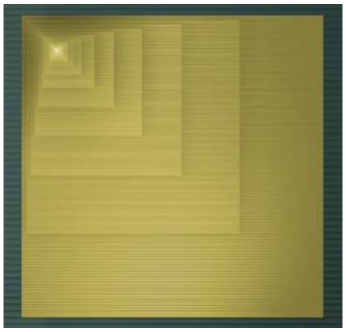


# Digital Design

Chapter 1: Introduction

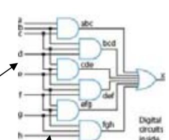
Slides to accompany the textbook *Digital Design*, First Edition,
by Frank Vahid, John Wiley and Sons Publishers, 2007.
http://www.ddvahid.com



1.1

## 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




| 1995 | 1997 | 1999 | 2001 | 2003 | 2005 | 2007 | |
|---|---|---|---|---|---|---|---|
| Portable music players | Satellites | Cell phones | DVD players | Cameras | Video recorders | TVs | Musical instruments / ??? |

- Years shown above indicate when digital version began to *dominate*
  - (*Not* the first year that a digital version appeared)

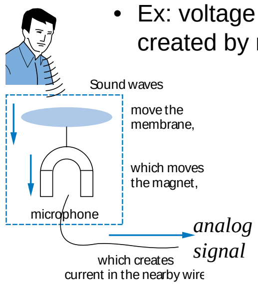


Note: Slides with animation are denoted with a small red "a" near the animated items

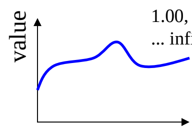
1.2

# What Does “Digital” Mean?

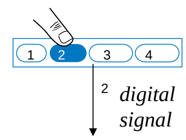
- Analog signal
  - Inifinite possible values
    - Ex: voltage on a wire created by microphone



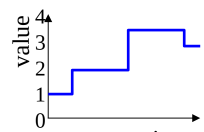

Possible values:
1.00, 1.01, 2.0000009,
... infinite possibilities




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




Possible values:
0, 1, 2, 3, or 4.
That’s it.

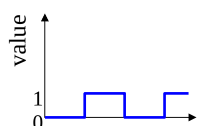







# Digital Signals with Only Two Values: Binary

- ***Binary*** digital signal -- only *two* possible values
  - Typically represented as **0** and **1**
  - One *b*inary dig*it* 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)

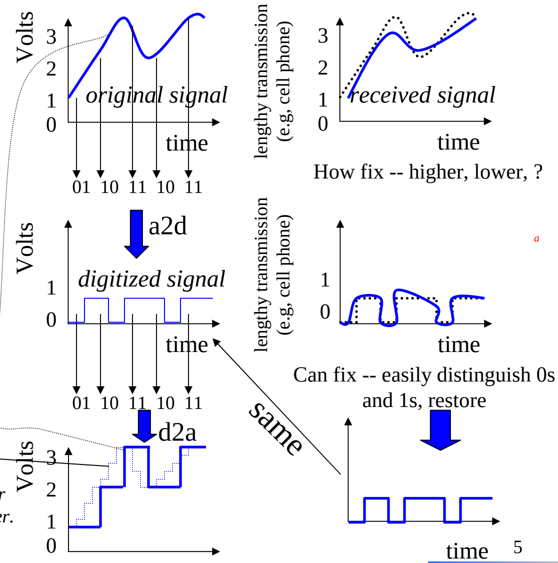


# Example of Digitization Benefit

- 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.*








# Digitized Audio: Compression Benefit

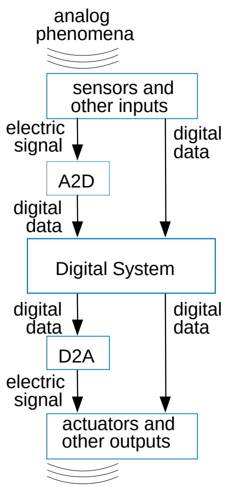
- Digitized audio can be compressed
  - e.g., MP3s
  - A CD can hold about 20 songs uncompressed, but about 200 compressed
- Compression also done on digitized pictures (jpeg), movies (mpeg), and more
- Digitization has many other benefits too

Example compression scheme:
00 --> 0000000000
01 --> 1111111111
1X --> X

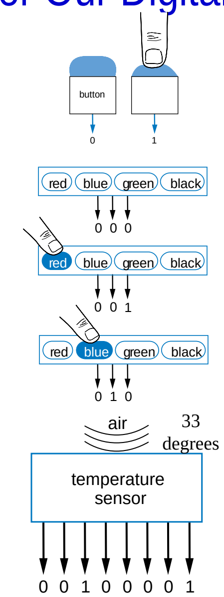
0000000000 0000000000 0000001111 1111111111

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 | Symbol | Encoding |
|---|---|---|---|
| R | 1010010 | r | 1110010 |
| S | 1010011 | s | 1110011 |
| T | 1010100 | t | 1110100 |
| L | 1001100 | l | 1101100 |
| N | 1001110 | n | 1101110 |
| E | 1000101 | e | 1100101 |
| 0 | 0110000 | 9 | 0111001 |
| . | 0101110 | ! | 0100001 |
| <tab> | 0001001 | <space> | 0100000 |

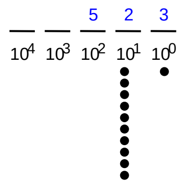
Question:
What does this ASCII bit sequence represent?
1010010 1000101 1010011 1010100

