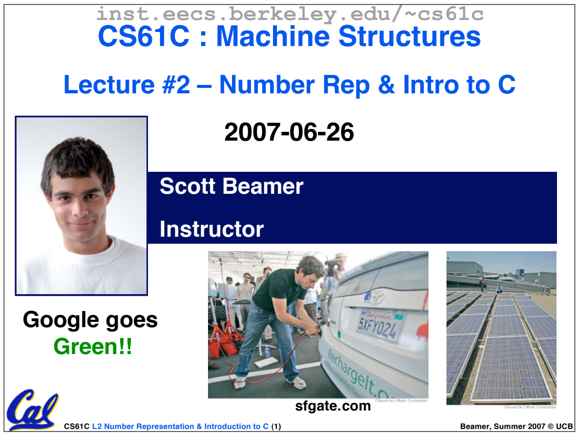


inst.eecs.berkeley.edu/~cs61c

CS61C : Machine Structures

Lecture #2 – Number Rep & Intro to C

2007-06-26

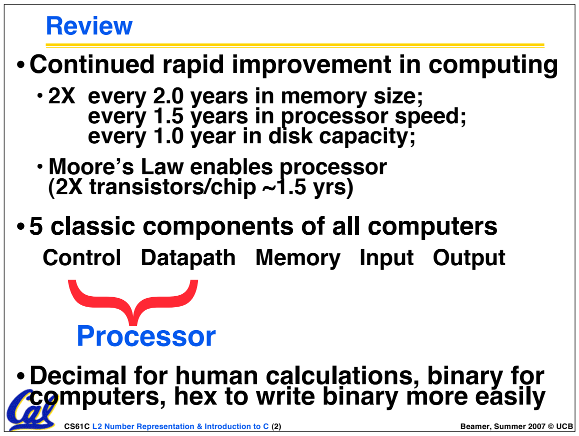
Scott Beamer

Instructor

Google goes Green!!

sfgate.com

Chronicle / Mark Costantini

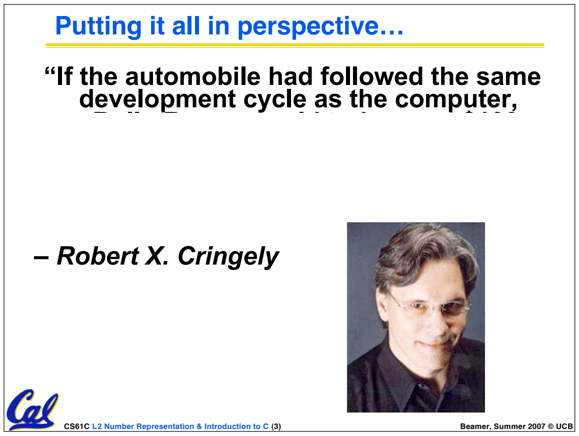


Review

- Continued rapid improvement in computing
  - 2X every 2.0 years in memory size;
    every 1.5 years in processor speed;
    every 1.0 year in disk capacity;
  - Moore's Law enables processor (2X transistors/chip ~1.5 yrs)
- 5 classic components of all computers

  Control Datapath Memory Input Output

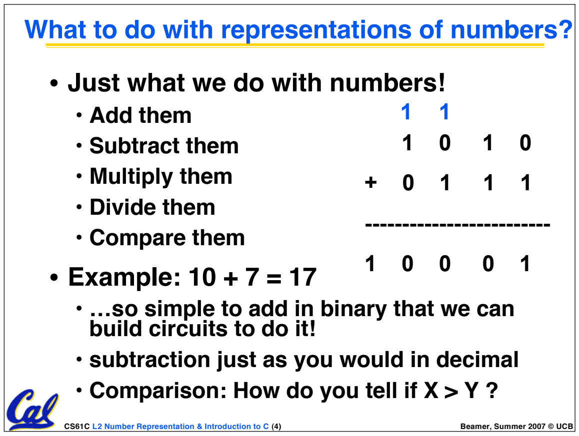
  $\underbrace{\text{Control Datapath}}_{\text{Processor}}$
- Decimal for human calculations, binary for computers, hex to write binary more easily



