CSE 241

Lecture 1

University at Buffalo
School of Engineering and Applied Sciences

Overview for this lecture

- Introduction
- Course Policies
- Number Systems

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Research Areas: Data Fusion, Representation and Analysis of Multimodal and Nonuniform Data, Engineering Education and Outreach

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Course Policies and Information

- Learning Outcomes
- Required Materials
- Attendance
- Collaboration
- Academic Integrity
- Grading Scheme

Learning Outcomes

- Understand and apply Boolean Algebra
- Understand logic gates and their operation
- Understand Karnaugh maps and apply them to simplify logic expressions
- Understand signed and unsigned integer representation and arithmetic
- MSI circuit decoders, multiplexers and design of combinational circuits
- Flip-flops and sequential circuit synthesis
- Verilog hardware description language, synthesis and simulation

Required Materials

- Textbook:
  - Digital Design: With an Introduction to the Verilog HDL by M. Morris Mano and Michael D. Ciletti, Prentice Hall; 5th edition (January 12, 2012), ISBN-13: 978-0132774208
- Lab Kit:
  - You can buy at Jameco using one collective part number: 2244818
  - It costs $22.97 + shipping and handling.
  - There is a more expensive version with an Arduino you can choose to get

No recitation today to give you time to get your kit- Will meet on Monday

Lecture Attendance

- Miss lecture at your own risk
- Slides will get posted before class or after class
- Examples will get posted after class
- Quizzes may not be announced if they are in class
- Quizzes outside class will be give a minimum 24 hours notice and you will have a minimum 24 hour window
- Exam Prep/Exam days are non-negotiable

Recitation Attendance

- Time to get help with your labs
- Time to get sign offs for your labs
- 24 hours notice will be given if I chose to use this time for a quiz

Collaboration

- All work you submit is expected to be your own
- Restrict collaboration to studying
- Do not work on assignments together unless told you can
- Excessive collaboration produces work that is too similar
  - This is an academic integrity violation

Academic Integrity

- Departmental Policy:
  - First Offense:
    - Gets reported
    - Fail the class or sanction of the instructor's discretion
  - Subsequent Offense(s):
    - Fail the class and it is reported

Some Examples of Academic Integrity Violation (non-exhaustive)

- Solicitation of work
- Copying other’s work
- Excessive Collaboration
- Plagiarism
- Selling work
- Unauthorized resources

Grading Scheme

- 20% Exam 1
- 30% Exam 2
- 15% Homework, Quizzes and other Assignments
- 35% Laboratory Assignments
- 2% Extra Credit

Late Work

- Assignments with Due Dates (Like Labs and Homework):
  - 24 hours grace period then worth nothing
- Exam Regrades
  - Start of class they are due
- Quizzes
  - In class
  - During the 24 hour window

Extra Credit

You can do one of the two options to earn a 2% overall extra credit

1. Community Service
    a. Go out and do some good, get a picture of you doing it
        i. Examples: donate blood, volunteer at a food bank, volunteer at an elderly home, volunteer with Big Brothers/Big Sisters, adopt a highway, habitat for humanity, Walk for ___
        ii. Speak to me if you volunteer at a place that can't take pictures and we will talk about how to document
    b. Monetary or item donation does not count
2. Book Report
    a. This is an analysis and reflection on the book "Tesla: A Man Out Of Time" by Margaret Cheney

Things to expect from me

- Responses to emails promptly
- Returned feedback and grades in a timely manner
- Open to suggestions and feedback
- If you ask for help, I will not give you the answer, but I will help you learn how to get there
- I will do my best to break up the lecture, but it will be a lot of me talking
- Accommodation for learning conditions, handicaps, and disabilities
  - Please let me know ahead of time/ early as possible

Things not to expect

- Extensions
- Answers
- Cookie cutter recipes and full guides on how to solve every step of the problem
- Tolerance on cheating or lying

Questions

- I will start out with an opportunity to ask them that is open floor for any
- During lectures if you have relevant questions, please ask
  - If it is during an example and I don’t see your hand please shout it out

Any questions?

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Let’s Get Started

Any Questions First?

Why are you here?

