CS61C : Machine Structures

Lecture 2 –
Introduction To C

2004-06-22

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Review

- Two's Complement ….

Another Attempt …

- Gedanken: Decimal Car Odometer

  00003 → 00002 → 00001 → 00000 → 99999 → 99998

- Binary Odometer:

  00011 → 00010 → 00001 → 00000 → 11111 → 11110

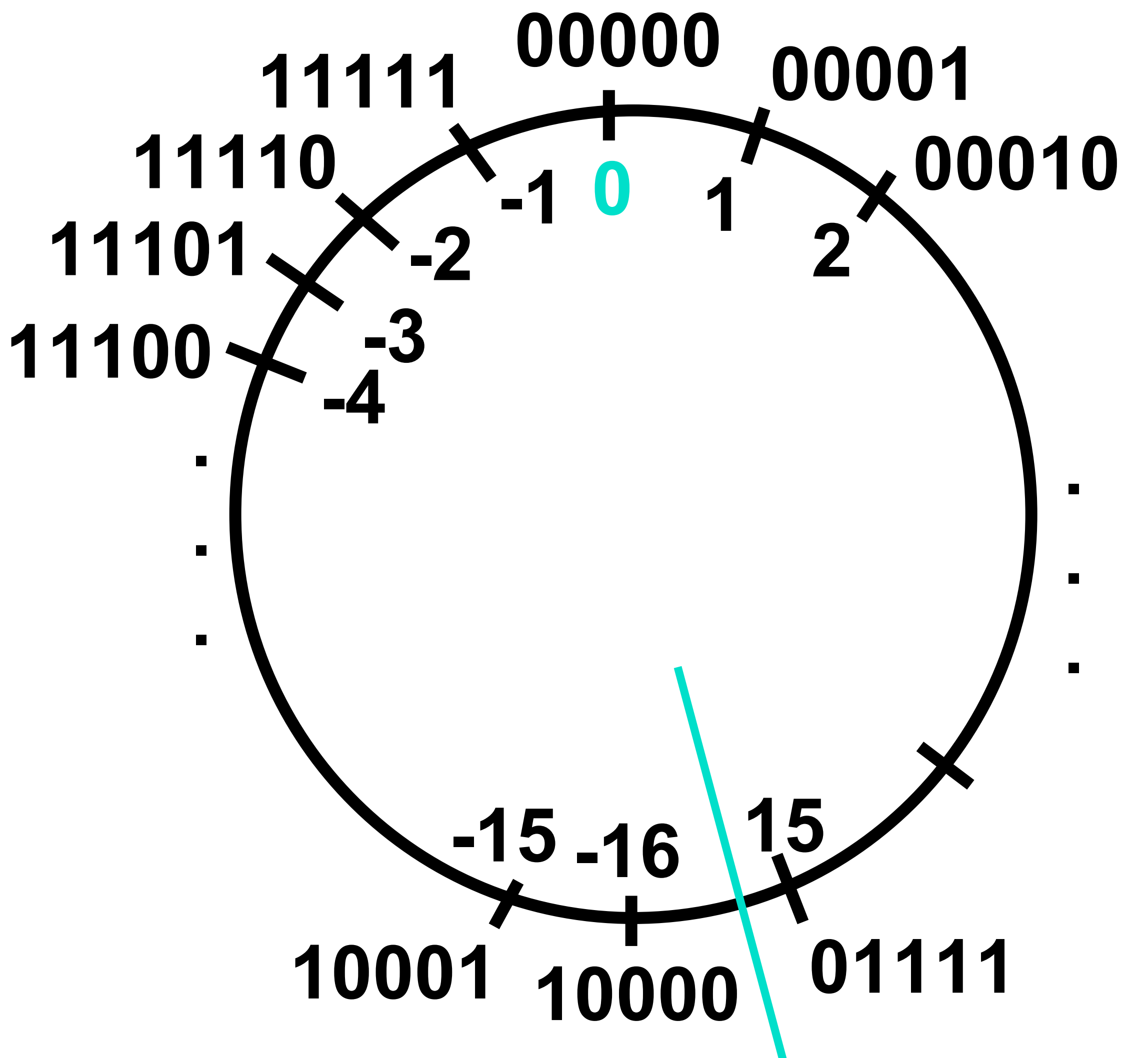
- With no obvious better alternative, pick representation that makes the math simple!
  - $99999_{ten} == -1_{ten}$
  - $11111_{two} == -1_{ten}$ $11110_{two} == -2_{ten}$
- This representation is Two's Complement

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 for N=32

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

- 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:

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

- Example: 1101_{two}

$= 1 \times -(2^3) + 1 \times 2^2 + 0 \times 2^1 + 1 \times 2^0$

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

$= -8 + 4 + 0 + 1$

$= -8 + 5$

$= -3_{ten}$

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' ⇒ 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: $1111\ 1111\ 1111\ 1111\ 1111\ 1111\ 1111\ 1101_{two}$

* 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:**

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

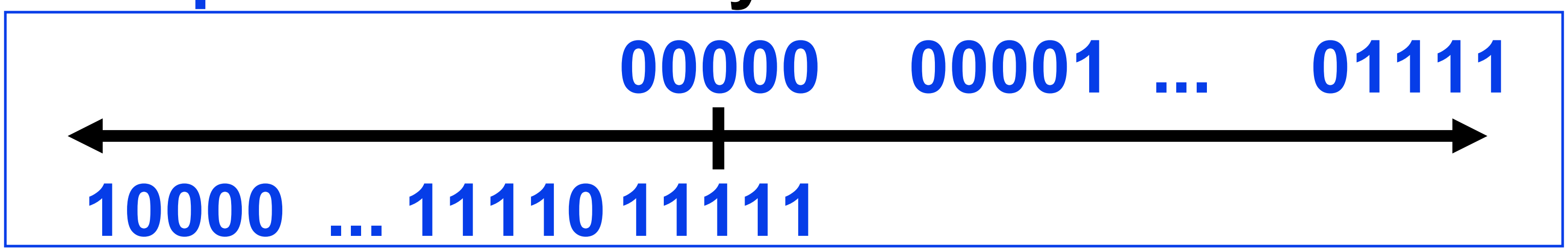
$$1111\ 1111\ 1111\ 1111\ 1111\ 1111\ 1111\ 1100_{two}$$

What if too big?

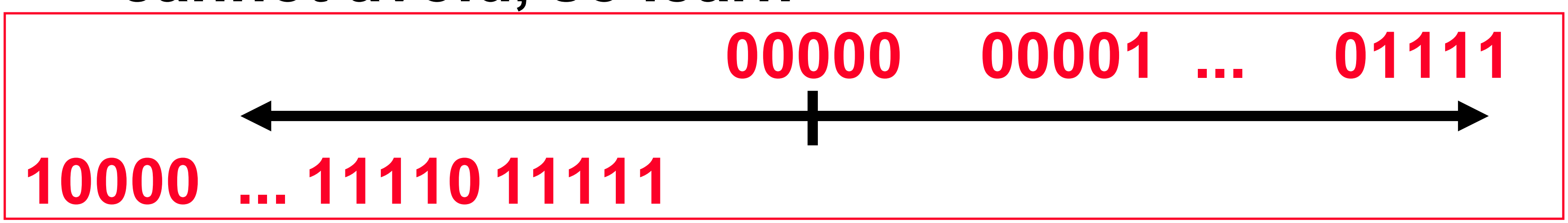
- **Binary bit patterns above are simply representatives of numbers. Strictly speaking they are called "numerals".**
- **Numbers really have an ∞ number of digits**
  - **with almost all being same (00…0 or 11…1) except for a few of the rightmost digits**
  - **Just don't normally show leading digits**
- **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 ⇒ 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!

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**

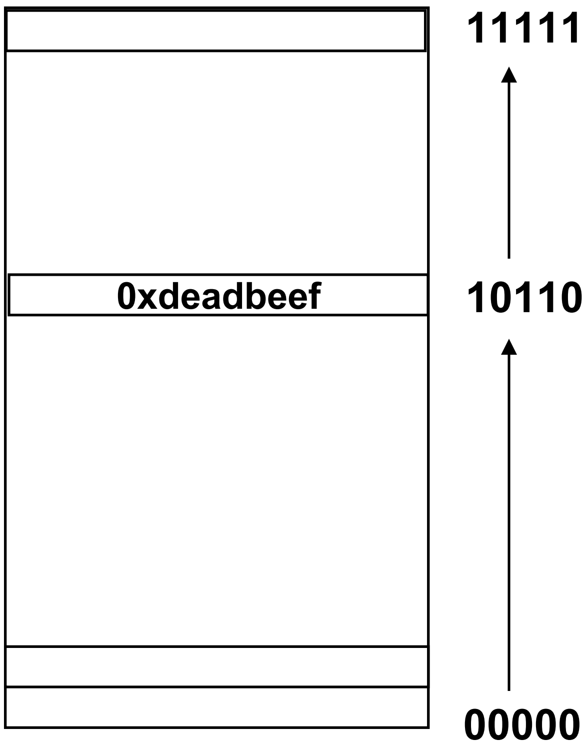
Big Idea

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

BIG IDEA: Bits can represent anything!!

