



Digital Design

Chapter 1: Introduction

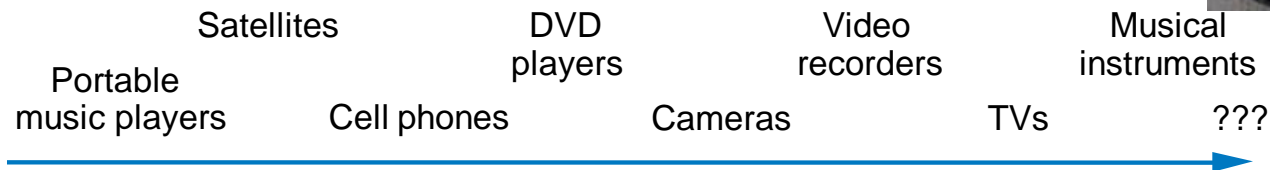
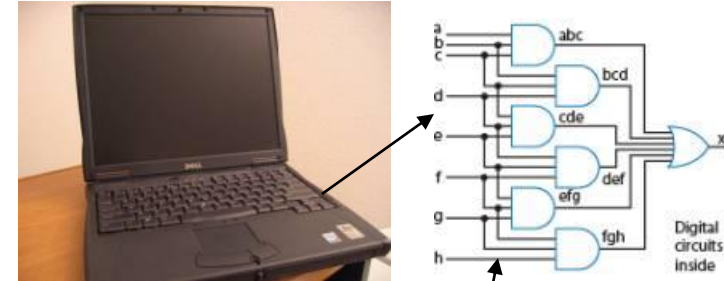
Slides to accompany the textbook *Digital Design*, First Edition,
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Why Study Digital Design?

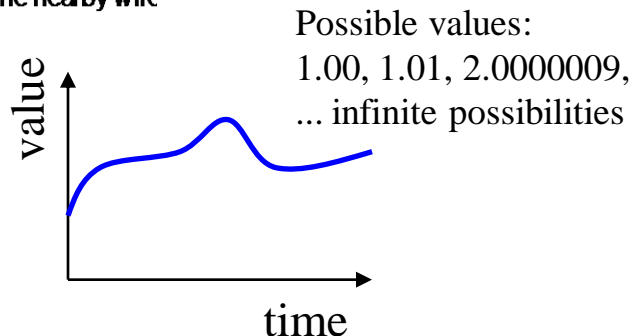
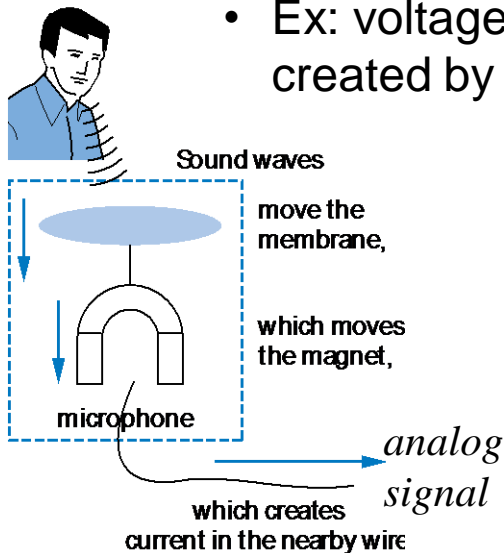
- Look “under the hood” of computers
 - Solid understanding --> confidence, insight, even better programmer when aware of hardware resource issues
- Electronic devices becoming digital
 - Enabled by shrinking and more capable chips
 - Enables:
 - Better devices: Better sound recorders, cameras, cars,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



What Does “Digital” Mean?

