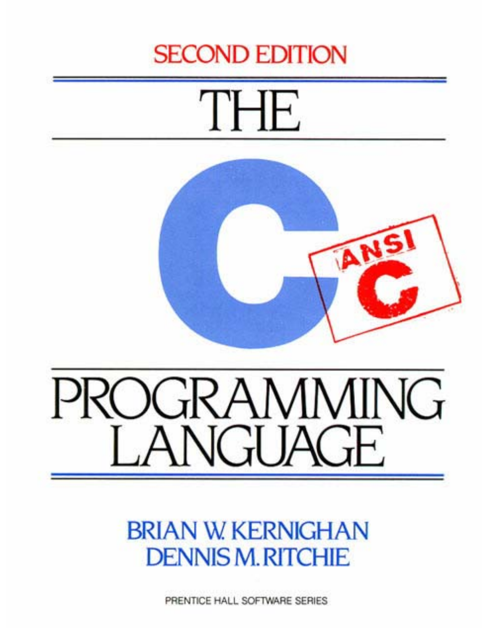
inst.eecs.berkeley.edu/~cs61c

CS61C : Machine Structures

Lecture 2: Introduction To C



2005-06-21

Andy Carle

Review

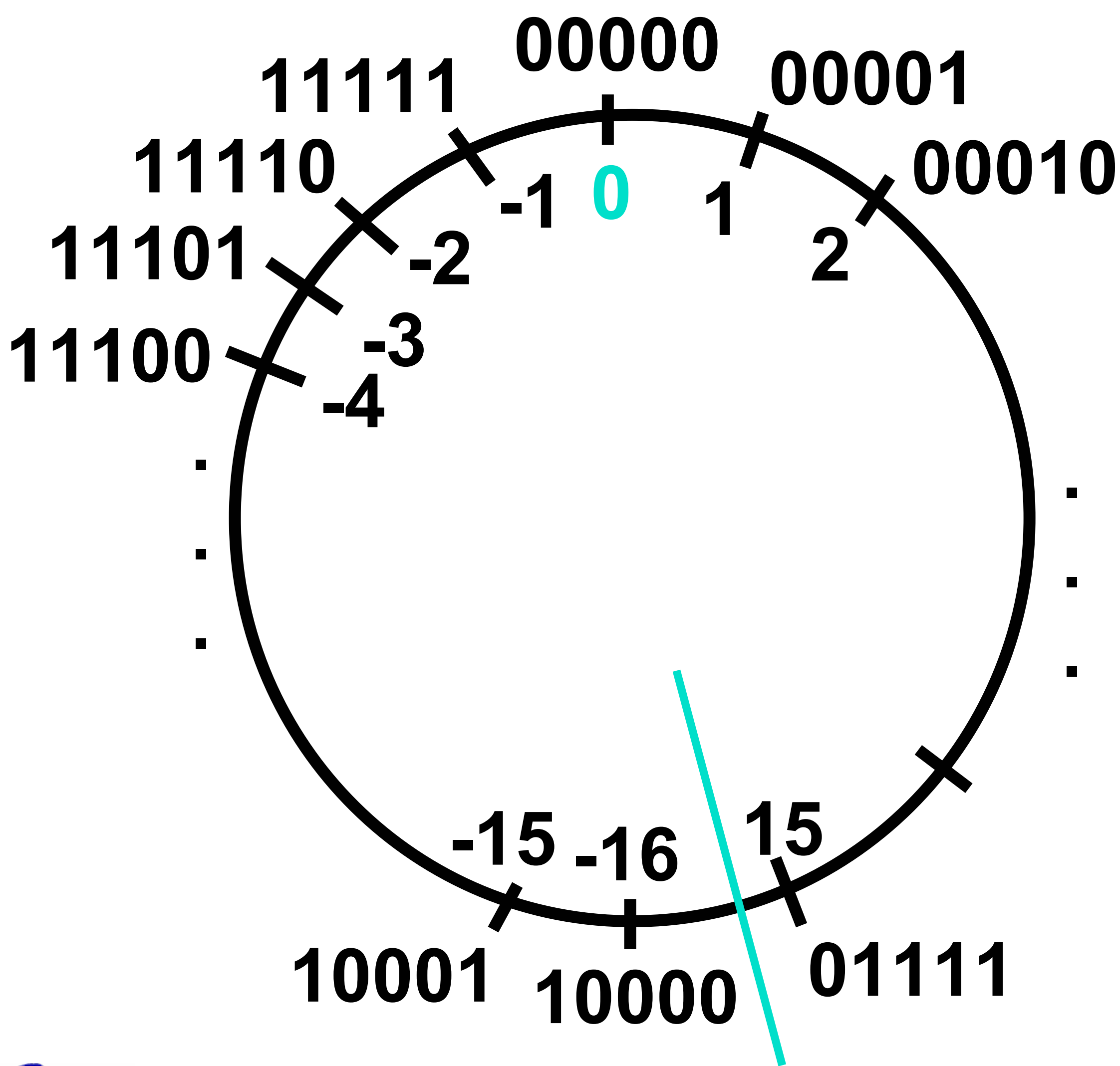
- Two's Complement ….

