CS 61C: Great Ideas in Computer Architecture (Machine Structures)

Introduction to C (Part I)

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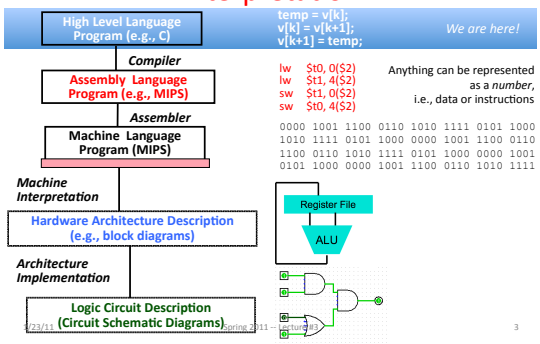
Agenda

- Scheme vs. Java vs. C
- Administrivia
- Quick Start Introduction to C
- Technology Break
- Pointers
- Summary

Levels of Representation/ Interpretation



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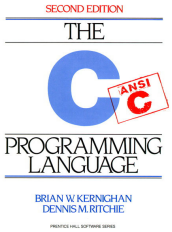
Introduction to C "the Universal Assembly Language"

- "Some" C experience is required before CS61C
  C++ or Java OK



- Based on pre-semester survey:
  - 83% already know JAVA
  - 54% already know C++
  - 34% already know C
  - 7% already know C#
  - About 10% have not taken 61B or equivalent
- If you have no experience in these languages, then start early and ask a lot of questions in discussion!

Disclaimer

- 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
    - Check online for more sources
  - "JAVA in a Nutshell," O'Reilly
    - Chapter 2, "How Java Differs from C"
    - http://oreilly.com/catalog/javanut/excerpt/
  - Brian Harvey's helpful transition notes
    - On CS61C class website
    - http://inst.eecs.berkeley.edu/~cs61c/resources/HarveyNotesC1-3.pdf
- Key C concepts: Pointers, Arrays, Implications for Memory management

C vs. Java

	C	Java
Type of Language	Function Oriented	Object Oriented
Program-ming Unit	Function	Class = Abstract Data Type
Compilation	gcc hello.c creates machine language code	javac Hello.java creates Java virtual machine language bytecode
Execution	a.out loads and executes program	java Hello interprets bytecode

hello, world	`#include<stdio.h>`
	`int main(void) {`
	`  printf("Hello\n");`
	`  return 0;`
	`}`
		`public class HelloWorld {`
		`  public static void main (String[] args) {`
		`  System.out.printl("Hello");`
		`  }`
		`}`

Storage	Manual (**`malloc`**, **`free`**)	Automatic (garbage collection)

From http://www.cs.princeton.edu/introcs/faq/c2java.html

Basic C Concepts

Compiler	Creates useable programs from C source
Typed variables	Kind of data that a variable contains
Typed functions	The kind of data returned from a function
Header files (.h)	Declare functions and variables in a separate file
Structs	Groups of related values
Enums	Lists of predefined values
Pointers	Aliases to other variables

These concepts distinguish C from other languages you may know

Compilation: Overview

- C *compilers* map C programs into 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
  - These differ mainly in exactly when your program is converted to low-level machine instructions ("levels of interpretation")
  - For C, generally a two part process of compiling .c files to .o files, then linking the .o files into executables; Assembling is also done (but is hidden, i.e., done automatically, by default)

Compilation: Advantages

- Excellent run-time performance: generally much faster than Scheme or Java for comparable code (because it optimizes for a given architecture)
- Fair compilation time: enhancements in compilation procedure (Makefiles) allow only modified files to be recompiled
- Why C?: *we can write programs that allow us to exploit underlying features of the architecture – memory management, special instructions, parallelism*

Compilation: Disadvantages

- Compiled files, including the executable, are architecture-specific, depending on CPU type and the operating system
- Executable must be rebuilt on each new system
  - I.e., "porting your code" to a new architecture
- "Change → Compile → Run [repeat]" iteration cycle can be slow, during the development cycle

Typed Variables in C

```
int   variable1   = 2;
float variable2   = 1.618;
char  variable3   = 'A';
```

- You have to declare the type of data a variable will hold
  - Types can't change