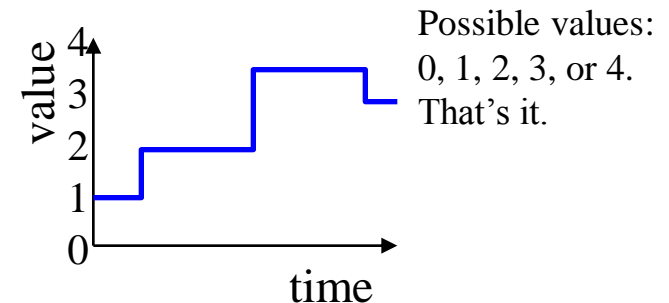
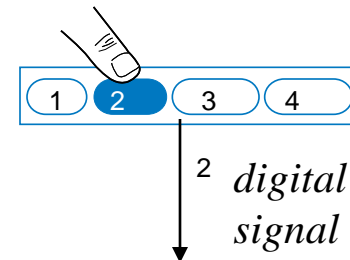
- Analog signal

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



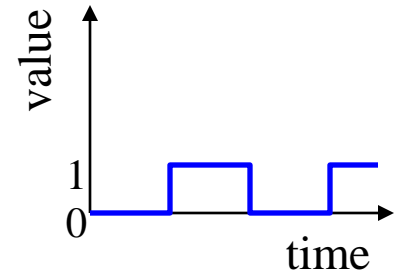
- Digital signal

- 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 (more in Chpt. 2)
 - Storing/transmitting one of *two* values is easier than three or more (e.g., loud beep or quiet beep, reflection or no reflection)



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

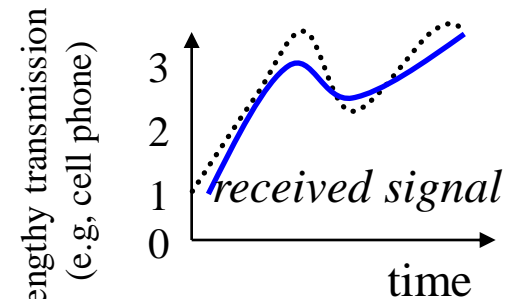
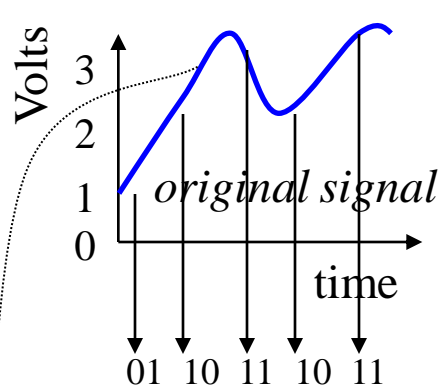
Let bit encoding be:

1 V: “01”

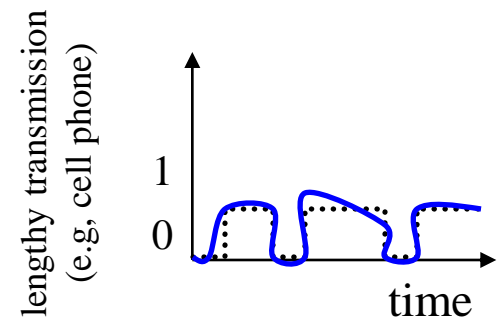
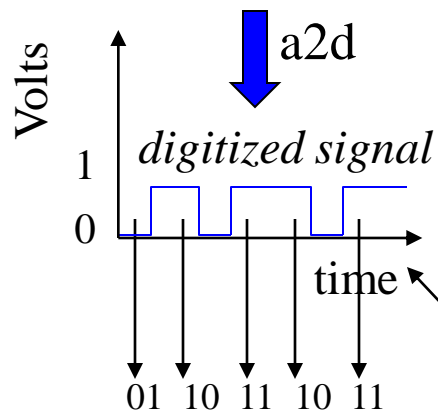
2 V: “10”

3 V: “11”

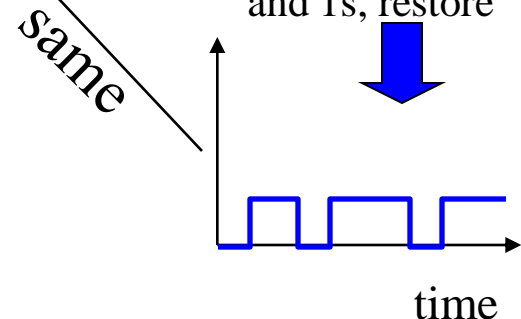
Digitized signal not perfect re-creation, but higher sampling rate and more bits per encoding brings closer.



