, view it before you come to lab
 - download the Xilinx software for lab on your personal computer
 - do the lab work before you come to lab

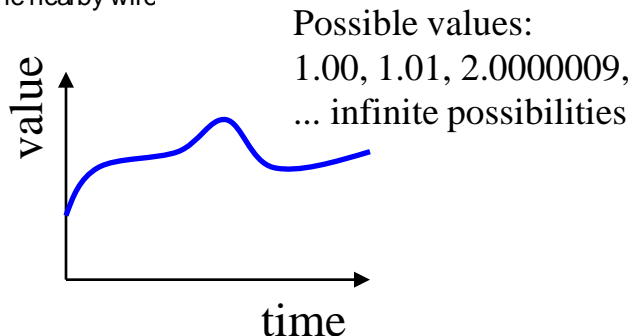
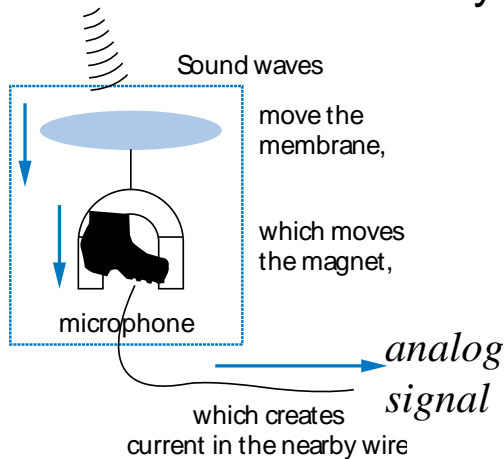
Questions?

- Is there lab this week? No
- Are there copies of the lecture? Yes, on course web site.
- When are the lectures updated? 30 minutes before class.
- Do I have to come to my assigned lab time? Yes
- Can I demo my lab work at another lab time? Yes
- Can I get late homework or lab work graded? No
- Is digital logic design really all that important? Only if you want things like an iPhone, iPod, computer, CD's or CD players ...
- Is this course difficult. No
- Is this course fun? Absolutely!

What Does "Digital" Mean?

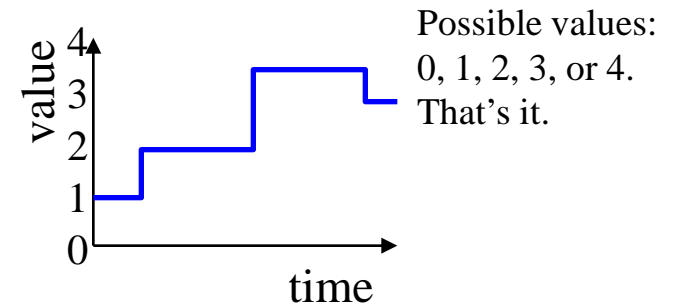
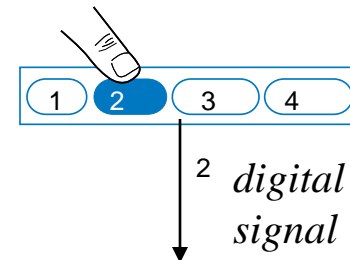
- Analog signal

- Infinite possible values
 - Ex: voltage on a wire created by microphone



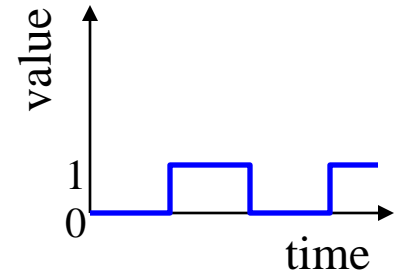
- Digital signal

- Finite possible values
 - Ex: button pressed on a keypad

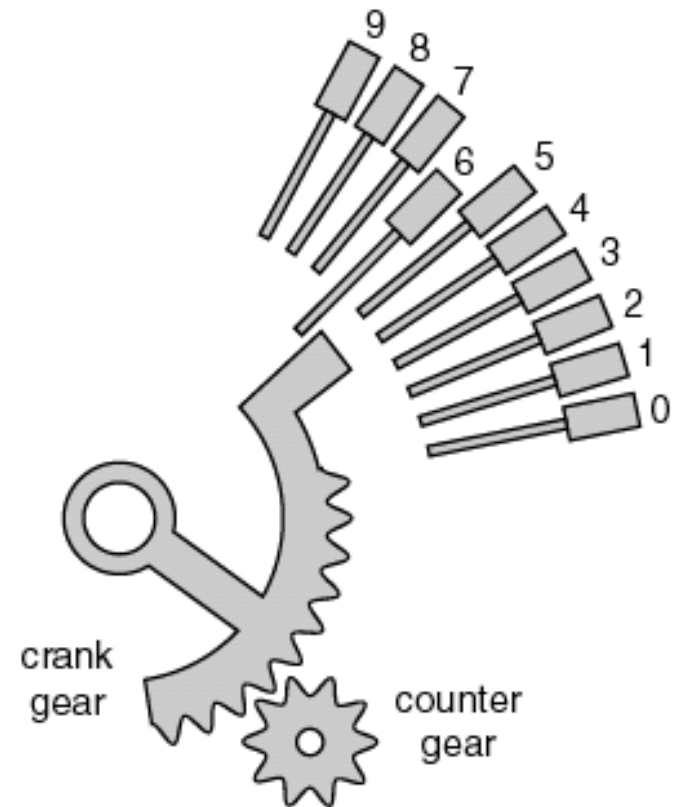
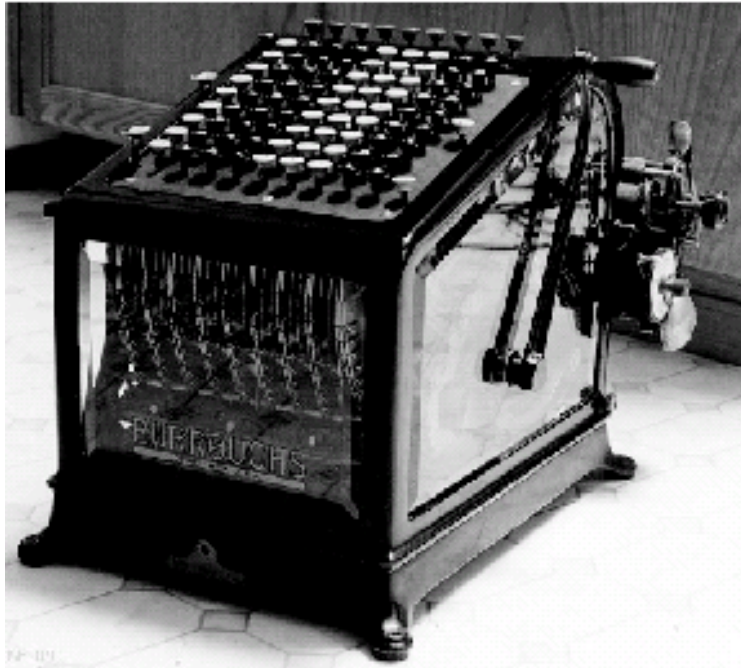