- **REMEMBER:** N digits in base B ⇒ B^N values
  - For binary in particular: N bits → 2^N values
- Characters?
  - 26 letters ⇒ 5 bits ($2^5 = 32$)
  - upper/lower case + punctuation ⇒ 7 bits (in 8) ("ASCII")
  - standard code to cover all the world languages ⇒ 16 bits ("Unicode")
- Logical values?
  - 0 ⇒ False, 1 ⇒ 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

New Topic

- **Course Administration**

Administrivia – Read the course handout

- Just about everything is in the course info handout.
  - Sec 2: Course is difficult over summer
    - Be prepared to commit 12 hrs/week in class and 20 hrs/week outside of class!
  - Sec 3: Textbooks: COD, K&R
  - Sec 4: Labs and Discussion
    - Go to your own this week
    - Log into your account!
    - Hand in survey/statement to TA.

Administrivia – Read the course handout

- **Sec 10: Assignments:**
  - **1) Online Pre-lecture Quizzes:**
    - Mandatory (Effort)
    - About 20 over the semester
    - Wednesday's is up now (or very soon)
    - In general, will be up at least two days in advance
    - No late quizzes; no partners
  - **2) Labs**
    - Mandatory (Correctness)
    - 2 per week
    - "Checked-off" by TA during section
      - » TA will ask questions – you answer them!
    - No late labs; "no partners"

Administrivia – Read the course handout

- **Sec 10: Assignments:**
  - **3) Homeworks**
    - Mandatory Online Turnin
      - » Graded once on correctness
      - » Chance to get back points
    - 2 Per week
    - Both due on Sunday 8:00pm after assigned
    - No late homeworks; no partners
  - **4) Projects**
    - Mandatory (Correctness) Online Turnin
      - » Probably graded face-to-face.
    - 1 Project roughly every 4 weeks
    - No late projects; "no partners"

Administrivia – Read the course handout

- **Sec 11: Grading:**

```
20 reading quizzes  @   0.5 points each  =  10 pts
15 labs             @     2 points each  =  30 pts
15 homeworks        @     4 points each  =  60 pts
 4 projects         @  12.5 points each  =  50 pts
 3 midterms         @    30 points each  =  90 pts
 1 final                                 =  60 pts
--                                          ---
58 assignments                              300 pts
```

- **Midterms/Final: On Fridays, 3 hours, cover two weeks at a time**

Administrivia – Read the course handout

- **Sec 11: Grading**

A+	280-300	A	270-279	A-	260-269
B+	250-259	B	240-249	B-	230-239
C+	220-229	C	210-219	C-	200-209
D+	190-199	D	180-189	D-	170-179

  - **I may adjust it in your favor**

Administrivia – Read the course handout

- **Sec 12: Assignment Grading**
  - **Labs: checkoff by TA**
  - **Quizzes: submit via www**
  - **HW:**
    - Submit via ‘submit’ program
    - Graded on correctness
    - If it appears that you put in honest effort, but got less than 90/100 ….
      - » Sign up for face-to-face session with grader
      - » Look up solutions, understand them, figure out what you did wrong
      - » Convince grader that you now understand what you got wrong
      - » Grader will give you up to 90/100 points back!

Administrivia – Read the course handout

- **Sec 13: Cheating**
  - **Don’t do it.**
  - **Detection:**
    – Automated programs,
    – Staff suspicions
    – Understanding of material
  - **Penalty:**
    – If you confess ➔ zero on assignment, “faculty disposition” to OSC (not noted in record)
    – If you don’t ➔ “Faculty referral” to OSC (noted in record if OSC finds against you)
  - **Please sign the “Statement on Cheating”.**

Big Idea

- **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 must-have reference.
    - 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`