How fix -- higher, lower, ?



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



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

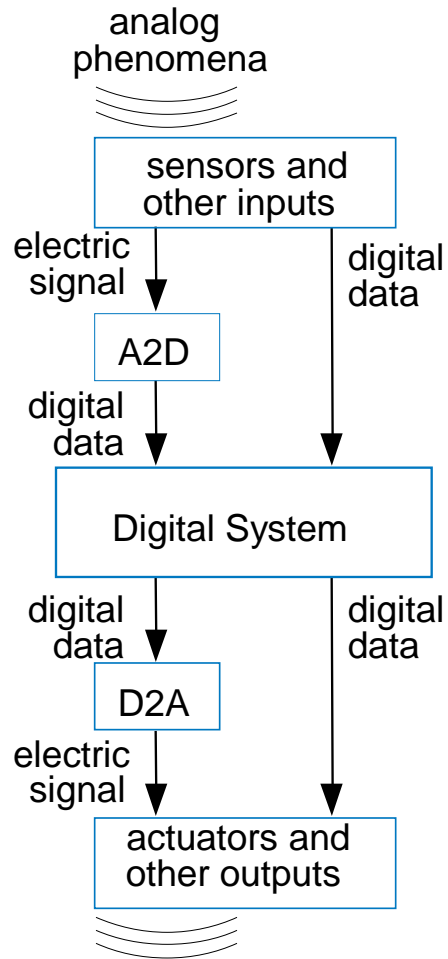
1X --> X

0000000000 0000000000 0000001111 1111111111

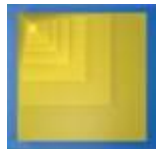
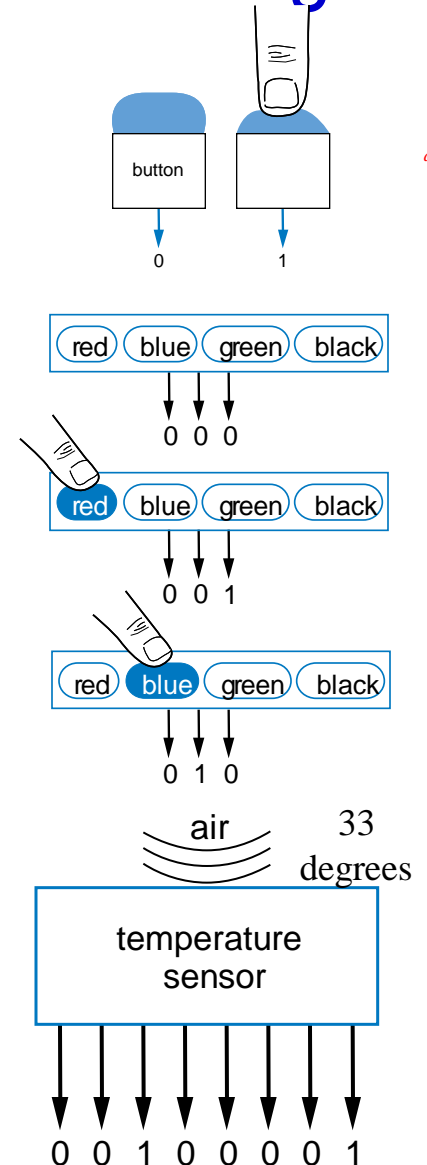
00 00 10000001111 01