2's Complement Properties

- 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.)

- Only 1 Zero!

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



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

Two's Complement Formula

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

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

- Example: 1101_{two}

$= 1x-(2^3) + 1x2^2 + 0x2^1 + 1x2^0$

$= -2^3 + 2^2 + 0 + 2^0$

$= -8 + 4 + 0 + 1$

$= -8 + 5$

$= -3_{ten}$

Two's Complement shortcut: Negation

- 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 $111...111_{two}$

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

  Let $x' \Rightarrow$ one's complement representation of x

  Then $x + x' = -1 \Rightarrow x + x' + 1 = 0 \Rightarrow x' + 1 = -x$

- 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: $1111\ 1111\ 1111\ 1111\ 1111\ 1111\ 1111\ 1101_{two}$

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

Two's comp. shortcut: Sign extension

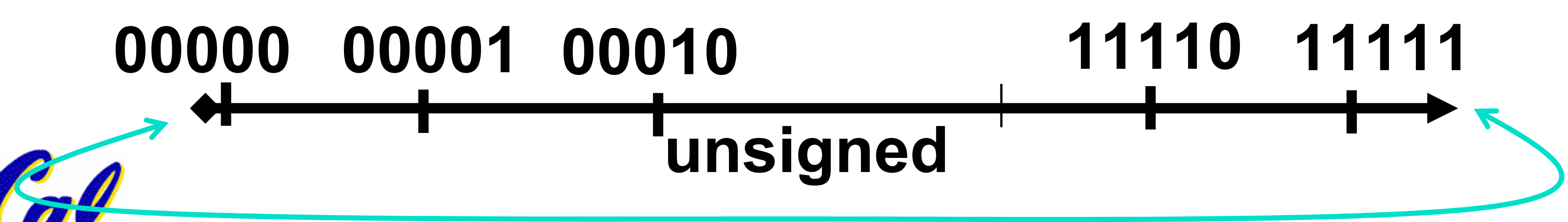
- **Convert 2's complement number rep. using n bits to more than n bits**
- **Simply replicate the most significant bit (sign bit) of smaller to fill new bits**
  - **2's comp. positive number has infinite 0s**
  - **2's comp. negative number has infinite 1s**
  - **Binary representation hides leading 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.



Number Summary

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

00000 00001 ... 01111

10000 ... 11110 11111

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

00000 00001 ... 01111

10000 ... 11110 11111

- Overflow: numbers ∞; computers finite, errors!

