# 15213 Recitation
## Fall 2014

Section A, 8th September

Vinay Bhat

# Welcome to a fun course!

- Yes, it really is fun!
- Recitation will be a place for …

  … a quick overview of the last week's lectures.

  … re-iteration of some key concepts.

  … some problem solving (if needed).

  … lab related discussion.
- Ask questions if you have – from textbooks or otherwise
- We will get back if we cannot answer immediately (yes, we may not know everything!)
- Let us know if you want anything else – we will try to squeeze it in

# Agenda

- Some general stuffs/tips/logistics
- Data Lab
- Bits and bytes
- Unsigned Numbers
- Signed Number
- Arithmetic/Logical Shift – Many questions on this!
- Floating Points – IEEE formats and rounding – Some questions on this!

# Getting help: how-to?

- Attend lectures – there is no substitution for this!
- Course website – Go over the FAQ section
- Refer the textbook – it will be useful long after this semester ends
- Always email the staff mailing list – you will get quicker response (15-213-staff@cs.cmu.edu)
- Attend recitations – some problems will/might be solved!
- All recitations are on Monday – different place and time – check course website
- Visit TA office hours – for any specific questions or lab problems
- All office hours are in WEH 5207 - 5:30 PM to 8:30 PM – different days of the week – check course website

# Data Lab - General

- Due this Thursday (Sept 11th)
- Try not to use grace days for the initial labs – the value of grace days appreciates as the semester progresses!
- If you have to use grace days – autolab will do it for you, just submit
- Beware - you can use only 2 grace days per lab! (Again, you should really be not using them now!)
- Try to get accustomed to shark machines – really! Future labs will force you to use only shark machines

# Data Lab – How to get started?

- Download the handout

  - From Autolab

  - If not registered yet, download from course website (schedule page)

- Un-tar on shark machine (tar xvf <tar-file-name>)

  - Else you might see permission denied error

  - If you see any permission related issues, try “chmod +x <filename>”

- Hope everyone has already done this by now!

# Data Lab – Which files to edit and submit?

- bits.c is the file you will be working on
- Read the instructions carefully – both in the bits.c file header and the lab writeup
- Run driver.pl before submitting – runs the same test that autolab uses to grade the lab
- You need to submit to autolab
- You have unlimited submission – but please do not use autolab as your own driver.pl

# Data Lab – The last slide!

- You are expected to write C which follows ANSI C standards – Only for this lab!
- This means you cannot mix statements with variable declarations – all variables declared at the beginning of the function
- The closing brace should be in the 1st column!
- Be aware of operator precedence in C – better use braces when you are not sure. Ex: (((a-b) >> 2) & (c | (~a) | 0x1))
- Be clever to use some special values – 0, ~0, Tmin, -1 etc
- Try and finish all puzzles before you set out to optimize your solution
- Any specific question?

# Bits and Bytes

- Computers understand everything in bits – in 0’s and 1’s
- So, even you should be able to understand bit level arithmetic – binary representation of numbers
- Might be difficult at first since we are more accustomed to counting in base-10
- But then, if it was easy then there would be no fun in it! (Right?)
- 8 bits make up 1 byte

# Bits and Bytes - Example Data Representation

| C Data Type | Typical 32-bit | Intel IA32 | x86-64 |
|---|---|---|---|
| char | 1 | 1 | 1 |
| short | 2 | 2 | 2 |
| int | 4 | 4 | 4 |
| long | 4 | 4 | 8 |
| long long | 8 | 8 | 8 |
| float | 4 | 4 | 4 |
| double | 8 | 8 | 8 |
| long double | 8 | 10/12 | 10/16 |
| pointer | 4 | 4 | 8 |

# Bits and Bytes - Endianness

- Order in which bits are stored in memory matters – called Endianness
- Not so important for Data Lab
- You will get to see this in Bomb Lab and Buffer Lab
- Big Endian
  - Most significant byte is stored in the smallest address in memory
  - i.e the ‘big’ part goes first into memory
- Little Endian
  - Least significant byte is stored in the smallest address in memory
  - i.e the ‘little’ part goes first into memory