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

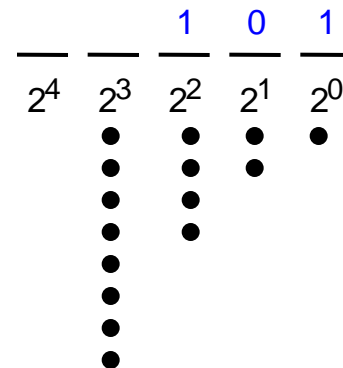
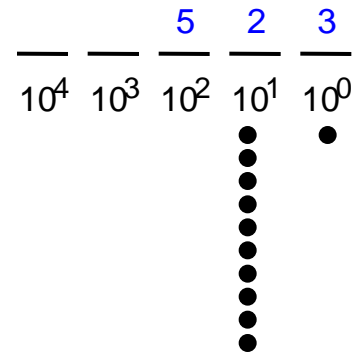
a

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

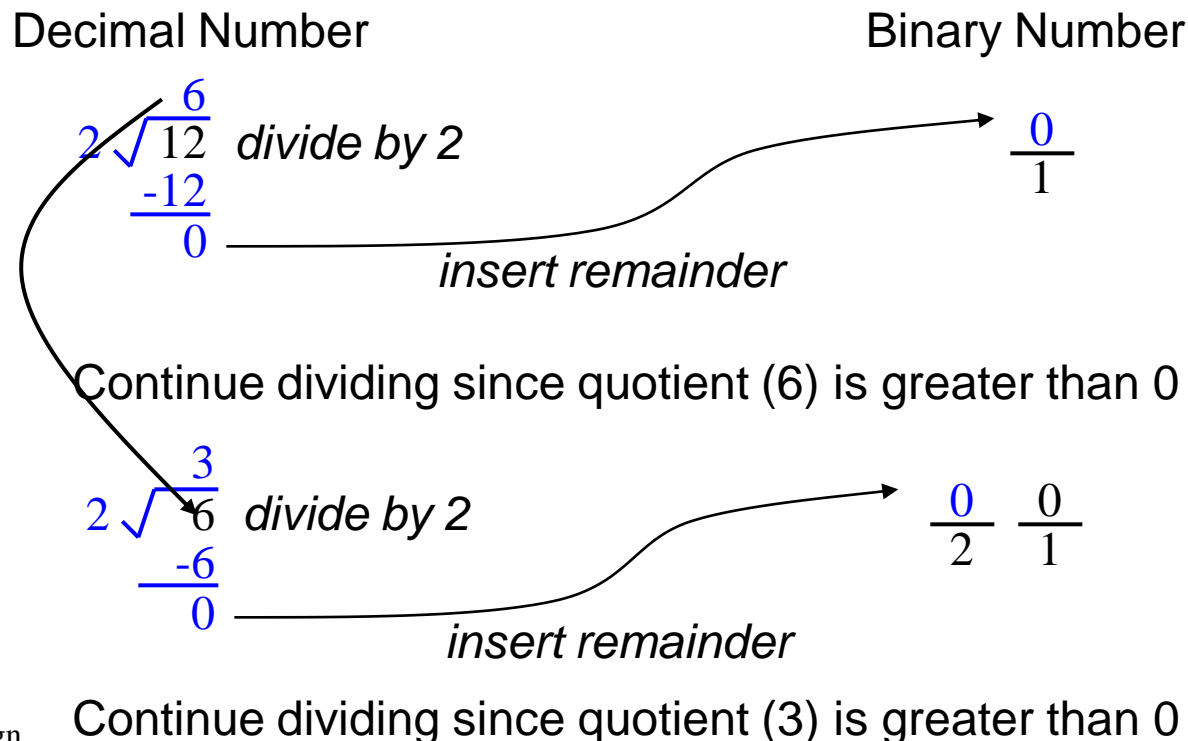
$\frac{0}{32}$ $\frac{1}{16}$ $\frac{0}{8}$ $\frac{1}{4}$ $\frac{1}{2}$ $\frac{1}{1}$