Type	Description	Examples
int	integer numbers, including negatives	0, 78, -1400
unsigned int	integer numbers (no negatives)	0, 46, 900
float	floating point decimal numbers	0.0, 1.618, -1.4
char	single text character or symbol	'a', 'D', '?'
double	greater precision FP number	
long	larger signed integer	

Typed Functions in C

```
int numberOfPeople ()
{
  return 3;
}

float dollarsAndCents ()
{
  return 10.33;
}

char firstLetter ()
{
  return 'A';
}
```

- You have to declare the type of data you plan to return from a function
- Return type can be any C variable type, and is placed to the left of the function name
- You can also specify the return type as `void`
  - Just think of this as saying that no value will be returned
- Also necessary to define types for values passed into a function
- Variables and functions MUST be defined before they are used

Structs in C

- Structs are structured groups of variables, e.g.,

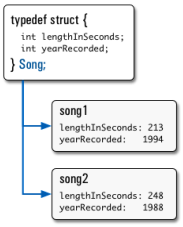
```
typedef struct {
  int lengthInSeconds;
  int yearRecorded;
} Song;

Song song1;

song1.lengthInSeconds =  213;
song1.yearRecorded    = 1994;

Song song2;

song2.lengthInSeconds =  248;
song2.yearRecorded    = 1988;
```



Dot notation: `x.y = value`

Consts and Enums in C

- Constant is assigned a value once in the declaration; value can't change until the program is restarted

```
const float goldenRatio = 1.618;
const int daysInWeek = 7;
```

- You can have a constant version of any of the standard C variable types
- Enums: a group of related constants used to parameterize libraries

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Administrivia

- We promised you that CS61c would be relentless!
  - This week: Lab #2, HW #2
  - Lab #2, Amazon EC2, will soon be posted
  - HW #2 will soon be posted
- TAs have their office hours late in the week – don't wait for last minute to get questions answered on HWs and Labs
  - Take a quick look when posted and come to discussion with questions
- We are amazed that there students who still haven't signed up for the class discussion/announcements group!
  - Wonderful to see the valuable discussion and help going on there!

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A First C Program: Hello World

Original C:

```
main()
{
  printf("\nHello World\n");
}
```

ANSI Standard C:

```
#include <stdio.h>

int main(void)
{
  printf("\nHello World\n");
  return (0);
}
```


A Second C Program: Compute Table of Sines

```
#include <stdio.h>
#include <math.h>

void main()
{
    int    angle_degree;
    double angle_radian, pi, value;
    /* Print a header */
    printf("\nCompute a table of the
   sine function\n\n");

    /* obtain pi once for all       */
    /* or just use pi = M_PI, where */
    /* M_PI is defined in math.h    */
    pi = 4.0*atan(1.0);
    printf("Value of PI = %f \n\n",
   pi);
    printf("angle     Sine \n");

    angle_degree = 0;
    /* initial angle value */
    /* scan over angle     */
    while (angle_degree <= 360)
    /* loop until angle_degree > 360 */
       {
          angle_radian = pi*angle_degree/180.0;
          value = sin(angle_radian);
          printf (" %3d      %f \n ",
                    angle_degree, value);
          angle_degree = angle_degree + 10;
          /* increment the loop index */
       }
    }
```


Second C Program Sample Output

```
Compute a table of the sine
   function

Value of PI = 3.141593

angle       Sine
   0      0.000000
  10      0.173648
  20      0.342020
  30      0.500000
  40      0.642788
  50      0.766044
  60      0.866025
  70      0.939693
  80      0.984808
  90      1.000000
 100      0.984808
 110      0.939693
 120      0.866025
 130      0.766044
 140      0.642788
 150      0.500000
 160      0.342020
 170      0.173648
 180      0.000000
 190     -0.173648
 200     -0.342020
 210     -0.500000
 220     -0.642788
 230     -0.766044
 240     -0.866025
 250     -0.939693
 260     -0.984808
 270     -1.000000
 280     -0.984808
 290     -0.939693
 300     -0.866025
 310     -0.766044
 320     -0.642788
 330     -0.500000
 340     -0.342020
 350     -0.173648
 360     -0.000000
```


C Syntax: `main`

- To get arguments to the main function, use:
  - `int main (int argc, char *argv[])`
- What does this mean?
  - `argc` contains the number of strings on the command line (the executable counts as one, plus one for each argument). Here `argc` is 2:
    unix% sort myFile
  - `argv` is a *pointer* to an array containing the arguments as strings (more on *pointers* later)