Putting it all in perspective…

"If the automobile had followed the same development cycle as the computer,

– *Robert X. Cringely*

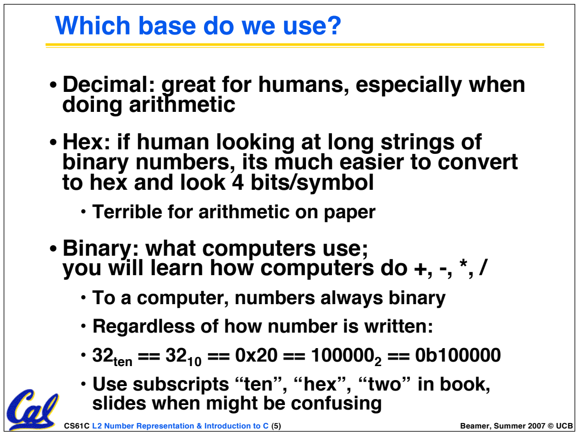


What to do with representations of numbers?

- Just what we do with numbers!
  - Add them
  - Subtract them
  - Multiply them
  - Divide them
  - Compare them

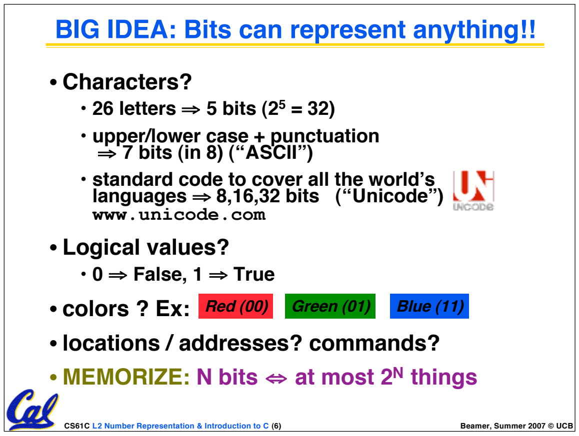
$$\begin{array}{rrrrr} & 1 & 1 & & \\ & 1 & 0 & 1 & 0 \\ + & 0 & 1 & 1 & 1 \\ \hline 1 & 0 & 0 & 0 & 1 \end{array}$$

- Example: 10 + 7 = 17
  - …so simple to add in binary that we can build circuits to do it!
  - subtraction just as you would in decimal
  - Comparison: How do you tell if X > Y ?



Which base do we use?

- Decimal: great for humans, especially when doing arithmetic
- Hex: if human looking at long strings of binary numbers, its much easier to convert to hex and look 4 bits/symbol
  - Terrible for arithmetic on paper
- Binary: what computers use; you will learn how computers do +, -, *, /
  - To a computer, numbers always binary
  - Regardless of how number is written:
  - $32_{ten} == 32_{10} == 0x20 == 100000_2 == 0b100000$
  - Use subscripts "ten", "hex", "two" in book, slides when might be confusing



BIG IDEA: Bits can represent anything!!

- Characters?
  - 26 letters ⇒ 5 bits ($2^5 = 32$)
  - upper/lower case + punctuation ⇒ 7 bits (in 8) ("ASCII")
  - standard code to cover all the world's languages ⇒ 8,16,32 bits ("Unicode") `www.unicode.com`
- Logical values?
  - 0 ⇒ False, 1 ⇒ True
- colors ? Ex: 🟥 Red (00) 🟩 Green (01) 🟦 Blue (11)
- locations / addresses? commands?
- MEMORIZE: N bits ⇔ at most 2^N things

How to Represent Negative Numbers?