Digital Signals with Only Two Values: Binary

- **Binary** digital signal -- only *two* possible values
 - Typically represented as **0** and **1**
 - One *binary digit* is a **bit**
 - We'll only consider *binary* digital signals
 - Binary is popular because
 - Transistors, the basic digital electric component, operate using *two* voltages (its like a switch: on or off)
 - Storing/transmitting one of *two* values is easier than an analog signal with a continuous range of values

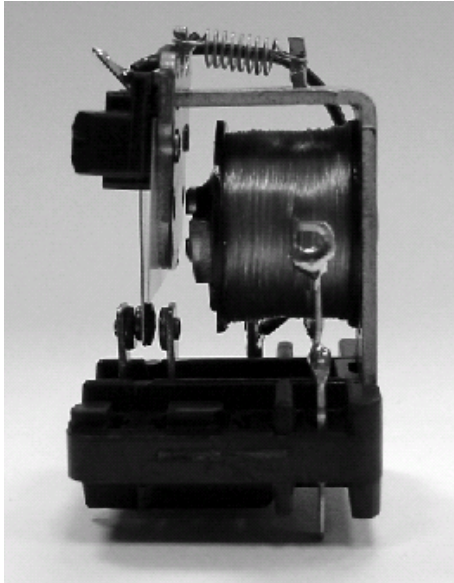


Burroughs Adding Machine

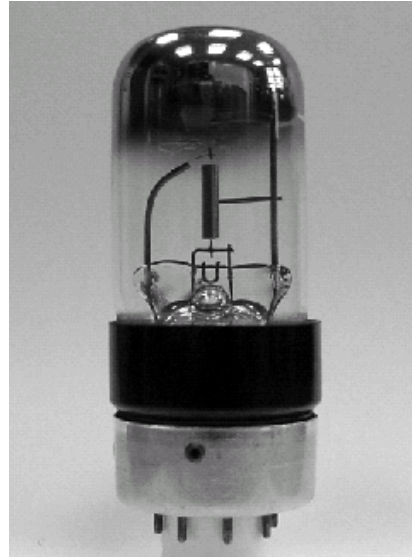


Evolution of Switches

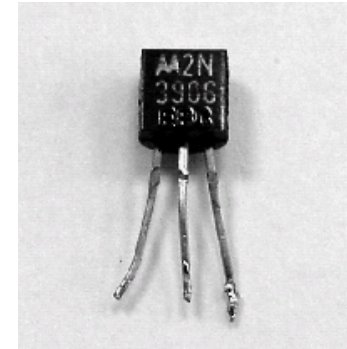
Relay



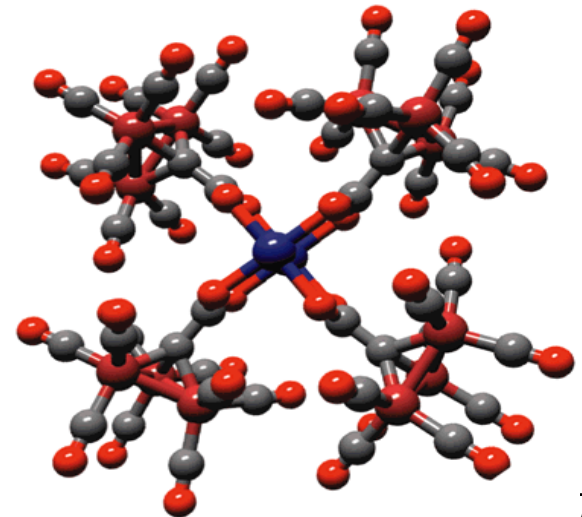
Vacuum Tube



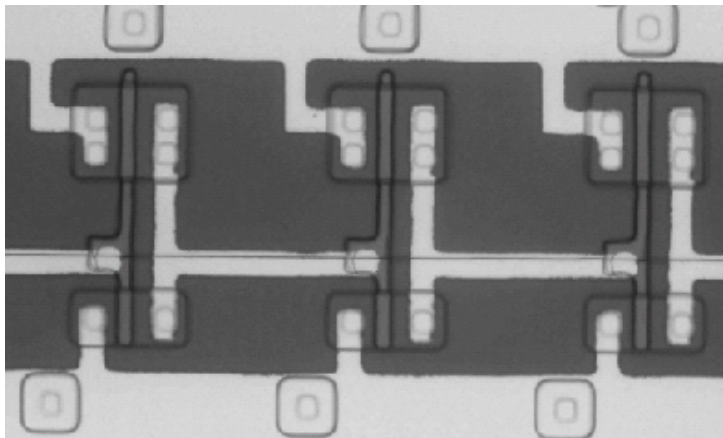
Transistor



Molecular



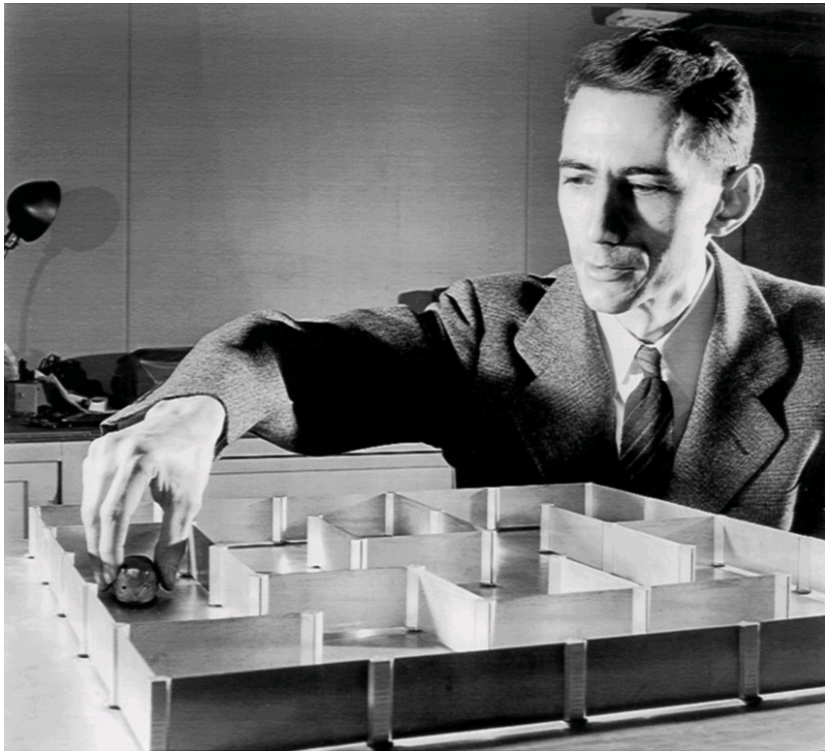
Integrated
Circuit



Size Matters

- You can fit 1.5 billion modern transistors inside a single vacuum tube of the ENIAC
- **April 1972**
 - Name of Processor: 8008
Clock speed: 200 kilohertz
Number of transistors: 3,500
- **Feb 2004**
 - Name of Processor: Pentium 4
Clock speed: 3.4 GHz
Number of transistors: 55 million
- **July 2006**
 - Name of Processor: Core 2 Duo
Level 2 cache 4 MB
Number of transistors: 253 million

Claude Shannon



MASS. INST. TECH.
DEC 20 1940
LIBRARY

A SYMBOLIC ANALYSIS
OF
RELAY AND SWITCHING CIRCUITS

by
Claude Elwood Shannon
B.S., University of Michigan
1936

Submitted in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
from the
Massachusetts Institute of Technology
1940

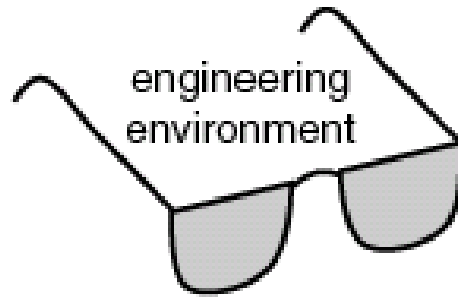
Signature of Author _____
Department of Electrical Engineering, August 10, 1937