Preview: Signed vs. Unsigned Variables

- Java just declares integers `int`
  - Uses two's complement
- C has declaration `int` also
  - Declares variable as a signed integer
  - Uses two's complement
- 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

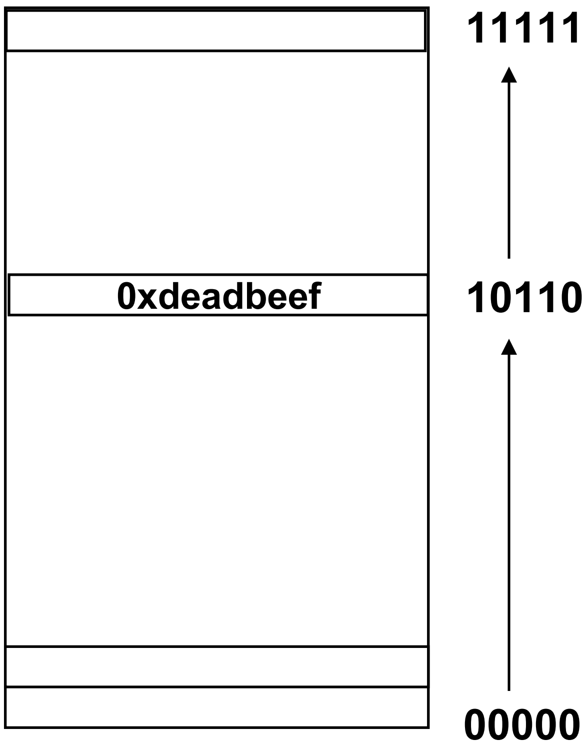
Big Idea

- **Next Topic: Numbers can Be Anything!**

BIG IDEA: Bits can represent anything!!

- **REMEMBER:** N digits in base B $\Rightarrow$ B^N values
  - For binary in particular: N bits → 2^N values
- Characters?
  - 26 letters $\Rightarrow$ 5 bits ($2^5 = 32$)
  - upper/lower case + punctuation $\Rightarrow$ 7 bits (in 8) ("ASCII")
  - standard code to cover all the world languages $\Rightarrow$ 16 bits ("Unicode")
- Logical values?
  - 0 $\Rightarrow$ False, 1 $\Rightarrow$ True
- colors ? Ex: *Red (00)* *Green (01)* *Blue (11)*
- locations / addresses? commands?

Example: Numbers represented in memory



- Memory is a place to store bits
- A *word* is a fixed number of bits (eg, 32) at an address
- *Addresses* are naturally represented as unsigned numbers in C

Moving Along

- Next Topic: Intro to C

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

- High memory overhead from class libraries
- Relatively Slow
- Arrays initialize to zero
- Syntax:

```
/* comment */
// comment
System.out.print
```

C

- Low memory overhead
- Relatively Fast
- Arrays initialize to garbage
- 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).

Administrivia

- First labs today ("lab is where the learning happens")
- The syllabus is still coming (tomorrow) – I'm making a slight tweak to the grading policy based on feedback Prof. Garcia got last semester
- You will receive a copy of the cheating policy to *sign and return* today in lab. The same information will be available in the syllabus and on the website
- We're still working on getting everyone enrolled in a section