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

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

Continue dividing since quotient (1) is greater than 0

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

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



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

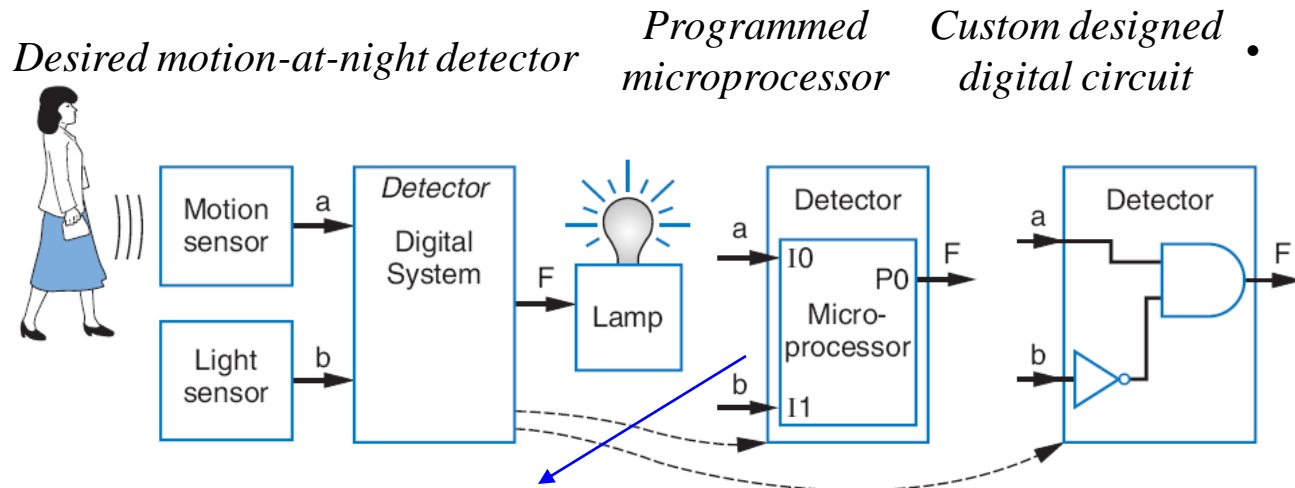
- Nice because each position represents four base two positions
 - Used as compact means to write binary numbers
- Known as *hexadecimal*, or just *hex*

Q: Write 11110000 in hex



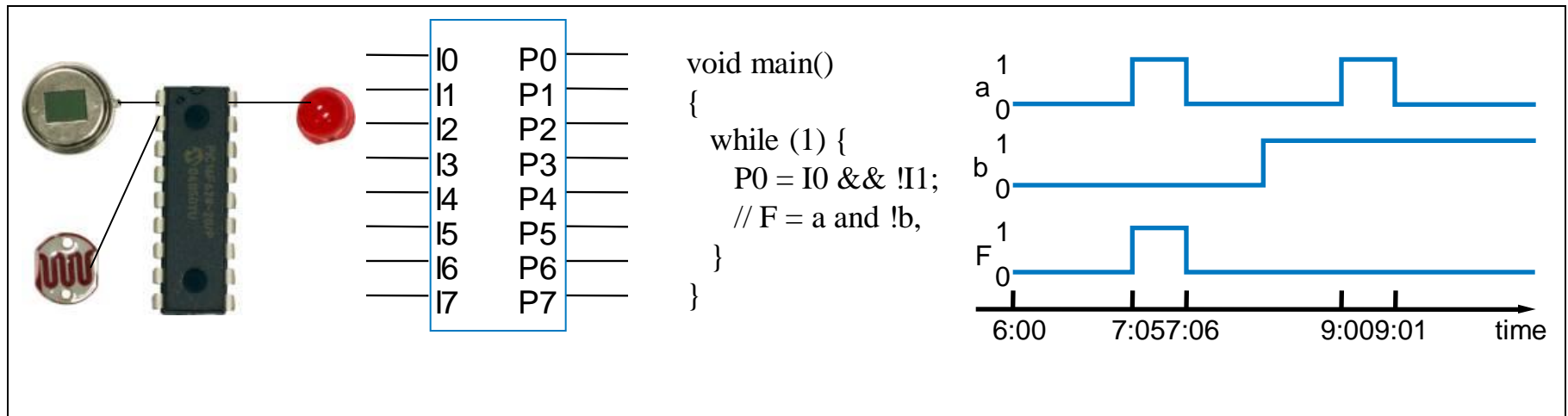
Implementing Digital Systems: Programming