Signature of Professor
In Charge of Research _____

Signature of Chairman of Department
Committee on Graduate Students _____



Perspectives on a Computer



Logical or Symbolic View

- Mathematical know-how

Physical View

- Implementation technology

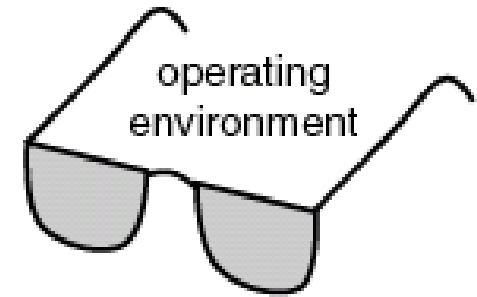
to process
information

has purpose

computing
machine

has form

to be
determined



Logical or Symbolic View

- Functions it can perform

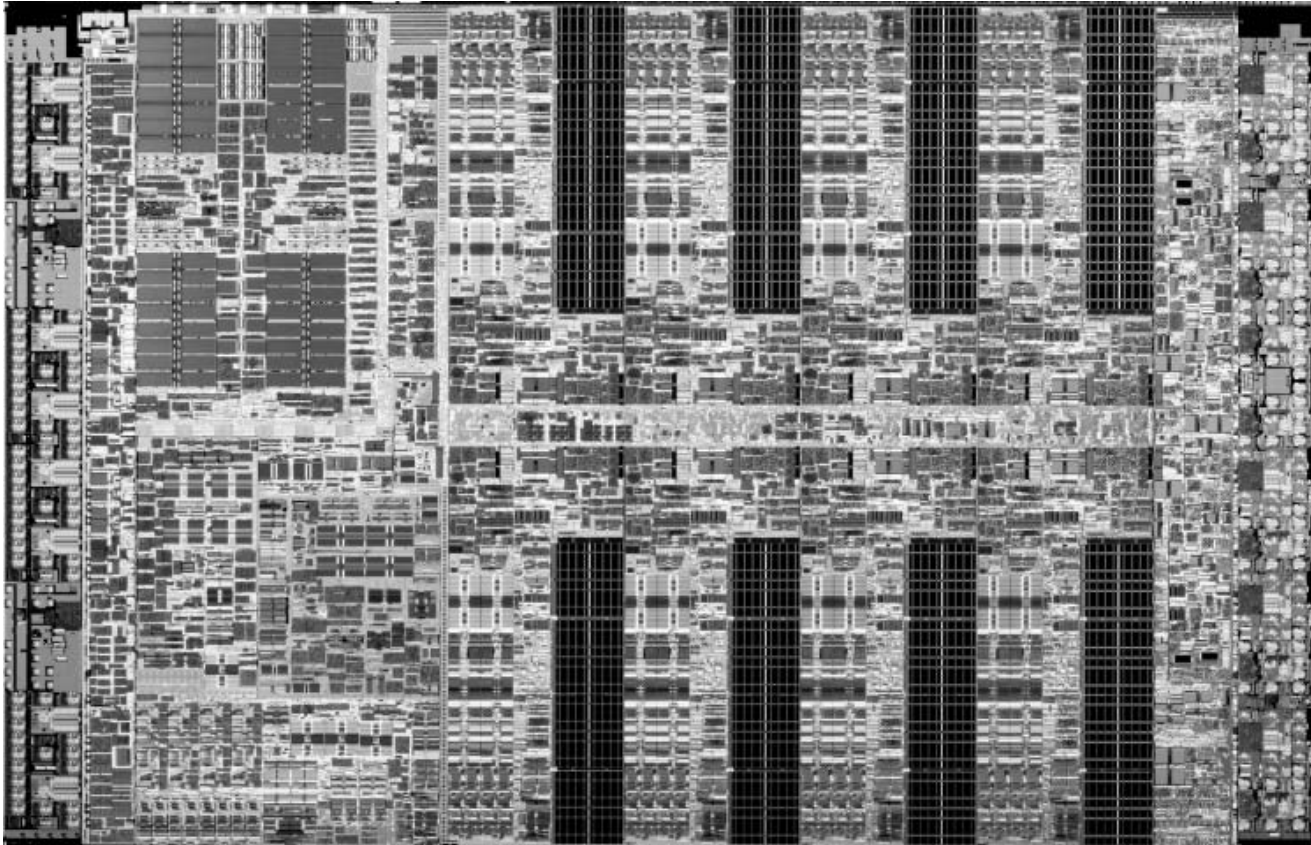
Physical View

- Physical properties (e.g size, speed, power)

Dissecting a PlayStation 3

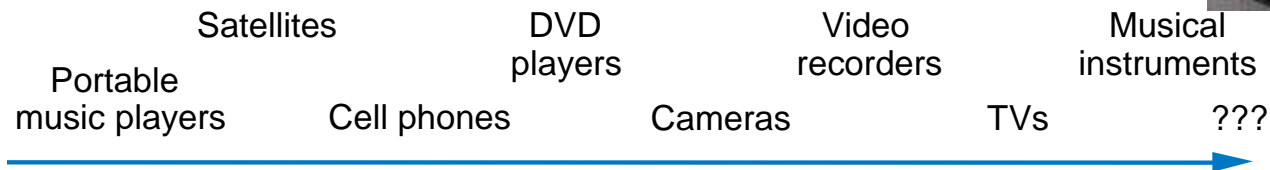
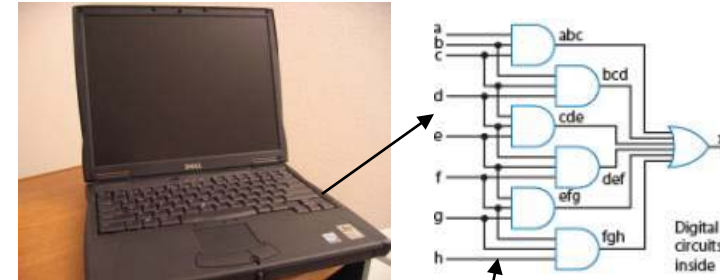


Cell Broadband Engine



Why Study Digital Design?

- Look “under the hood” of computers
 - Solid understanding --> confidence, insight, even better programmer when aware of hardware resource issues
- Electronic devices becoming digital
 - Enabled by shrinking and more capable chips
 - Enables:
 - Better devices: Better sound recorders, cameras, cars, cell phones, medical devices, ...