- So far, unsigned numbers
- Obvious solution: define leftmost bit to be sign!
  - 0 ⇒ +, 1 ⇒ –
  - Rest of bits can be numerical value of number
- Representation called sign and magnitude
- MIPS uses 32-bit integers. $+1_{ten}$ would be:

0000 0000 0000 0000 0000 0000 0000 0001

- And -1_{ten} in sign and magnitude would be:

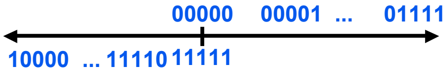
1000 0000 0000 0000 0000 0000 0000 0001

Shortcomings of sign and magnitude?

- Arithmetic circuit complicated
  - Special steps depending whether signs are the same or not
- Also, two zeros
  - 0x00000000 = $+0_{ten}$
  - 0x80000000 = -0_{ten}
  - What would two 0s mean for programming?
- Therefore sign and magnitude abandoned

Another try: complement the bits

- Example: $7_{10} = 00111_2$ $-7_{10} = 11000_2$
- Called One's Complement
- Note: positive numbers have leading 0s, negative numbers have leadings 1s.



- What is -00000 ? Answer: 11111
- How many positive numbers in N bits?
- How many negative ones?

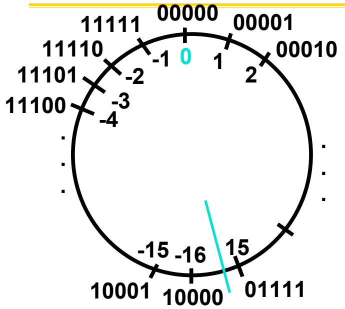
Shortcomings of One's complement?

- Arithmetic still a somewhat complicated.
- Still two zeros
  - `0x00000000` = $+0_{ten}$
  - `0xFFFFFFFF` = -0_{ten}
- Although used for awhile on some computer products, one's complement was eventually abandoned because another solution was better.

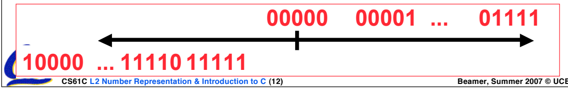
Standard Negative Number Representation

- What is result for unsigned numbers if tried to subtract large number from a small one?
  - Would try to borrow from string of leading 0s, so result would have a string of leading 1s
    - 3 - 4 ⇒ 00…0011 - 00…0100 = 11…1111
  - With no obvious better alternative, pick representation that made the hardware simple
  - As with sign and magnitude, leading 0s ⇒ positive, leading 1s ⇒ negative
    - 000000...xxx is ≥ 0, 111111...xxx is < 0
    - except 1…1111 is -1, not -0 (as in sign & mag.)
- This representation is Two's Complement

2's Complement Number "line": N = 5



- 2^{N-1} non-negatives
- 2^{N-1} negatives
- one zero
- how many positives?



Two’s Complement for N=32

$0000 \ldots 0000\ 0000\ 0000\ 0000_{two} = 0_{ten}$
$0000 \ldots 0000\ 0000\ 0000\ 0001_{two} = 1_{ten}$
$0000 \ldots 0000\ 0000\ 0000\ 0010_{two} = 2_{ten}$
. . .
$0111 \ldots 1111\ 1111\ 1111\ 1101_{two} = 2{,}147{,}483{,}645_{ten}$
$0111 \ldots 1111\ 1111\ 1111\ 1110_{two} = 2{,}147{,}483{,}646_{ten}$
$0111 \ldots 1111\ 1111\ 1111\ 1111_{two} = 2{,}147{,}483{,}647_{ten}$
$1000 \ldots 0000\ 0000\ 0000\ 0000_{two} = -2{,}147{,}483{,}648_{ten}$
$1000 \ldots 0000\ 0000\ 0000\ 0001_{two} = -2{,}147{,}483{,}647_{ten}$
$1000 \ldots 0000\ 0000\ 0000\ 0010_{two} = -2{,}147{,}483{,}646_{ten}$
. . .
$1111 \ldots 1111\ 1111\ 1111\ 1101_{two} = -3_{ten}$
$1111 \ldots 1111\ 1111\ 1111\ 1110_{two} = -2_{ten}$
$1111 \ldots 1111\ 1111\ 1111\ 1111_{two} = -1_{ten}$