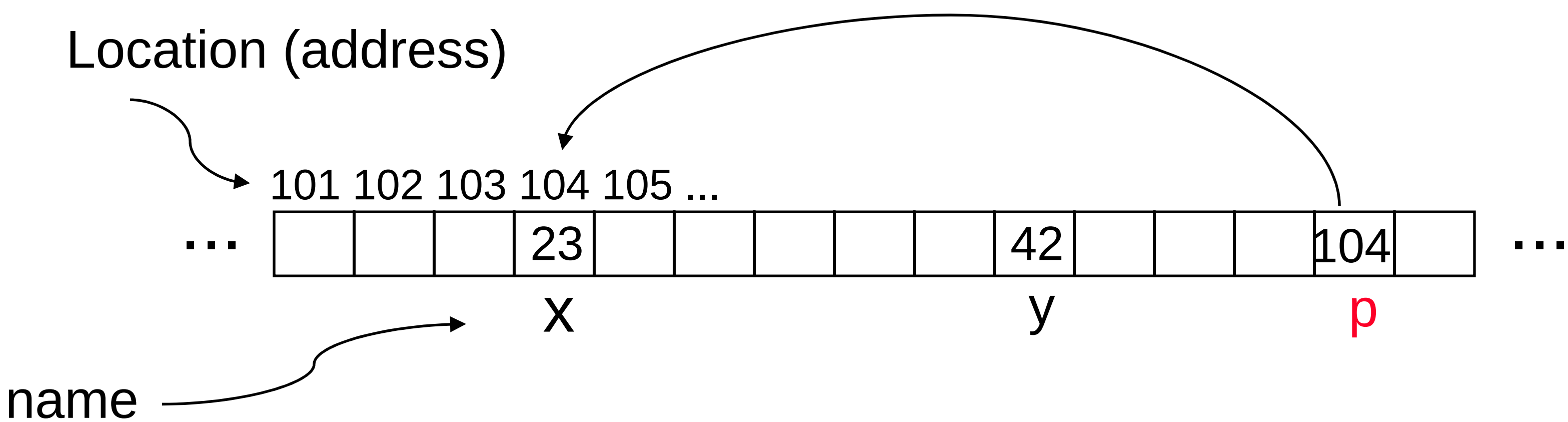
Address vs. Value

- 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.
- Don’t confuse the address referring to a memory location with the value stored in that location.

	101	102	103	104	105 ...											
…				23						42						…

Pointers

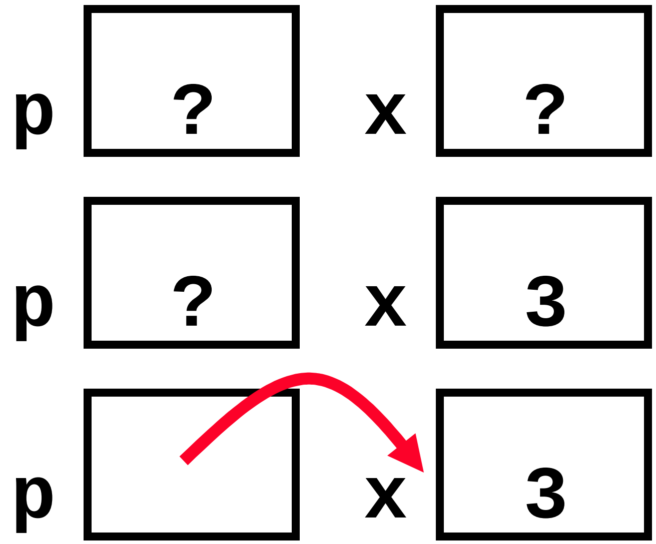
- An address refers to a particular memory location. In other words, it <u>points</u> to a memory location.
- **Pointer**: A variable that contains the <u>address</u> of another variable.



Pointers

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

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



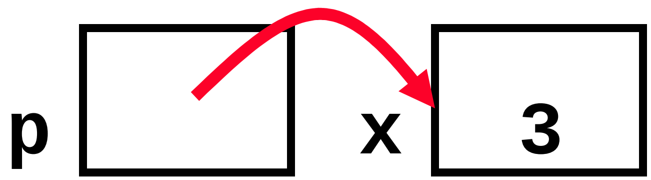
Note the "*" gets used 2 different ways in this example. In the declaration to indicate that **`p`** is going to be a pointer, and in the **`printf`** to get the value pointed to by **`p`**.

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

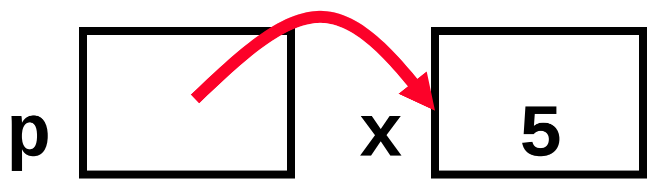
```
printf("p points to %d\n",*p);
```

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

- A proven method for increasing student understanding
- The steps:
  - I ask you a question
  - You *silently* contemplate your answer
    - Here, we're supposed to vote… I'm working on a mechanism to make that happen in this room
  - When I tell you to, talk to your neighbors about your answer and settle on a new answer as a group
    - Here we should vote again. I'll probably just ask someone random for their answer

The 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?

My 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.

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