 - New devices: Video games, PDAs, ...
 - Known as “embedded systems”
 - Thousands of new devices every year
 - Designers needed: Potential career direction



Example of Digitization Benefit

- Analog signal (e.g., audio) may lose quality
 - Voltage levels not saved/copied/transmitted perfectly
- Digitized version enables near-perfect save/cpy/trn.
 - “Sample” voltage at particular rate, save sample using bit encoding
 - Voltage levels still not kept perfectly
 - But we can distinguish 0s from 1s

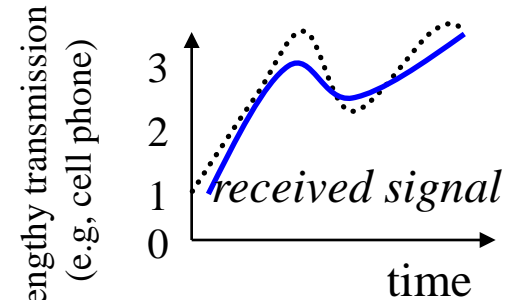
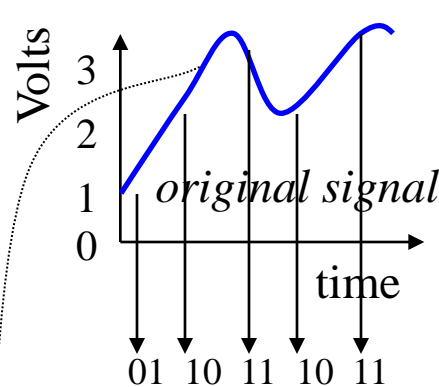
Let bit encoding be:

1 V: “01”

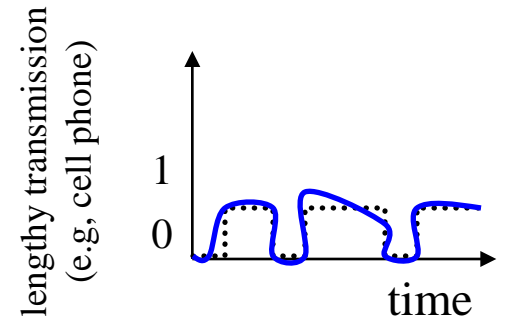
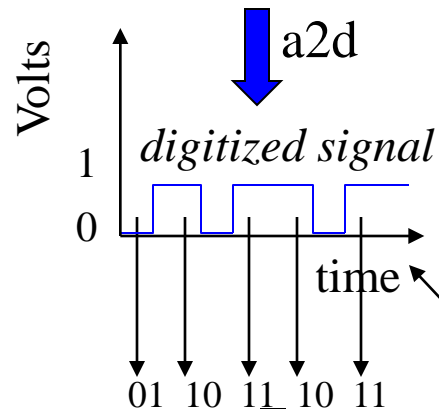
2 V: “10”

3 V: “11”

Digitized signal not perfect re-creation, but higher sampling rate and more bits per encoding brings closer.

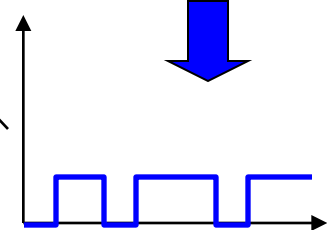
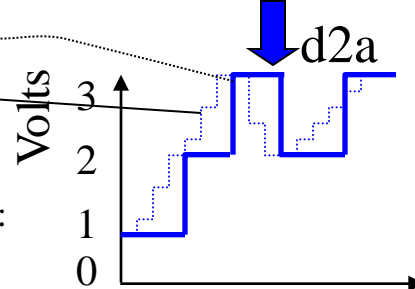


How fix -- higher, lower, ?