C Syntax: Variable Declarations

- Similar to Java, but with a few minor but important differences
- *All* variable declarations must appear before they are used (e.g., at the beginning of the block)
- A variable may be initialized in its declaration; if not, it holds garbage!
- Examples of declarations:
  - Correct: `{`
    `int a = 0, b = 10;`
    `...`
  - Incorrect: `for (int i = 0; i < 10; i++)`
    `}`

C Syntax : Flow Control (1/2)

- Within a function, remarkably close to Java constructs in methods (shows its legacy) in terms of flow control
  - `if-else`
    - `if (expression) statement`
    - `if (expression) statement1`
      `else statement2`
  - `while`
    - `while (expression)`
      `statement`
    - `do`
      `statement`
      `while (expression);`

C Syntax : Flow Control (2/2)

- Within a function, remarkably close to Java constructs in methods (shows its legacy) in terms of flow control
  - `for`
    - `for (initialize; check; update) statement`
  - `switch`
    - `switch (expression){`
      `case const1: statements`
      `case const2: statements`
      `default: statements`
      `}`
    - `break`

C Syntax: True or False

- What evaluates to FALSE in C?
  - 0 (integer)
  - NULL (a special kind of *pointer*: more on this later)
  - No explicit Boolean type
- What evaluates to TRUE in C?
  - Anything that isn't false is true
  - Same idea as in scheme: only #f is false, anything else is true!

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Pointers in C

- A pointer is just another kind of value
  - A basic type in C

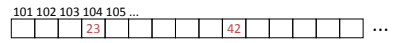
```
int *ptr;
```

Variable "ptr" is a pointer to an "int"

Some of these slides come from "Arrays and Pointers in C" by Alan Cox and T.S. Ng, Rice University, *www.clear.rice.edu/comp221/html/ppt/03-arrays-**pointers**.ppt*

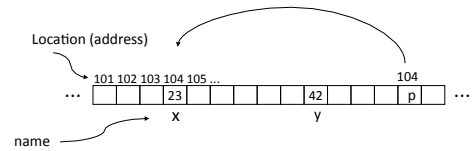
Address vs. Value

- 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 there



Pointers

- An *address* refers to a particular memory location; e.g., it points to a memory location
- *Pointer*: A variable that contains the address of a variable



Pointers in C

- If `T` is a type, `T *p` declares `p` a pointer to that type
- You can use `p` as a pointer to a `T`
- You can use `*p` as a `T`
- `p++` increments `p` by the size of a `T`
  - Important because of the way arrays are treated
- You can make a pointer to any variable
  - If `x` is any variable, then `&x` is its address

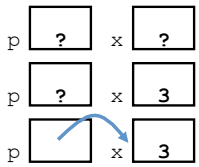
Pointer Operations in C

- Creation
  - `&` *variable* Returns variable's memory address
- Dereference
  - `*` *pointer* Returns contents stored at address
- Indirect assignment
  - `*`*pointer* = *val* Stores value at address
- Of course, still have … assignment
  - *pointer* = *ptr* Stores pointer in another variable

Pointer Examples

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

```
int *p, x;
```




```
x = 3;

p = &x;
```

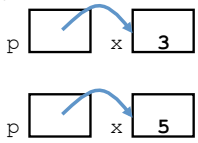
Note the "*" gets used 2 different ways in this example. In the declaration to indicate that **p** is going to be a pointer, and in the **printf** to get the value pointed to by **p**.

- How get a value pointed to?
  - `*` "dereference operator": get the value that the pointer points to

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


Pointer Examples

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




```
*p = 5;
```

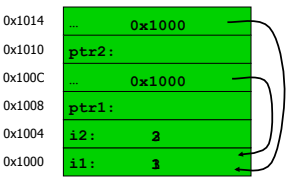

Pointer Examples

```
int  i1;
int  i2;
int *ptr1;
int *ptr2;

i1 = 1;
i2 = 2;

ptr1 = &i1;
ptr2 = ptr1;

*ptr1 = 3;
i2 = *ptr2;
```



Pointer Examples

```
int  int1     = 1036;   /* some data to point to  */
int  int2     = 8;

int *int_ptr1 = &int1;  /* get addresses of data  */
int *int_ptr2 = &int2;

*int_ptr1 = int_ptr2;

*int_ptr1 = int2;
```

What happens?