Microprocessors Vs. Designing Digital Circuits



• Microprocessors a common choice to implement a digital system

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

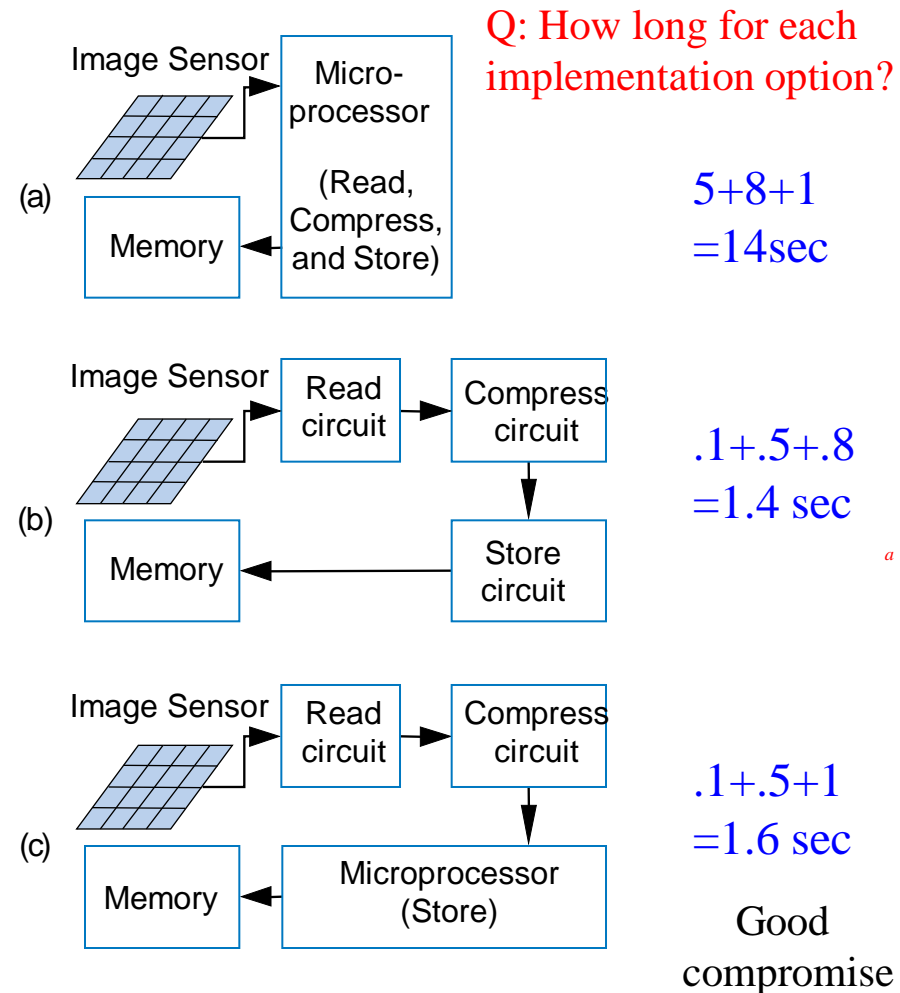


Digital Design: When Microprocessors Aren't Good Enough

- 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