Can fix -- easily distinguish 0s and 1s, restore

same



time 14



Digitized Audio: Compression Benefit

- Digitized audio can be compressed
 - e.g., MP3s
 - A CD can hold about 20 songs uncompressed, but about 200 compressed
- Compression also done on digitized pictures (jpeg), movies (mpeg), and more
- Digitization has many other benefits too

Example compression scheme:

00 --> 0000000000

01 --> 1111111111

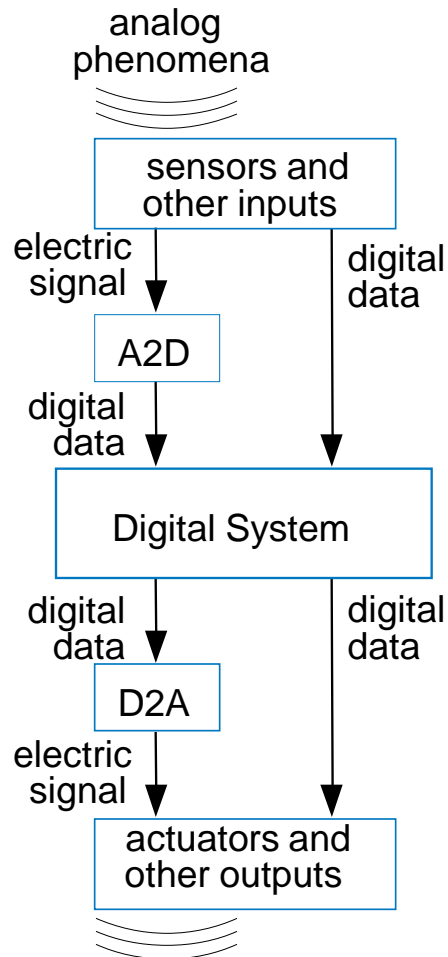
1X --> X

0000000000 0000000000 0000001111 1111111111

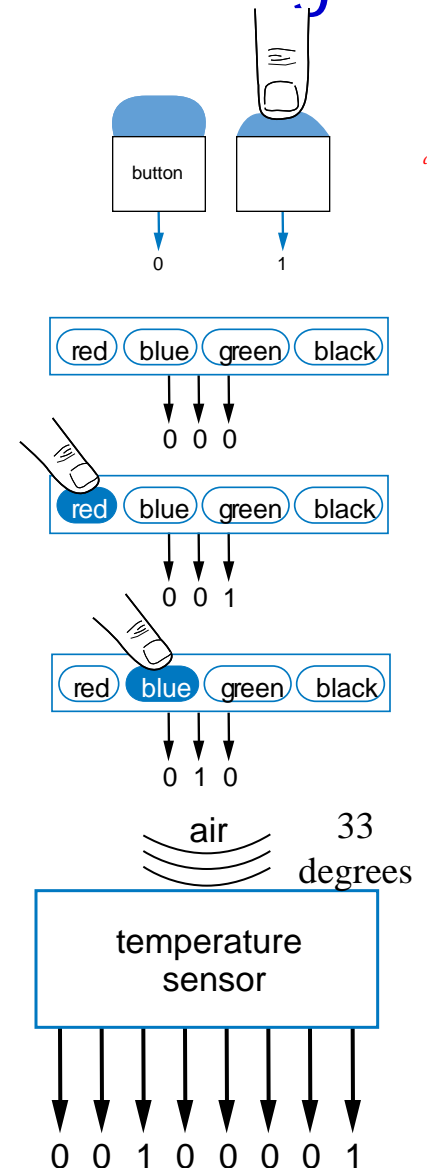
00 00 10000001111 01



How Do We Encode Data as Binary for Our Digital System?



- Some inputs inherently binary
 - Button: not pressed (0), pressed (1)
- Some inputs inherently digital
 - Just need encoding in binary
 - e.g., multi-button input: encode red=001, blue=010, ...
- Some inputs analog
 - Need analog-to-digital conversion
 - As done in earlier slide -- sample and encode with bits



How to Encode Text: ASCII, Unicode

- ASCII: 7- (or 8-) bit encoding of each letter, number, or symbol
- Unicode: Increasingly popular 16-bit bit encoding
 - Encodes characters from various world languages

Symbol	Encoding
R	1010010
S	1010011
T	1010100
L	1001100
N	1001110
E	1000101
0	0110000
.	0101110
<tab>	0001001

Symbol	Encoding
r	1110010
s	1110011
t	1110100
l	1101100
n	1101110
e	1100101
9	0111001
!	0100001
<space>	0100000

Question:

What does this ASCII bit sequence represent?

1010010 1000101 1010011 1010100

↓ ↓ ↓ ↓
R E S T

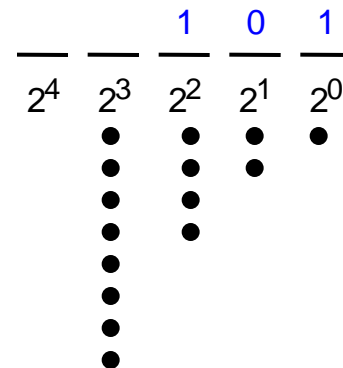
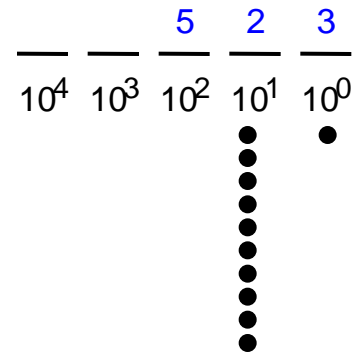
a

Note: small red “a” (*a*) in a slide indicates animation ←



How to Encode Numbers: Binary Numbers

- Each position represents a quantity; symbol in position means how many of that quantity
 - Base ten (**decimal**)
 - Ten symbols: 0, 1, 2, ..., 8, and 9
 - More than 9 -- next position
 - So each position power of 10
 - Nothing special about base 10 -- used because we have 10 fingers
 - Base two (**binary**)
 - Two symbols: 0 and 1
 - More than 1 -- next position
 - So each position power of 2



Q: How much?