# Unsigned Numbers

- Unsigned are non-negative numbers (including zero)
- Represented using direct binary notation
- Using k bits, we can represent $2^k$ distinct numbers
- So, the range becomes 0 to $2^k-1$
- So, $U_{min} = 0$ and $U_{max} = 2^k-1$

# Signed Numbers (C ‘int’s)

- Most significant bit used to represent the sign
  - MSB = 0 for +ve integers
  - MSB = 1 for –ve integers
- So, with k bits, we get only k-1 bits to encode the value
- Using k bits, we can represent $2^{k-1}$ distinct ‘int’s
- The range becomes $-2^{k-1}$ to $(2^{k-1}-1)$
- Note how we can represent one more negative integer than the number of positive integer
- This is where the expression “$|T_{min}| = T_{max} + 1$” comes from

# Operators of interest

- Bitwise
  - AND -> &
  - OR -> |
  - NOT -> ~
  - XOR -> ^
- Logical
  - AND -> &&
  - OR -> ||
  - NOT -> !
- Mixing logical AND/OR with bitwise AND/OR is a common source of bug (and frustration)
- Ex: x = (2 & 1) makes x to be equal to 0
- Ex: x = (2 && 1) makes x to be equal to 1

# Operators of interest

- Bitwise Shift

  - Right Shift -> ‘>>’

  - Left Shift -> ‘<<‘

- Mixing bitwise shift with relational operators is a common source of bug (and frustration)
- Ex: x = (4 >> 1) makes x to be equal to 2
- Ex: x = (4 > 1) makes x to be equal to 1

# Some insights on right shifts

- Most modern machine performs arithmetic right shift on signed numbers i.e int’s
- This means that the sign bit is extended on right shift of signed numbers
- Wrong assumption - shark machines always perform arithmetic right shift
- Right assumption - shark machines always perform arithmetic right shift on signed numbers
- Int’s are signed in C. Unsigned are, well, not-signed numbers in C
- So, what actually determines the arithmetic or logical right shifts are not the machines. It is the signed-ness of the number

# Some insights on right shifts

- Long story short
  - Arithmetic right shift on int’s: MSB gets filled with the sign bit
  - Logical right shift on unsigned: MSB always gets filled with a 0
- Remember, in C, numbers are ‘typed’ to be signed (i.e int) only after specifying it explicitly.
- By default everything is unsigned
- Try this out to get a clear picture:

```
int x = 0x80000000;
x = x >> 1;
printf(“%x\n”, x);
```

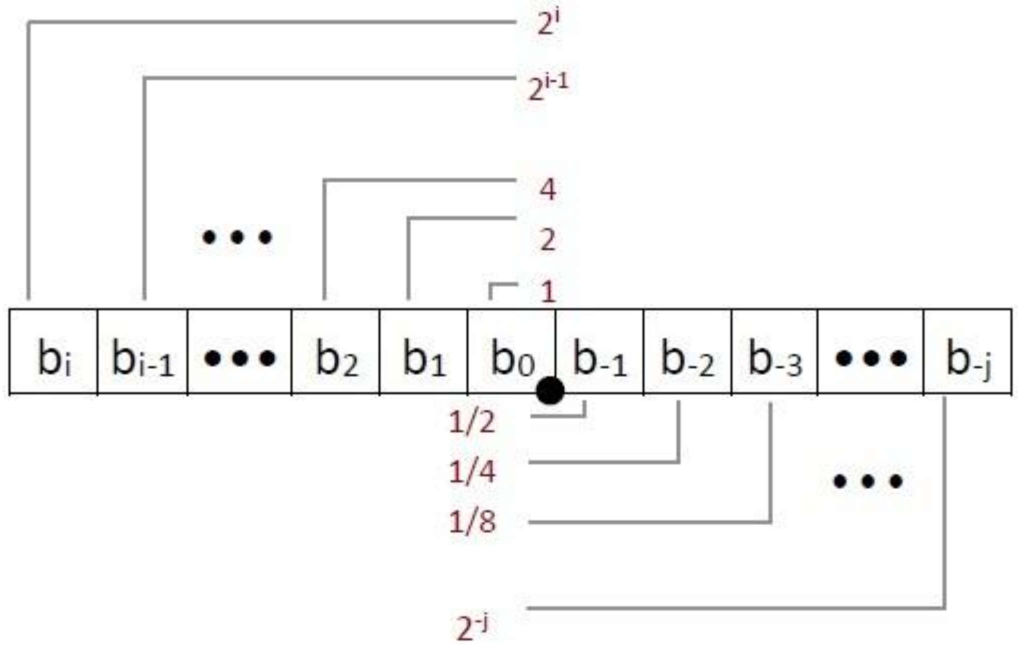
```
int x = 0x80000000 >> 1;
printf(“%x\n”, x);
```