- One zero; 1st bit called sign bit
- 1 “extra” negative:no positive $2{,}147{,}483{,}648_{ten}$

Two’s Complement Formula

- Can represent positive and negative numbers in terms of the bit value times a power of 2:

$d_{31} \times \boxed{-(2^{31})} + d_{30} \times 2^{30} + \ldots + d_2 \times 2^2 + d_1 \times 2^1 + d_0 \times 2^0$

- Example: 1101_{two}

$= 1x\text{-}(2^3) + 1x2^2 + 0x2^1 + 1x2^0$
$= -2^3 + 2^2 + 0 + 2^0$
$= -8 + 4 + 0 + 1$
$= -8 + 5$
$= -3_{ten}$

Two’s Complement shortcut: Negation

*Check out `www.cs.berkeley.edu/~dsw/twos_complement.html`

- Change every 0 to 1 and 1 to 0 (invert or complement), then add 1 to the result
- Proof*: Sum of number and its (one’s) complement must be $111\ldots111_{two}$

  However, $111\ldots111_{two} = -1_{ten}$

  Let x’ ⇒ one’s complement representation of x

  Then x + x’ = -1 ⇒ x + x’ + 1 = 0 ⇒ x’ + 1 = -x

- Example: -3 to +3 to -3

x : $1111\ 1111\ 1111\ 1111\ 1111\ 1111\ 1111\ 1101_{two}$
x’: $0000\ 0000\ 0000\ 0000\ 0000\ 0000\ 0000\ 0010_{two}$
+1: $0000\ 0000\ 0000\ 0000\ 0000\ 0000\ 0000\ 0011_{two}$
()’: $1111\ 1111\ 1111\ 1111\ 1111\ 1111\ 1111\ 1100_{two}$
+1: $1111\ 1111\ 1111\ 1111\ 1111\ 1111\ 1111\ 1101_{two}$

You should be able to do this in your head…

Two’s comp. shortcut: Sign extension

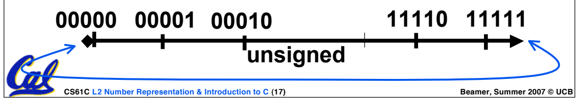
- Convert 2’s complement number rep. using n bits to more than n bits
- Simply replicate the most significant bit (sign bit) of smaller to fill new bits
  - 2’s comp. positive number has infinite 0s
  - 2’s comp. negative number has infinite 1s
  - Binary representation hides leading bits; sign extension restores some of them
  - 16-bit -4_{ten} to 32-bit:

$1111\ 1111\ 1111\ 1100_{two}$

$1111\ 1111\ 1111\ 1111\ 1111\ 1111\ 1111\ 1100_{two}$

What if too big?

- Binary bit patterns above are simply representatives of numbers. Strictly speaking they are called “numerals”.
- Numbers really have an ∞ number of digits
  - with almost all being same (00…0 or 11…1) except for a few of the rightmost digits
  - Just don’t normally show leading digits
- If result of add (or -, *, /) cannot be represented by these rightmost HW bits, overflow is said to have occurred.

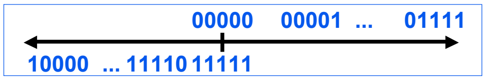


Preview: Signed vs. Unsigned Variables

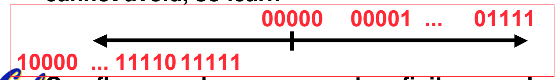
- Java and C declare integers `int`
  - Use two’s complement (signed integer)
- Also, C declaration `unsigned int`
  - Declares a unsigned integer
  - Treats 32-bit number as unsigned integer, so most significant bit is part of the number, not a sign bit

Number summary...