● + ● = ●
 ● ● ●
 ● ● ●
 ● ● ●
 4 + 1 = 5



How to Encode Numbers: Binary Numbers

- Working with binary numbers
 - In base ten, helps to know powers of 10
 - one, ten, hundred, thousand, ten thousand, ...
 - In base two, helps to know powers of 2
 - one, two, four, eight, sixteen, thirty two, sixty four, one hundred twenty eight
 - (Note: unlike base ten, we don't have common names, like "thousand," for each position in base ten -- so we use the base ten name)

2^9	2^8	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
512	256	128	64	32	16	8	4	2	1

- Q: count up by powers of two

512 256 128 64 32 16 8 4 2 1 a



Converting from Decimal to Binary Numbers: Subtraction Method (Easy for Humans)

- Goal
 - Get the binary weights to add up to the decimal quantity
 - Work from left to right
 - (Right to left – may fill in 1s that shouldn't have been there – try it).

Desired decimal number: **12**

<u>32</u>	<u>16</u>	<u>8</u>	<u>4</u>	<u>2</u>	<u>1</u>	
1						=32
32	16	8	4	2	1	too much

<u>32</u>	<u>16</u>	<u>8</u>	<u>4</u>	<u>2</u>	<u>1</u>	
0	1					=16
32	16	8	4	2	1	too much

<u>32</u>	<u>16</u>	<u>8</u>	<u>4</u>	<u>2</u>	<u>1</u>	
0	0	1				=8
32	16	8	4	2	1	ok, keep going

<u>32</u>	<u>16</u>	<u>8</u>	<u>4</u>	<u>2</u>	<u>1</u>	
0	0	1	1			=8+4=12
32	16	8	4	2	1	DONE

<u>32</u>	<u>16</u>	<u>8</u>	<u>4</u>	<u>2</u>	<u>1</u>	
0	0	1	1	0	0	answer
32	16	8	4	2	1	



Converting from Decimal to Binary Numbers: Subtraction Method (Easy for Humans)

- Subtraction method
 - To make the job easier (especially for big numbers), we can just subtract a selected binary weight from the (remaining) quantity
 - Then, we have a new remaining quantity, and we start again (from the present binary position)
 - Stop when remaining quantity is 0

Remaining quantity: 12

<u>32</u>	<u>16</u>	<u>8</u>	<u>4</u>	<u>2</u>	<u>1</u>	
<u>1</u>						32 is too much
<u>32</u>	<u>16</u>	<u>8</u>	<u>4</u>	<u>2</u>	<u>1</u>	

<u>0</u>	<u>1</u>					16 is too much
<u>32</u>	<u>16</u>	<u>8</u>	<u>4</u>	<u>2</u>	<u>1</u>	

<u>0</u>	<u>0</u>	<u>1</u>				<u>12</u> - 8 = <u>4</u>
<u>32</u>	<u>16</u>	<u>8</u>	<u>4</u>	<u>2</u>	<u>1</u>	

<u>0</u>	<u>0</u>	<u>1</u>	<u>1</u>			<u>4</u> - 4 = <u>0</u> DONE
<u>32</u>	<u>16</u>	<u>8</u>	<u>4</u>	<u>2</u>	<u>1</u>	

<u>0</u>	<u>0</u>	<u>1</u>	<u>1</u>	<u>0</u>	<u>0</u>	answer
<u>32</u>	<u>16</u>	<u>8</u>	<u>4</u>	<u>2</u>	<u>1</u>	



Converting from Decimal to Binary Numbers: Subtraction Method Example

- Q: Convert the number “23” from decimal to binary

A: Remaining quantity

23

Binary Number

$\frac{0}{32}$ $\frac{0}{16}$ $\frac{0}{8}$ $\frac{0}{4}$ $\frac{0}{2}$ $\frac{0}{1}$

$\frac{23}{-16}$
7

$\frac{0}{32}$ $\frac{1}{16}$ $\frac{0}{8}$ $\frac{0}{4}$ $\frac{0}{2}$ $\frac{0}{1}$

$\frac{7}{-4}$
3

$\frac{0}{32}$ $\frac{1}{16}$ $\frac{0}{8}$ $\frac{1}{4}$ $\frac{0}{2}$ $\frac{0}{1}$
8 is more than 7, can't use

$\frac{4}{-2}$
1

$\frac{0}{32}$ $\frac{1}{16}$ $\frac{0}{8}$ $\frac{1}{4}$ $\frac{1}{2}$ $\frac{0}{1}$

$\frac{1}{-1}$
0

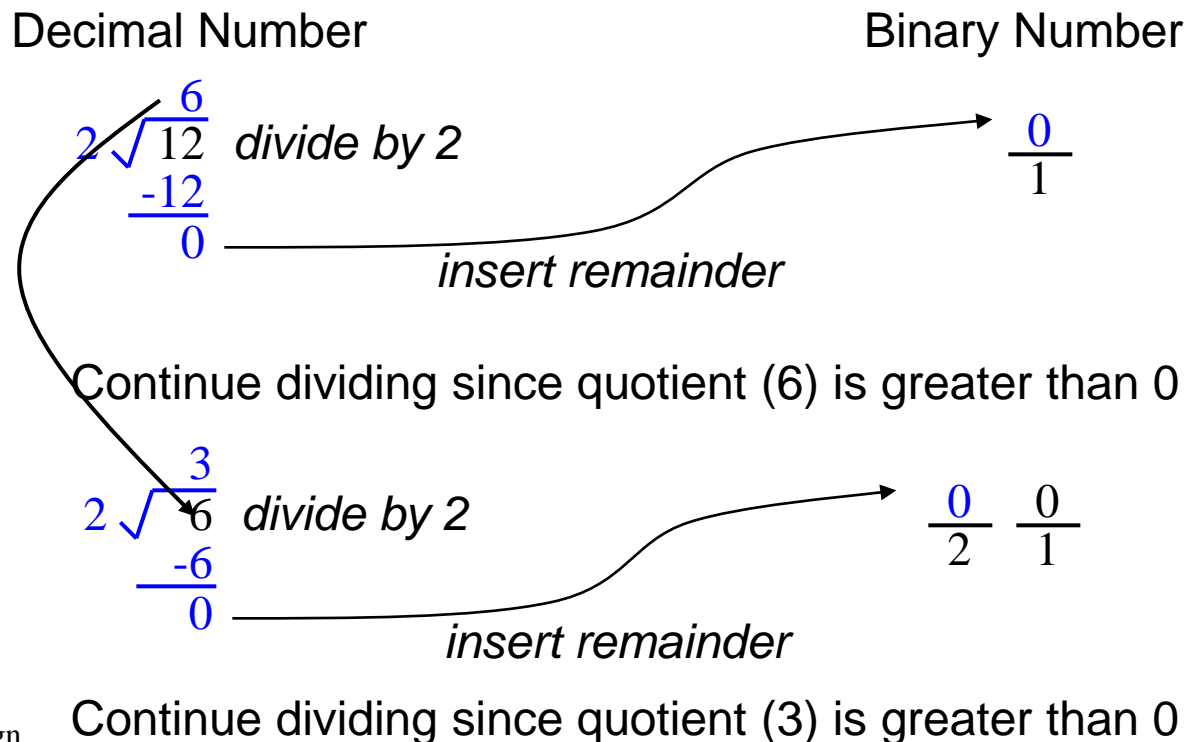
$\frac{0}{32}$ $\frac{1}{16}$ $\frac{0}{8}$ $\frac{1}{4}$ $\frac{1}{2}$ $\frac{1}{1}$