# Floating Point – Binary Fractions

- Bits to the right of 'binary point' indicate fractional powers of 2
- How to calculate the value:

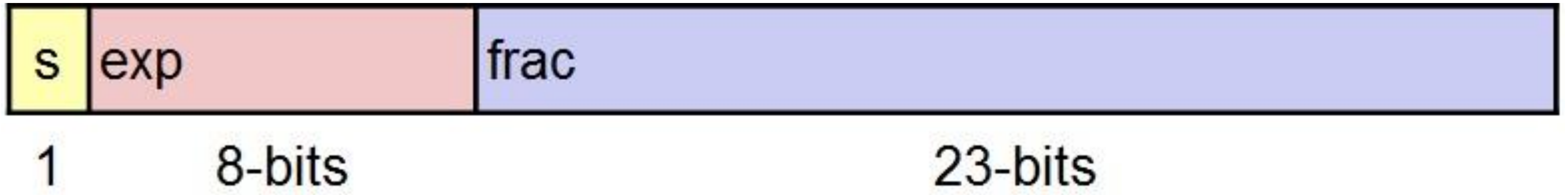
$$\sum_{k=-j}^{i} b_k \times 2^k$$

- Ex: 1101.1011

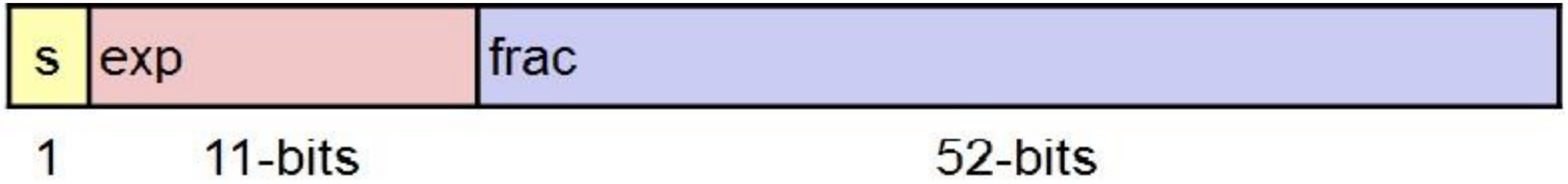


# Floating Point – IEEE Standards

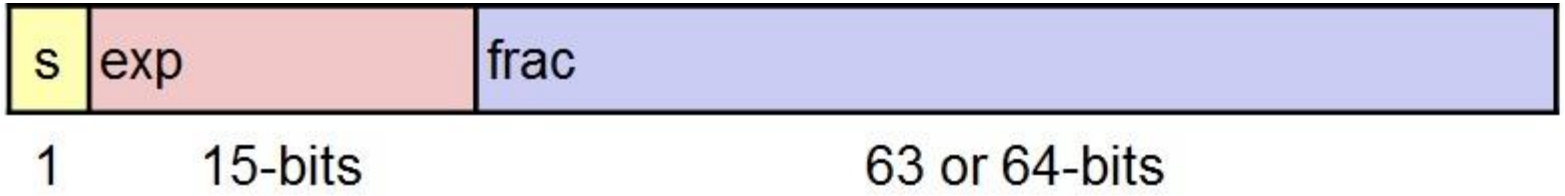
- Single Precision: 32 bits




- Double Precision: 64 bits




- Extended Precision: 80 bits (Intel only)