- We represent "things" in computers as particular bit patterns: N bits ⇒ 2^N
- Decimal for human calculations, binary for computers, hex to write binary more easily
- 1's complement - mostly abandoned



- 2's complement universal in computing: cannot avoid, so learn



- Overflow: numbers ∞; computers finite,errors!

Peer Instruction Question

X = 1111 1111 1111 1111 1111 1111 1111 1100_{two}

Y = 0011 1011 1001 1010 1000 1010 0000 0000_{two}

A. X > Y (if signed)

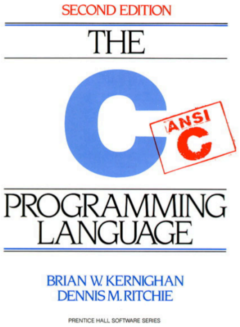
B. X > Y (if unsigned)

	AB
1:	FF
2:	FT
3:	TF
4:	TT

Administrivia

- Enrollment Issues http://summer.berkeley.edu/
- Lab Today
  - We'll ask you to sign a document saying you understand the cheating policy (from Lec #1) and agree to abide by it.
- HW
  - HW1 due Sunday @ 23:59 PST
  - HW2 due following Wed @ 23:59 PST
- Reading
  - K&R Chapters 1-5 (lots, get started now!);
- Get cardkeys from CS main office Soda Hall 3rd fl
  - Soda locks doors @ 6:30pm & on weekends
- UNIX Helpsession, Today @ 5pm in 271 Soda

Introduction to C


SECOND EDITION
THE
C
ANSI C
PROGRAMMING
LANGUAGE
BRIAN W. KERNIGHAN
DENNIS M. RITCHIE
PRENTICE HALL SOFTWARE SERIES

Disclaimer

- Important: You will not learn how to fully code in C in these lectures! You'll still need your C reference for this course.
  - K&R is a great reference.
    - But… check online for more sources.
  - "JAVA in a Nutshell" – O'Reilly.
    - Chapter 2, "How Java Differs from C".

Compilation : Overview

C *compilers* take C and convert it into an architecture specific machine code (string of 1s and 0s).

- Unlike Java which converts to architecture independent bytecode.
- Unlike most Scheme environments which interpret the code.
- Generally a 2 part process of compiling .c files to .o files, then linking the .o files into executables

Compilation : Advantages

- **Great run-time performance**: generally much faster than Scheme or Java for comparable code (because it optimizes for a given architecture)
- **OK compilation time**: enhancements in compilation procedure (Makefiles) allow only modified files to be recompiled

Compilation : Disadvantages

- All compiled files (including the executable) are architecture specific, depending on *both* the CPU type and the operating system.
- Executable must be rebuilt on each new system.
  - Called "porting your code" to a new architecture.
- The "change→compile→run [repeat]" iteration cycle is slow

C vs. Java™ Overview (1/2)

Java	C
Object-oriented (OOP)	No built-in object abstraction. Data separate from methods.
"Methods"	"Functions"
Class libraries of data structures	C libraries are lower-level
Automatic memory management	Manual memory management
	Pointers

C vs. Java™ Overview (2/2)

Java	C
High memory overhead from class libraries	Low memory overhead
Relatively Slow	Relatively Fast
Arrays initialize to zero	Arrays initialize to garbage

Syntax:
`/* comment */`
`// comment`
`System.out.print`
	Syntax:
	`/* comment */`
	`printf`

C Syntax: Variable Declarations

- Very similar to Java, but with a few minor but important differences
- All variable declarations must go before they are used (at the beginning of the block).
- A variable may be initialized in its declaration.
- Examples of declarations:
  - correct: `{`

```
    int a = 0, b = 10;
        ...
```

  - incorrect: `for (int i = 0; i < 10; i++)`

C Syntax: True or False?

- What evaluates to FALSE in C?
  - 0 (integer)
  - NULL (pointer: more on this later)
  - no such thing as a Boolean
- What evaluates to TRUE in C?
  - everything else…
  - (same idea as in scheme: only `#f` is false, everything else is true!)