Done! 23 in decimal is 10111 in binary.



Converting from Decimal to Binary Numbers: Division Method (Good for Computers)

- Divide decimal number by 2 and insert remainder into new binary number.
 - Continue dividing quotient by 2 until the quotient is 0.
- Example: Convert decimal number 12 to binary



Converting from Decimal to Binary Numbers: Division Method (Good for Computers)

- Example: Convert decimal number 12 to binary (continued)

Decimal Number

Binary Number

$$\begin{array}{r} 2 \overline{) 12} \\ \underline{-2} \\ 10 \\ \underline{-10} \\ 0 \end{array} \quad \begin{array}{l} \text{divide by 2} \\ \text{insert remainder} \end{array} \quad \begin{array}{l} \frac{1}{4} \quad \frac{0}{2} \quad \frac{0}{1} \end{array}$$

Continue dividing since quotient (1) is greater than 0

$$\begin{array}{r} 2 \overline{) 6} \\ \underline{-0} \\ 6 \\ \underline{-6} \\ 0 \end{array} \quad \begin{array}{l} \text{divide by 2} \\ \text{insert remainder} \end{array} \quad \begin{array}{l} \frac{1}{8} \quad \frac{1}{4} \quad \frac{0}{2} \quad \frac{0}{1} \end{array}$$

Since quotient is 0, we can conclude that 12 is 1100 in binary



Dibble-Dabble Algorithm

2|12 $r = 0$ least significant bit

2|6 $r = 0$

2|3 $r = 1$

2|1 $r = 1$ most significant bit

$$12_{10} = 1100_2$$

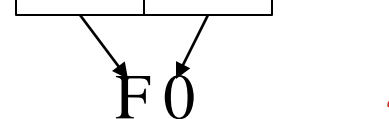
Base Sixteen: Another Base Sometimes Used by Digital Designers

$\frac{\quad}{16^4}$	$\frac{\quad}{16^3}$	$\frac{8}{16^2}$	$\frac{A}{16^1}$	$\frac{F}{16^0}$
		8	A	F
		↓	↓	↓
		1000	1010	1111

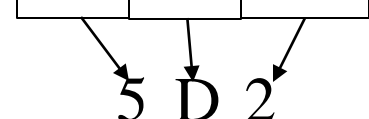
hex	binary	hex	binary
0	0000	8	1000
1	0001	9	1001
2	0010	A	1010
3	0011	B	1011
4	0100	C	1100
5	0101	D	1101
6	0110	E	1110
7	0111	F	1111

- Nice because each position represents four base two positions
 - Used as compact means to write binary numbers
- Known as *hexadecimal*, or just *hex*