- To learn about digital systems
- This includes
  - Number systems
  - Boolean Algebra
  - Karnaugh Maps
  - Combinational and Sequential Logic
  - Verilog
- What is the point?
  - Helps you understand the fundamentals how how computers think
  - Means you can design better computers later on

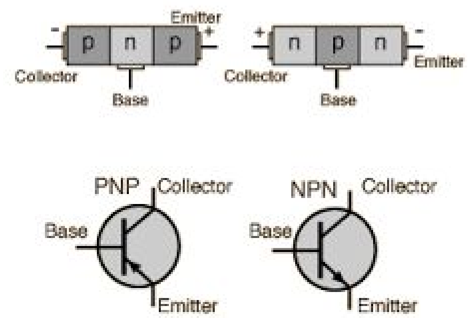
Analog VS Digital

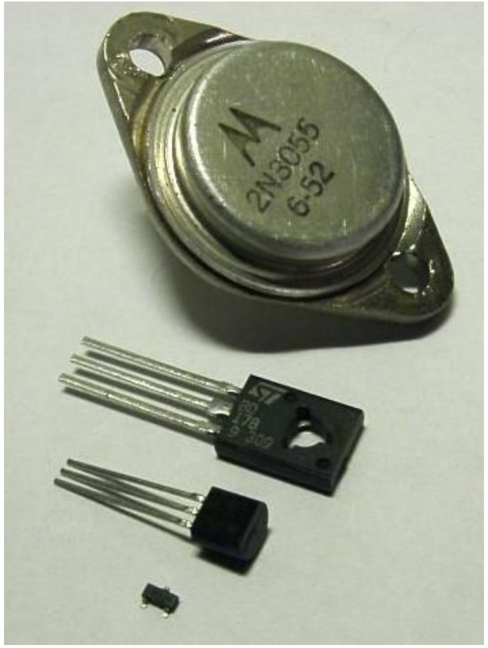
- Analog signals can take any value across a continuous range of current, voltage, etc.
- Digital circuits can too.
  - They just don’t.
  - They restrict themselves to two discrete values of 0 and 1, low and high, false and true.

Why is digital important?

THE TRANSISTOR

(Vacuum Tubes before that)





Moore's Law

- April 19, 1965 issue of Electronics magazine
- The complexity for minimum component costs has increased at a rate of roughly a factor of two per year ... Certainly over the short term this rate can be expected to continue, if not to increase. Over the longer term, the rate of increase is a bit more uncertain, although there is no reason to believe it will not remain nearly constant for at least 10 years. That means by 1975, the number of components per integrated circuit for minimum cost will be 65,000. I believe that such a large circuit can be built on a single wafer. -- Gordon Moore, co-founder of Intel Corp., "Cramming more components onto integrated circuits"

What is a number?

- A mathematical object
- Something used to count

Number Systems

- Different bases and systems that can be used to represent the quantities
- Why do we need different bases?

Base 10- Decimal

0

1

2

3

4

5

6

7

8

9

Binary


There are only 10 types
of people in the world:
Those who understand binary
and those who don't.
science.memebase.com

- 2 states in this number system: 0 and 1
- Represents lots of things: true/false, heads/tales, buy/sell, tall/short

How do we make bigger numbers than 1?

- Use more places/digits
- We can count to 3 with 2 digits:
    - 00
    - 01
    - 10
    - 11

In terms of decimal how large of a value can you have with each count of digits?

- 1 digit = 1
- 2 digits = 3 = $2^2 - 1$
- 3 digits = 7 = $2^3 - 1$
- 4 digits = 15 = $2^4 - 1$
- 5 digits = ?

Next step- Converting between decimal and binary

Decimal to binary- divide by 2

Binary to decimal- powers of 2

Now let’s look at Oct

- Base 8
- Values 0-7

Let’s convert between binary and Oct

All about groups of 3

What about Dec and Oct?

Go to binary first, it is easier that way!

Hex

- Base 16
- Values 0-15

Let’s convert between Binary and Hex

All about groups of 4

What about Dec and Hex?

Use binary as an in between step

Binary Addition

- When we add in decimal, we:
  - Line up the columns of the same power of 10
  - Add the columns together
  - If the sum > 10, there is a carry out
  - Next column gets that as a carry in
- Binary addition works almost exactly the same.