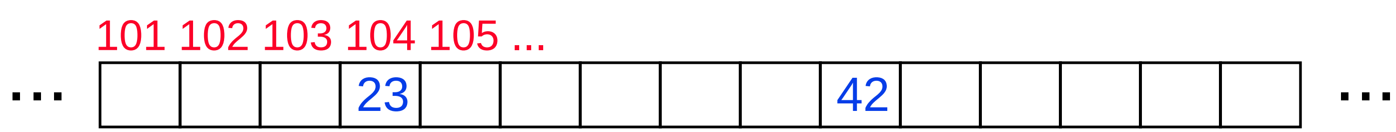
- To get the main function to accept arguments, use this:

```
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).

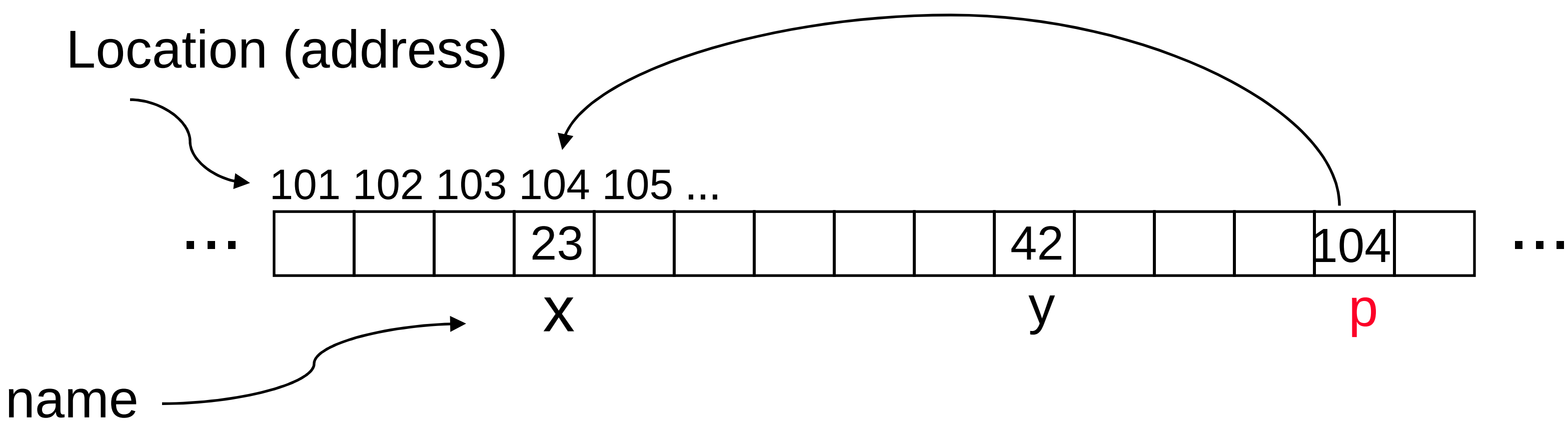
Address vs. Value

- 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.



Pointers

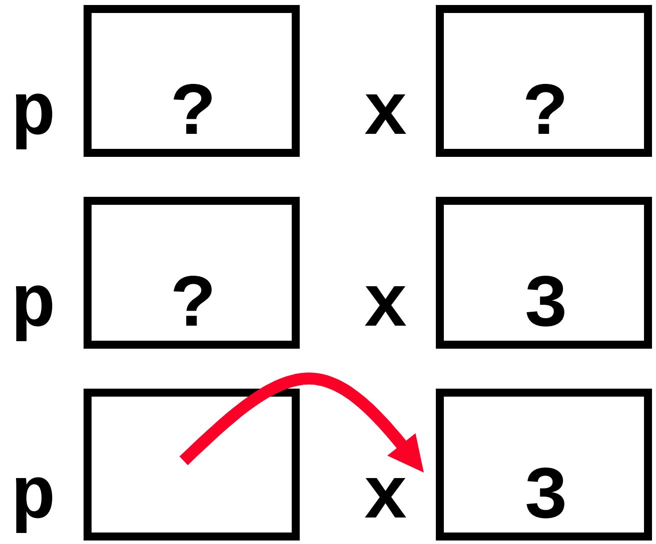
- An address refers to a particular memory location. In other words, it <u>points</u> to a memory location.
- **Pointer**: A variable that contains the <u>address</u> of a variable.



Pointers

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

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



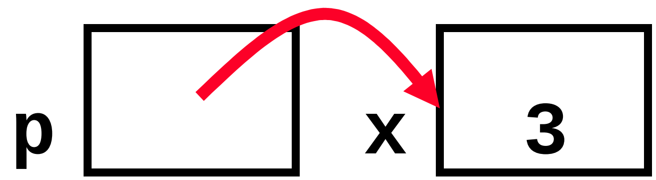
Note the "*" gets used 2 different ways in this example. In the declaration to indicate that **p** is going to be a pointer, and in the **`printf`** to get the value pointed to by **p**.

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

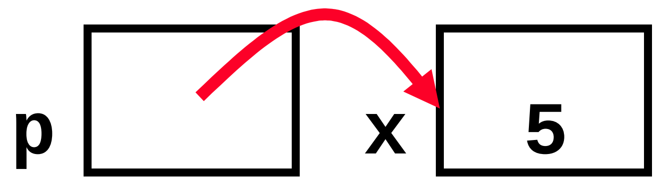
```
printf("p points to %d\n",*p);
```

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 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