Q: Write 11110000 in hex

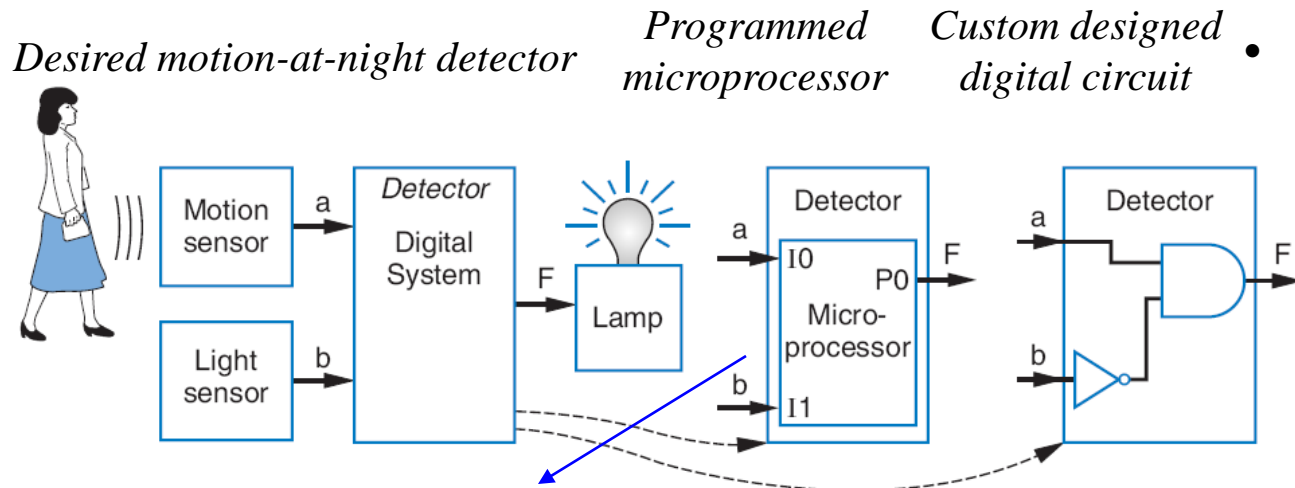


Q: Write 10111010010 in hex



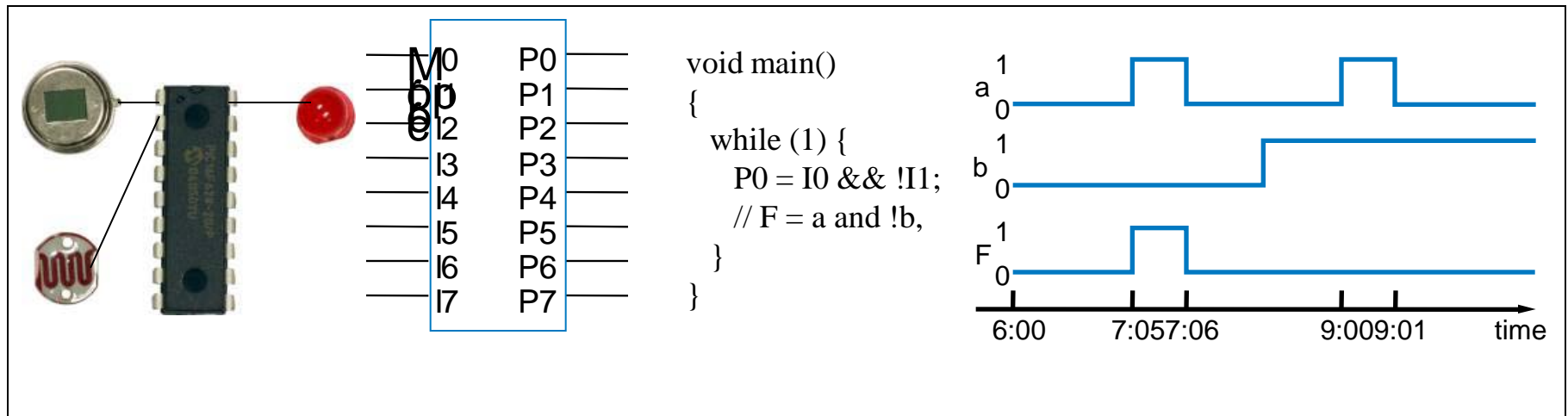
Implementing Digital Systems: Programming

Microprocessors Vs. Designing Digital Circuits



• Microprocessors a common choice to implement a digital system

- Easy to program
- Cheap (as low as \$1)
- Available now

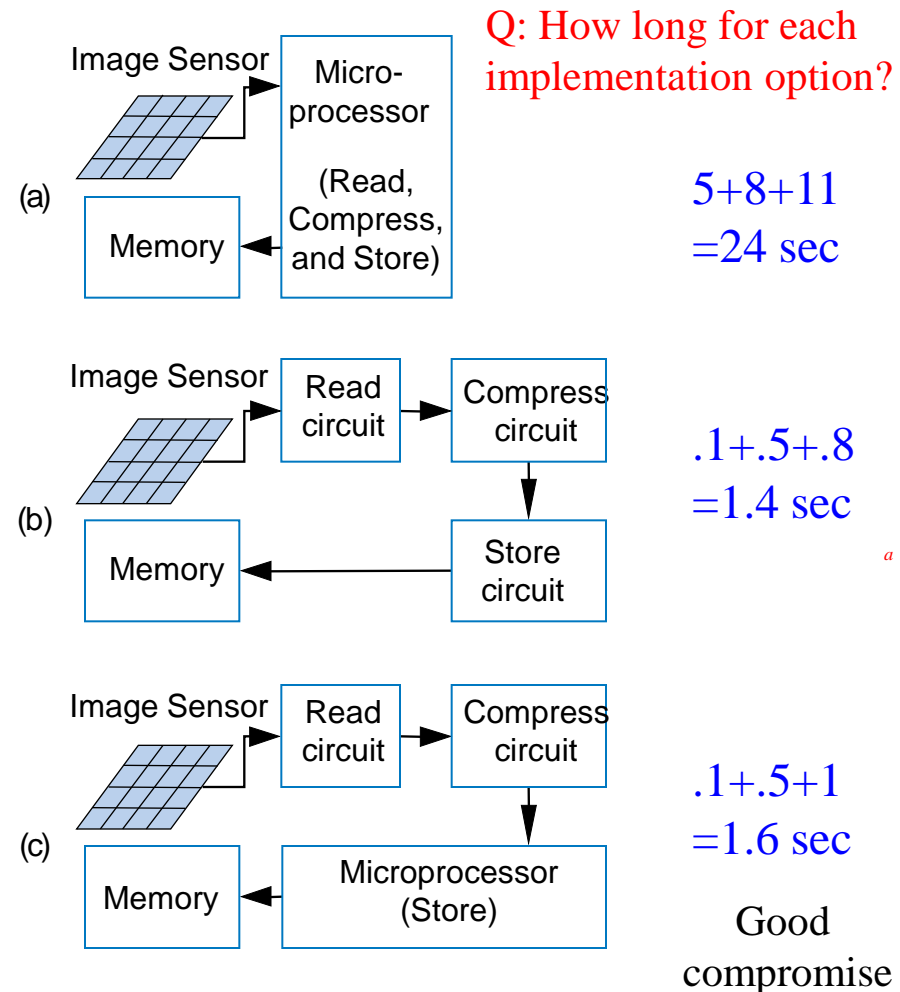


Digital Design: When Microprocessors Aren't Good Enough

- With microprocessors so easy, cheap, and available, why design a digital circuit?
 - Microprocessor may be too slow
 - Or too big, power hungry, or costly

Sample digital camera task execution times (in seconds) on a microprocessor versus a digital circuit:

Task	Microprocessor	Custom Digital Circuit
Read	5	0.1
Compress	8	0.5
Store	1	0.8



Chapter Summary

- Digital systems surround us
 - Inside computers
 - Inside huge variety of other electronic devices (embedded systems)
- Digital systems use 0s and 1s
 - Encoding analog signals to digital can provide many benefits
 - e.g., audio -- higher-quality storage/transmission, compression, etc.
 - Encoding integers as 0s and 1s: Binary numbers
- Microprocessors (themselves digital) can implement many digital systems easily and inexpensively
 - But often not good enough -- need custom digital circuits



Homework

- Chapter 1: 1, 6, 9, 12, 16, 21
- Due date: Thursday, January 21