- In general, we talk about:
  - x and y, the addends
  - s, the sum bit
  - c, the carry out bit

```
  x
+ y
-----
 c s
```

Simple Addition

- 0 + 0 = 00
- 0 + 1 = 01
- 1 + 0 + 01
- 1 + 1 = 10

- x + y = cs

Example Addition

b1010110 + b1100001

Exercise

Add 0b110011 and 0b101110

Signed Integers

- Only one representation of the number 0 (zero)
- Subtraction dealt with as simply adding negatives
  - How the numbers go on a number circle
  - Whether there needs to be any “fixing” of the numbers.
- Maximum Range
- Minimum Confusion

Signed Numbers

- Binary
  - Leftmost bit is sign bit.
  - 0 = positive
  - 1 = negative
  - MSB is second bit from left.

Integer Representation

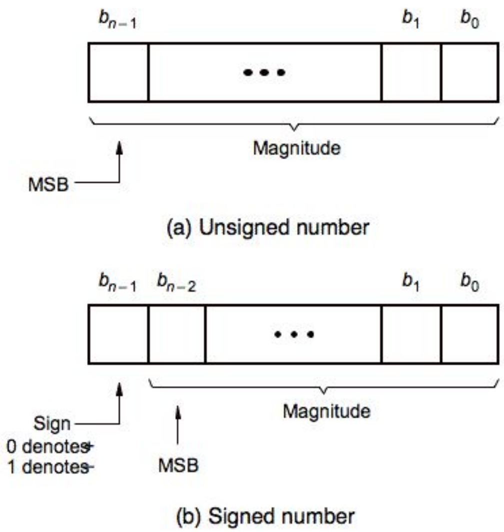


Figure 5.8. Formats for representation of integers.

Negative Numbers

- Sign-and-magnitude
- All we do is slap a sign bit next to the magnitude of the unsigned binary number.
  - Pros:
    - Easy for people
    - Ummm…
- Cons
    - Negative Zero
    - Math is hard
- Example: Find -5 in 4-bit sign and magnitude.

+5 = b0101

-5 = b1101

- 1’s complement
  - Take and flip every bit of the positive number to get the negative number
  - Pros:
    - Reasonably easy for people
    - Better than SAM for computers (subtraction is particularly easy)
  - Cons
    - Still have a negative zero

Example: Find -5 in 4-bit 1’s complement.

+5 = b0101

-5 = b1010

2’s Complement

- Take the positive number, flip every bit and add one.
- Pros:
  - Great for computers and binary math.
  - Only one zero.
- Cons
  - Math Hard-Brain Hurt

Example: Find -5 in 4-bit 2's complement.

+5 = 0101

-5 = 1011

-5 in 8-bit 2's complement would be 11111011. (Fill to the left with 1's for negative number.)

Wraps around like an odometer.

Sign Extending 2's Complement

- Values only require a certain number of bits, but it can be useful (or necessary) to represent them using more bits.
- To do this in 2's Complement, we "sign-extend" the number.
    - Just replicate the sign bit out to the left until you have as many bits as you want.

Example: -12 = b10100 (5 bits) = b11110100 (8 bits)

Example: 12 = b01100 = b00001100

Example

42 = b00101010

-42 = ????

Exercise

Represent -27 in 8-bit 2's complement

Comparison

b3b2b1b0	SAM	1's Complement	2's Complement
0111	+7	+7	+7
0110	+6	+6	+6
0101	+5	+5	+5
0100	+4	+4	+4
0011	+3	+3	+3
0010	+2	+2	+2
0001	+1	+1	+1
0000	+0	+0	0
1000	-0	-7	-8
1001	-1	-6	-7
1010	-2	-5	-6
1011	-3	-4	-5
1100	-4	-3	-4
1101	-5	-2	-3
1110	-6	-1	-2
1111	-7	-0	-1

Addition

- Sign-and-magnitude addition
  - simple if both operands have same sign
  - complex if they have opposite signs
  - smaller magnitude must be subtracted from larger
- 1's complement addition
  - Correction sometimes needed when carry out of the sign bit
- 2's complement addition
  - Simple and correct when in range