C syntax : flow control

- Within a function, remarkably close to Java constructs in methods (shows its legacy) in terms of flow control
  - `if-else`
  - `switch`
  - `while` and `for`
  - `do-while`

C Syntax: `main`

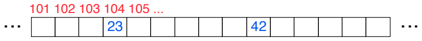
- To get the main function to accept arguments, use this:

```
int main (int argc, char *argv[])
```

- What does this mean?
  - `argc` will contain the number of strings on the command line (the executable counts as one, plus one for each argument).
    - Example: `unix% sort myFile`
  - `argv` is a pointer to an array containing the arguments as strings (more on pointers later).

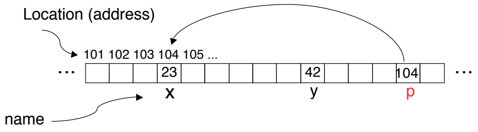
Address vs. Value

- Consider memory to be a single huge array:
  - Each cell of the array has an address associated with it.
  - Each cell also stores some value
  - Do you think they use signed or unsigned numbers? Negative address?!
- Don't confuse the address referring to a memory location with the value stored in that location.



Pointers

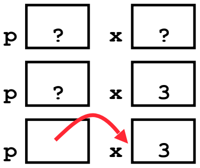
- An address refers to a particular memory location. In other words, it points to a memory location.
- Pointer: A variable that contains the address of another variable.



Pointers

- How to create a pointer:
  - `&` operator: get address of a variable

```
int *p, x;
   x = 3;
   p =&x;
```



Note the "*" gets used 2 different ways in this example. In the declaration to indicate that `p` is going to be a pointer, and in the `printf` to get the value pointed to by `p`.

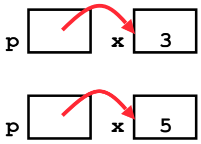
- How get a value pointed to?
  - `*` "dereference operator": get value pointed to

```
printf("p points to %d\n",*p);
```

Pointers

- How to change a variable pointed to?
  - Use dereference `*` operator on left of =

```
*p = 5;
```



Pointers and Parameter Passing

- Java and C pass a parameter "by value"
  - procedure/function gets a copy of the parameter, so changing the copy cannot change the original

```
void addOne (int x) {
   x = x + 1;
}
int y = 3;
addOne(y);
```

- `y` is still = 3

Pointers and Parameter Passing

- How to get a function to change a value?

```
void addOne (int *p) {
  *p = *p + 1;
}
int y = 3;


addOne(&y);
```

- `y` is now = 4

Pointers

- Normally a pointer can only point to one type (`int`, `char`, a `struct`, etc.).
  - `void *` is a type that can point to anything (generic pointer)
  - Use sparingly to help avoid program bugs… and security issues… and a lot of other bad things!

Peer Instruction Question

```
void main(); {
  int *p, x=5, y; // init
  y = *(p = &x) + 10;
  int z;
  flip-sign(p);
  printf("x=%d,y=%d,p=%d\n",x,y,p);
}
flip-sign(int *n){*n = -(*n)}
```

How many errors?

```
#Errors
     1
     2
     3
     4
     5
     6
     7
     8
     9
  (1)0
```

Peer Instruction Answer

```
void main(); {
  int *p, x=5, y; // init
  y = *(p = &x) + 10;
  int z;
  flip-sign(p);
  printf("x=%d,y=%d,p=%d\n",x,y,*p);
}
flip-sign(int *n){*n = -(*n);}
```

How many errors? I get 7.

```
#Errors
     1
     2
     3
     4
     5
     6
     7
     8
     9
  (1)0
```

And in conclusion…

- All declarations go at the beginning of each function.
- Only 0 and NULL evaluate to FALSE.
- All data is in memory. Each memory location has an address to use to refer to it and a value stored in it.
- A pointer is a C version of the address.
  - * "follows" a pointer to its value
  - & gets the address of a value