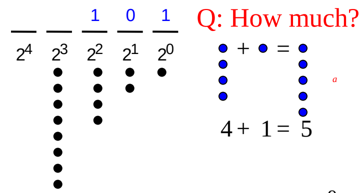
R E S T

*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



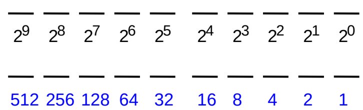








# How to Encode Numbers: Binary Numbers

- 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)
    - Q: count up by powers of two




512 256 128 64 32 16 8 4 2 1

## 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**

| 32 | 16 | 8 | 4 | 2 | 1 | |
|---|---|---|---|---|---|---|
| _ | _ | _ | _ | _ | _ | |
| 1 | _ | _ | _ | _ | _ | =32 too much |
| 0 | 1 | _ | _ | _ | _ | =16 too much |
| 0 | 0 | 1 | _ | _ | _ | =8 ok, keep going |
| 0 | 0 | 1 | 1 | _ | _ | =8+4=12 DONE |
| **0** | **0** | **1** | **1** | **0** | **0** | answer |

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## 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**

| 32 | 16 | 8 | 4 | 2 | 1 | |
|---|---|---|---|---|---|---|
| _ | _ | _ | _ | _ | _ | |
| 1 | _ | _ | _ | _ | _ | 32 is too much |
| 0 | 1 | _ | _ | _ | _ | 16 is too much |
| 0 | 0 | 1 | _ | _ | _ | **12 – 8 = 4** |
| 0 | 0 | 1 | 1 | _ | _ | **4-4=0** DONE |
| **0** | **0** | **1** | **1** | **0** | **0** | answer |

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## Converting from Decimal to Binary Numbers: Subtraction Method Example

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

| A: Remaining quantity | Binary Number (32, 16, 8, 4, 2, 1) |
|---|---|
| 23 | 0 0 0 0 0 0 |
| 23 − 16 = 7 | 0 1 0 0 0 0 |
| 7 − 4 = 3 | 0 1 0 1 0 0 (8 is more than 7, can’t use) |
| 4 − 2 = 1 | 0 1 0 1 1 0 |
| 1 − 1 = 0 | 0 1 0 1 1 1 |

0 → 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

| Decimal Number | Binary Number |
|---|---|
| 12 ÷ 2 = 6, 12 − 12 = 0 (*divide by 2*; *insert remainder*) | 0 (1) |
| Continue dividing since quotient (6) is greater than 0 | |
| 6 ÷ 2 = 3, 6 − 6 = 0 (*divide by 2*; *insert remainder*) | 0 0 (2 1) |
| Continue dividing since quotient (3) is greater than 0 | |

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

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

Decimal Number | Binary Number

$2\overline{)3}$ = 1   *divide by 2*
-2
1 → *insert remainder*

Binary: $\frac{1}{4}$ $\frac{0}{2}$ $\frac{0}{1}$

Continue dividing since quotient (1) is greater than 0

$2\overline{)1}$ = 0   *divide by 2*
-0
1 → *insert remainder*

Binary: $\frac{1}{8}$ $\frac{1}{4}$ $\frac{0}{2}$ $\frac{0}{1}$

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





# Base Sixteen: Another Base Sometimes Used by Digital Designers

| | | 8 | A | F |
|---|---|---|---|---|
| $16^4$ | $16^3$ | $16^2$ | $16^1$ | $16^0$ |

8 → 1000, A → 1010, F → 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 |

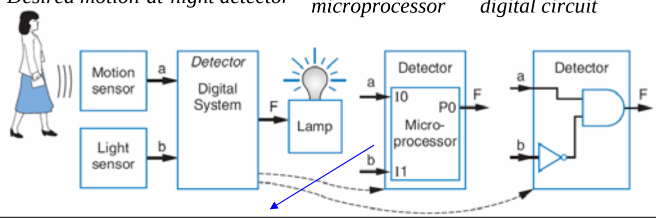
- Nice because each position represents four base two positions
  - Used as compact means to write binary numbers
- Known as ***hexadecimal***, or just ***hex***

Q: Write 11110000 in hex

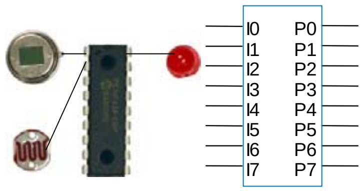
F 0

# Implementing Digital Systems: Programming Microprocessors Vs. Designing Digital Circuits

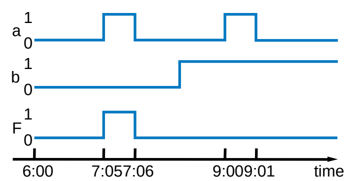
*Desired motion-at-night detector* | *Programmed microprocessor* | *Custom designed digital circuit*




- Microprocessors a common choice to implement a digital system
  - Easy to program
  - Cheap (as low as $1)
  - Available now




```
void main()
{
  while (1) {
    P0 = I0 && !I1;
    // F = a and !b,
  }
}
```





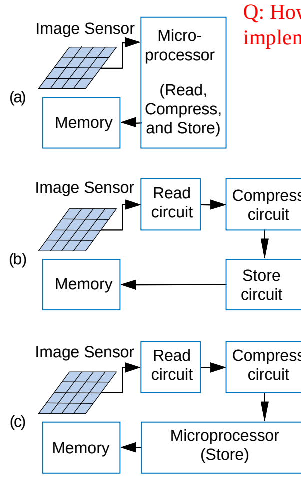



# Digital Design: When Microprocessors Aren't Good Enough

- 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 |




Q: How long for each implementation option?

(a) 5+8+11 =24 sec

(b) .1+.5+.8 =1.4 sec

(c) .1+.5+1 =1.6 sec

Good compromise

## 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