2’s complement subtraction

- complement subtrahend and add

Just as a reminder:

minuend - subtrahend = difference

1’s Complement Addition

$$\begin{array}{r} (+5) \\ +(+2) \\ \hline (+7) \end{array} \qquad \begin{array}{r} 0\,1\,0\,1 \\ +\,0\,0\,1\,0 \\ \hline 0\,1\,1\,1 \end{array} \qquad\qquad \begin{array}{r} (-5) \\ +(+2) \\ \hline (-3) \end{array} \qquad \begin{array}{r} 1\,0\,1\,0 \\ +\,0\,0\,1\,0 \\ \hline 1\,1\,0\,0 \end{array}$$

$$\begin{array}{r} (+5) \\ +(-2) \\ \hline (+3) \end{array} \qquad \begin{array}{r} 0\,1\,0\,1 \\ +\,1\,1\,0\,1 \\ \hline 1\,0\,0\,1\,0 \\ \hookrightarrow 1 \\ \hline 0\,0\,1\,1 \end{array} \qquad\qquad \begin{array}{r} (-5) \\ +(-2) \\ \hline (-7) \end{array} \qquad \begin{array}{r} 1\,0\,1\,0 \\ +\,1\,1\,0\,1 \\ \hline 1\,0\,1\,1\,1 \\ \hookrightarrow 1 \\ \hline 1\,0\,0\,0 \end{array}$$

2’s Complement Addition

$$\begin{array}{r} (+5) \\ +\ (+2) \\ \hline (+7) \end{array} \qquad \begin{array}{r} 0101 \\ +\ 0010 \\ \hline 0111 \end{array} \qquad\qquad \begin{array}{r} (-5) \\ +\ (+2) \\ \hline (-3) \end{array} \qquad \begin{array}{r} 1011 \\ +\ 0010 \\ \hline 1101 \end{array}$$

$$\begin{array}{r} (+5) \\ +\ (-2) \\ \hline (+3) \end{array} \qquad \begin{array}{r} 0101 \\ +\ 1110 \\ \hline 10011 \end{array} \qquad\qquad \begin{array}{r} (-5) \\ +\ (-2) \\ \hline (-7) \end{array} \qquad \begin{array}{r} 1011 \\ +\ 1110 \\ \hline 11001 \end{array}$$

ignore   ignore

2's Complement Subtraction

$$
\begin{array}{r}
(+5) \\
-\,(+2) \\ \hline
(+3)
\end{array}
\qquad
\begin{array}{r}
0101 \\
-\,0010 \\ \hline
\end{array}
\quad \Rightarrow \quad
\begin{array}{r}
0101 \\
+\,1110 \\ \hline
10011
\end{array}
$$

ignore

$$
\begin{array}{r}
(-5) \\
-\,(+2) \\ \hline
(-7)
\end{array}
\qquad
\begin{array}{r}
1011 \\
-\,0010 \\ \hline
\end{array}
\quad \Rightarrow \quad
\begin{array}{r}
1011 \\
+\,1110 \\ \hline
11001
\end{array}
$$

ignore

$$
\begin{array}{r}
(+5) \\
-\,(-2) \\ \hline
(+7)
\end{array}
\qquad
\begin{array}{r}
0101 \\
-\,1110 \\ \hline
\end{array}
\quad \Rightarrow \quad
\begin{array}{r}
0101 \\
+\,0010 \\ \hline
0111
\end{array}
$$

$$
\begin{array}{r}
(-5) \\
-\,(-2) \\ \hline
(-3)
\end{array}
\qquad
\begin{array}{r}
1011 \\
-\,1110 \\ \hline
\end{array}
\quad \Rightarrow \quad
\begin{array}{r}
1011 \\
+\,0010 \\ \hline
1101
\end{array}
$$

Example

Let A = b10110, B = b01111 and C = b01010

- Which numbers are positive? Negative?
- What are the decimal magnitudes of each number?
- A + B = ? B + C = ? C - B = ?

Exercise

In 2’s complement A = b0101 and B = b1101.

- Find A + B and A - B.

Overflow

- Addition of two positive or two negative numbers may result in answer out of range.
- If there is a carry into AND out of the sign bit, everything's okay. Ignore the carry out.
- If there is a carry into the sign bit but not out or out of the sign bit but not into it, the result is wrong!
- What do you do about it?
  - Simply declare "out of range", "overflow" and leave it at that.
    - OR...