Type check warning: `int_ptr2` **is not an** `int`

`int1` **becomes 8**

Pointer Examples

```
int  int1     = 1036;   /* some data to point to  */
int  int2     = 8;

int *int_ptr1 = &int1;  /* get addresses of data  */
int *int_ptr2 = &int2;

int_ptr1 = *int_ptr2;

int_ptr1 = int_ptr2;
```

What happens?

Type check warning: `*int_ptr2` **is not an** `int *`

Changes `int_ptr1` **– doesn't change** `int1`

Pointers and Parameter Passing

- Java and C pass parameters "by value"
  - Procedure/function/method 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 remains equal to 3

Pointers and Parameter Passing

- How can we get a function to change a value?

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

addOne(&y);
```

y is now equal to 4

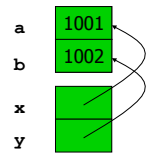
Pass By Reference

- In C, the default passing strategy is pass by copy
- To pass by reference, we use pass by copy – because in C, *everything* is pass by copy
- *Value* that we pass by copy is *address* of the actual argument: we achieve the through the *address operator* &
- In C, pass by reference is actually pass by copy – because you copy the address

Getting Pass-by-Reference

```
void
set_x_and_y(int *x,
            int *y)
{
   *x = 1001;
   *y = 1002;
}

void
f(void)
{
   int a = 1;
   int b = 2;
   set_x_and_y(&a,&b);
}
```



Pointers

- Pointers are used to point to any kind of data (`int`, `char`, a `struct`, etc.)
- Normally a pointer only points 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 other bad things!

Peer Instruction Question

```
void main(); {
  int *p, x=5, y; // init
  y = *(p = &x) + 1;
  int z;
  flip-sign(p);
  printf("x=%d,y=%d,p=%d\n",x,y,p);
}
flip-sign(int *n){*n = -(*n)}
```

How many syntax + logic errors in this C code?

```
#Errors
Red: 1
Orange: 2
Green: 3
Yellow: 4
Pink: 5
```


More C Pointer Dangers

- Declaring a pointer just allocates space to hold the pointer – it does not allocate the thing being pointed to!
- Local variables in C are not initialized, they may contain anything (aka "garbage")
- What does the following code do?

```
void f()
{
    int *ptr;
    *ptr = 5;
}
```


Pointers in C

- Why use pointers?
  - If we want to pass a large struct or array, it's easier / faster / etc. to pass a pointer than the whole thing
  - In general, pointers allow cleaner, more compact code
- So what are the drawbacks?
  - Pointers are probably the single largest source of bugs in C, so be careful anytime you deal with them
    - Most problematic with dynamic memory management—which you will to know by the end of the semester, but not for the projects (there will be a lab later in the semester)
    - *Dangling references* and *memory leaks*

Why Pointers in C?

- At time C was invented (early 1970s), compilers often didn't produce efficient code
  - Computers 25,000 times faster today, compilers better
- C designed to let programmer say what they want code to do without compiler getting in way
  - Even give compilers hints which registers to use!
- Today's compilers produce much better code, so may not need to use pointers
  - Compilers even ignore hints since they do it better!

FYI—Update to ANSI C

- "C99" or "C9x" standard
  - `gcc -std=c99` to compile
- References
  - http://en.wikipedia.org/wiki/C99
  - http://home.tiscalinet.ch/t_wolf/tw/c/c9x_changes.html
- Highlights
  - Declarations in for loops, like Java
  - Java-like // comments (to end of line)
  - Variable-length non-global arrays
  - `<inttypes.h>`: explicit integer types
  - `<stdbool.h>`: for boolean logic types and definitions

And In Conclusion, …

- All data is in memory
  - Each memory location has an address to use to refer to it and a value stored in it
- Pointer is a C version (abstraction) of a data address
  - `*` "follows" a pointer to its value
  - `&` gets the address of a value
  - Arrays and strings are implemented as variations on pointers
- C is an efficient language, but leaves safety to the programmer
  - Array bounds not checked
  - Variables not automatically initialized
  - Use pointers with care: they are a common source of bugs in programs