# Floating Point – IEEE Standards

- Can be thought of as : $(-1^{sign})\ M\ 2^{E}$
- MSB represents the sign: 1 for negative, 0 for positive
- The exp field encodes E (but is not equal to E)
- The frac field encodes M (but is not equal to M)

# Floating Point – Normalized Values

- When exp ≠ 000..0 and exp ≠ 111..1
- E = Exp – bias
  - Exp = unsigned value of exp
  - bias = $2^{k-1} - 1$, where k = number of exp bits
- Significand coded with implied leading 1: M = 1.xxx…xxx (base 2)
  - xxx…xxx: bits of frac
- For single precision: k=8, bias=127
- Ex: 15213 = 11 1011 0110 1101 = 1.1101101101101 * $2^{13}$

  Exp = E + bias = 13 + 127 = 140 = 1000 1100 (base 2)

  frac = <u>1101101101101</u>0000000000
- Ex: 15213.0 = 0 10001100 11011011011010000000000

# Floating Point – Denormalized Values

- When exp = 000…0
- E = -bias + 1
- Significand coded with implied leading 0: M = 0.xxx…xxx (base 2)

  - xxx…xxx: bits of frac
- Exp = 000…0 and frac = 000…0 represents 0

  - +0 and -0 have different representation!
- Exp = 000…0 and frac != 000…0 represents numbers closest to 0.0

# Floating Point – Special Values

- When exp = 111…1
- Exp = 111…1 and frac = 000…0

  - Represents infinity (∞)

  - Both positive and negative (depending on sign bit)
- Exp = 111…1 and frac ≠ 000…0

  - Represents Not-a-Number (NaN)

  - Ex: √-1, ∞- ∞, ∞ * 0

# Floating Point - Rounding

- Cannot accurately represent all fractional ranges with limited number of bits
- Fractions need to be rounded most of the time
- Rounding scheme – round to even
- Ex:

  10.1011 → More than ½, round up → 10.11

  10.1010 → Equal to ½, round down to even → 10.10

  10.0101 → Less than ½, round down → 10.01

  10.0110 → Equal to ½, round up to even → 10.10
- Round up/down to even used only in interesting cases (Equal to ½ cases above)
- All other cases involve rounding up or rounding down

# Floating Point - Examples

- Consider the following 5 bit floating point representation
  - $k=3$ exponent bits
  - $n=2$ frac bits
  - no sign bit (only positive floats)
- Bias = ?
- Largest normalized number = ?
- Smallest normalized number = ?
- Largest denormalized number = ?
- Smallest denormalized number = ?

# Floating Point - Examples

- Consider the following 5 bit floating point representation
  - k=3 exponent bits
  - n=2 frac bits
  - no sign bit (only positive floats)
- Bias = 3
- Largest normalized number = 110 11 = $1110.0_2$ = 14
- Smallest normalized number = 001 00 = $0.0100_2$ = 1/4
- Largest denormalized number = 000 11 = $0.0011_2$ = 3/16
- Smallest denormalized number = 000 01 = $0.0001_2$ = 1/16

# Floating Point - Examples

- When converting to IEEE floating points, assume that the IEEE floating point would be normalized
- It will be - most of the time
- If not, you can easily tell – exponent would not make any sense

# Floating Point - Examples

- Consider the following 5 bit floating point representation

  - k=3 exponent bits

  - n=2 frac bits

  - no sign bit (only positive floats)

| Value in Decimal | IEEE floating point representation | Rounded Value |
|---|---|---|
| 9/32 | | |
| 3 | | |
| 9 | | |
| 3/16 | | |
| 15/2 | | |

# Floating Point - Examples

- Consider the following 5 bit floating point representation
  - k=3 exponent bits
  - n=2 frac bits
  - no sign bit (only positive floats)

| Value in Decimal | IEEE Floating point representation | Rounded Value |
|---|---|---|
| 9/32 | 001 00 | 1/4 |
| 3 | 100 10 | 3 |
| 9 | 110 00 | 8 |
| 3/16 | 000 11 | 3/16 |
| 15/2 | 110 00 | 8 |

# Credits

- http://www.cs.cmu.edu/~213/
- The course text book
- Lecture slides
- Previous recitation slides