Redo the math with a larger number of bits.

Determining the Overflow

$$\begin{array}{r} (+7) \\ +\,(+2) \\ \hline (+9) \end{array} \qquad \begin{array}{r} 0111 \\ +\,0010 \\ \hline 1001 \end{array} \qquad \begin{array}{l} c_4 = 0 \\ c_3 = 1 \end{array}$$

$$\begin{array}{r} (-7) \\ +\,(+2) \\ \hline (-5) \end{array} \qquad \begin{array}{r} 1001 \\ +\,0010 \\ \hline 1011 \end{array} \qquad \begin{array}{l} c_4 = 0 \\ c_3 = 0 \end{array}$$

$$\begin{array}{r} (+7) \\ +\,(-2) \\ \hline (+5) \end{array} \qquad \begin{array}{r} 0111 \\ +\,1110 \\ \hline 10101 \end{array} \qquad \begin{array}{l} c_4 = 1 \\ c_3 = 1 \end{array}$$

$$\begin{array}{r} (-7) \\ +\,(-2) \\ \hline (-9) \end{array} \qquad \begin{array}{r} 1001 \\ +\,1110 \\ \hline 10111 \end{array} \qquad \begin{array}{l} c_4 = 1 \\ c_3 = 0 \end{array}$$

Exercise

A = +4 B = +6 C = -7 D = -4

- Find A + B, A + C, C + D, and A - C.
- State which results are valid in 4-bit 2’s complement.

Multiplication

- Unsigned numbers
  - Similar to decimal multiplication with simpler table

0 * 0 = 0

1 * 0 = 0 * 1 = 0

1 * 1 = 1

Unsigned Multiplication

Proceeds pretty much like decimal multiplication

- Start on right
- Sense multiplier bit
- If 1, add multiplicand to partial product. Then shift.
- If 0, shift.

Example

```
    1011
  x 1001
----------
   1011
  0000
 0000
1011
---------
1100011
```

- Check our answer…

Exercise

1011 x 1101

Signed Multiplication

- Just remember normal multiplication rules:
  - Positive times positive = positive
  - Negative times negative = positive
  - Positive times negative = negative

- For PxP, just do it like unsigned multiplication.
- For NxN, convert both numbers and multiply.
- For NxP, convert the negative number, multiply and convert the result.

Division

Really complicated

Fixed Point Numbers

RADIX POINT

- $B = b_{n-1}b_{n-2}\ldots b_1b_0.b_{-1}b_{-2}\ldots b_{-k}$
- $V(B) = \sum(b_i \times 2_i)$ from $i = -k$ to $n-1$
- The “dot” is generically called the “radix point”

What happens to the right of the radix point?

- Decimal to Binary- Multiply by 2
- Binary to decimal- 2^{-x}
  - Where X is the position
  - 2^{-1}=.5
  - 2^{-2}=.25
  - 2^{-3}=.125
  - 2^{-4}=.0625

Let’s do an example

Convert 58.123 to Fixed Point

You Try

Convert 12.45 to fixed point

Let’s do an example the other direction

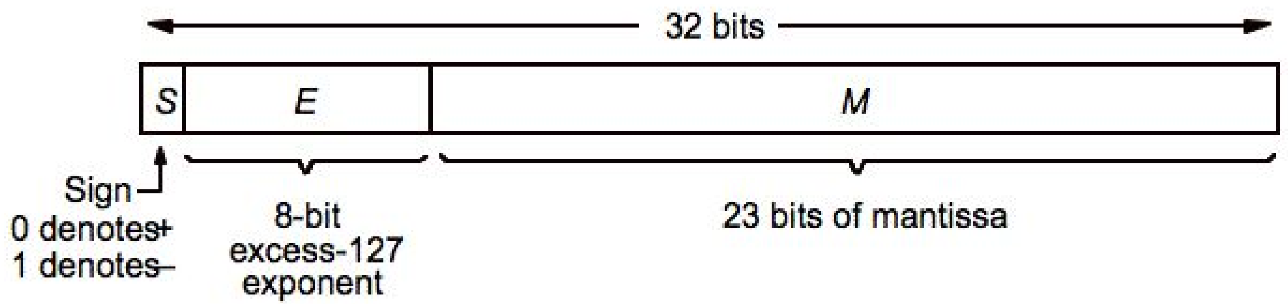
0b101001.1101

You Try

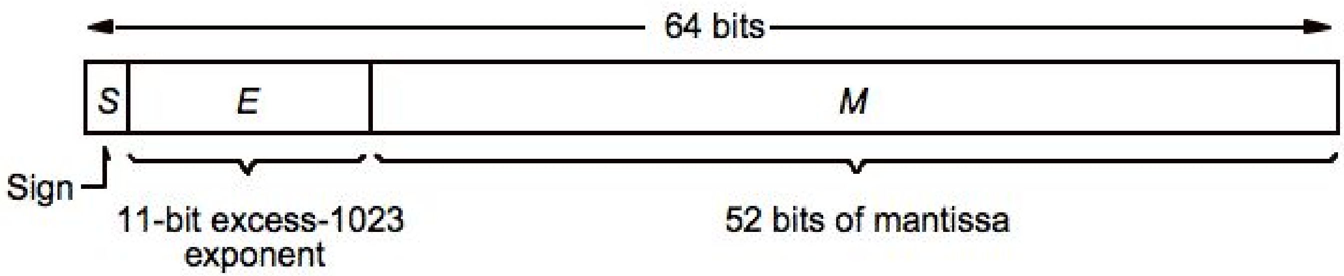
0b101.11

Floating Point Numbers

- Mantissa has significant digits.
- Exponent has power of 2
- Number has form
  - mantissa x 2^{exponent}
- Typically normalized so mantissa has one assumed bit to the left of the radix point
- “Binary Scientific Notation”



(a) Single precision



(c) Double precision

- Single-precision (32 bits)
  - left bit is sign (0 = +, 1 = -)
  - 23-bit mantissa
  - precision of about seven decimal digits
  - MSB bit of 1 is omitted
  - 8-bit sign (excess-127) (Exponent = E-127)
  - E = 0 denotes exactly 0
  - E = 255 denotes infinity
  - Range of about $10^{\pm 38}$
  - Value = $\pm 1.M \times 2^{E - 127}$

- Double-precision (64 bits)
  - left bit is sign (0 = +, 1 = -)
  - 52 bit mantissa
  - left bit assumed to be 1
  - precision of about 16 decimal digits
  - 11 bit exponent
  - excess-1023
  - range of about $10^{\pm 308}$
  - Value = $1.M \times 2^{(E - 1023)}$

How do we calculate it?

1. Determine sign
   a. This can be done at almost any step, I like to do it first
2. Convert the whole part of the number to binary
3. Convert the fraction part to binary
4. Put the whole and fraction parts in binary together
5. Calculate the exponent for scientific notation
6. Calculate the exponent field
7. Put it all together

Let’s do an example

124.1495 to Floating Point

You will practice for Homework

Let’s go the other direction

11011001010010010010010100000000

BCD Numbers

- Binary Coded Decimal
- Cuts the binary system off where we stop with decimal values
- Larger values require “two” digits

Decimal	Binary	BCD	Hex
0	0000	0000	0
1	0001	0001	1
2	0010	0010	2
3	0011	0011	3
4	0100	0100	4
5	0101	0101	5
6	0110	0110	6
7	0111	0111	7
8	1000	1000	8
9	1001	1001	9
10	1010	0001 0000	A
11	1011	0001 0001	B
12	1100	0001 0010	C
13	1101	0001 0011	D
14	1110	0001 0100	E

How do we add BCD?

- Add like normal in Binary
- Then force a carry when appropriate
- When is it appropriate?

- How do you force a carry?

Example

Let’s add 5+9 in BCD

Exercise

You try adding 18 and 7 in BCD

Other Representations

- Gray Code
  - Shifts only one digit's value at a time
- Excess X
  - Places 0 at X and allows for positive and negative values

What to do next

- Review: Chapter 1
- Do your HW
    - Due on Monday at 11:59 pm
    - Closes out Tuesday at 11:59pm
    - Submit as a pdf on UBlearns
- No recitation today
- Monday’s recitation we will cover circuit basics to get ready for your first lab- Circuit basics

If there is time...

Any concepts that you want reviewed?