CS 33

Introduction to C

Some of this lecture is based on material prepared by Pascal Van Hentenryck.

A C Program

```
int main( ) {
  printf("Hello world!\n");
  return 0;
}
```


Following K&R, this is everyone's first C program. Note that C programs start in a procedure called *main*, which is a function returning an integer. This integer is interpreted as an error code, where 0 means no errors and anything else is some sort of indication of a problem. We'll see later how we can pass arguments to main.

Compiling and Running It

```
$ ls
hello.c
$ gcc hello.c
$ ls
a.out       hello.c
$ ./a.out
Hello world!
$ gcc -o hello hello.c
$ ls
a.out       hello       hello.c
$ ./hello
Hello world!
$
```


gcc (the Gnu C compiler), as do other C compilers, calls its output “a.out” by default. (This is supposed to mean the output of the assembler, since the original C compilers compiled into assembly language, which then had to be sent to the assembler.) To give the output of the C compiler, i.e., the executable, a more reasonable name, use the “-o” option.

What's gcc?

- gnu C compiler
  - it's actually a two-part script
    - » part one compiles files containing programs written in C (and certain other languages) into binary machine code (known as object code)
    - » part two takes the just-compiled object code and combines it with other object code from libraries to create an executable
      - the executable can be loaded into memory and run by the computer

What's gnu? It's a project of the Free Software Foundation and stands for "gnu's not Unix." That it's not Unix was pretty important when the gnu work was started in the 80s. At the time, AT&T was the owner of the Unix trademark and was very touchy about it. Today the trademark is owned by The Open Group, who is less touchy about it.

gcc Flags

- gcc [-Wall] [-g] [-std=c99]
  - -Wall
    - » provide warnings about pretty much everything that might conceivably be objectionable
      - much of this probably won't be objectionable to you …
  - -g
    - » provide extra information in the object code, so that gdb (gnu debugger) can provide more informative debugging info
      - discussed in lab
  - -std=c99
    - » use the 1999 version of C syntax, rather than the 1990 version

The use of the –Wall flag will probably produce lots of warning messages about things you had no idea might possibly be considered objectionable. In most cases, it's safe to ignore them (unless they also show up when you don't use the flag).

Unless you're really concerned about getting the last ounce of performance from your program, it's a good idea always to use the –g flag.

Most of what we will be doing is according to the C90 specification. The C99 specification cleaned a few things up and added a few features. There's also a C11 (2011) specification that is not yet supported by gcc.

Declarations in C

```
int main() {
 int i;
 float f;
 char c;
 return 0;
}
```

- Types are promises
  - promises can be broken
- Types specify memory sizes
  - cannot be broken

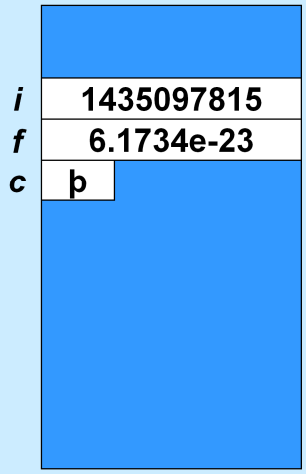
Declarations in C

```
int main() {
 int i;
 float f;
 char c;
 return 0;
}
```

- Declarations reserve memory space
  - where?
- Local variables are uninitialized
  - junk
  - whatever was there before

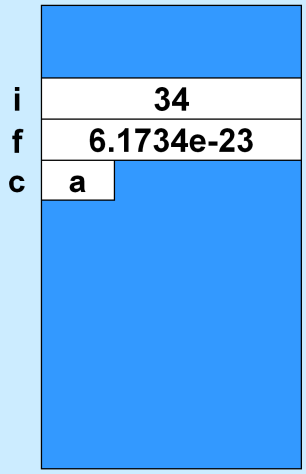
Declarations in C

```
int main() {
 int i;
 float f;
 char c;
 return 0;
}
```



Using Variables

```
int main() {
    int i;
    float f;
    char c;
    i = 34;
    c = 'a';
}
```



printf Again

```
int main() {
   int i;
   float f;
   char c;
   i = 34;
   c = 'a';
   printf("%d\n",i);
   printf("%d\t%c\n",i,c);
}
```

```
$ ./a.out
34
34      a
```

printf Again

```
int main() {
   …
   printf("%d\t%c\n",i,c);
}
```

```
$ ./a.out
34      a
```

Two parts

- **formatting instructions**
- **arguments**

printf Again

```
int main() {
   …
   printf("%d\t%c\n",i,c);
}
```

```
$ ./a.out
34      a
```

Formatting instructions

- **Special characters**
  - **\n : newline**
  - **\t : tab**
  - **\b : backspace**
  - **\" : double quote**
  - **\\ : backslash**

printf Again

```
int main() {
   …
   printf("%d\t%c",i,c);
}
```

```
$ ./a.out
34      a
```

Formating instructions

- **Types of arguments**
  - **%d: integers**
  - **%f: floating-point numbers**
  - **%c: characters**

printf Again

```
int main() {
   …
   printf("%6d%3c",i,c);
}
```

```
$ ./a.out
    34  a
```

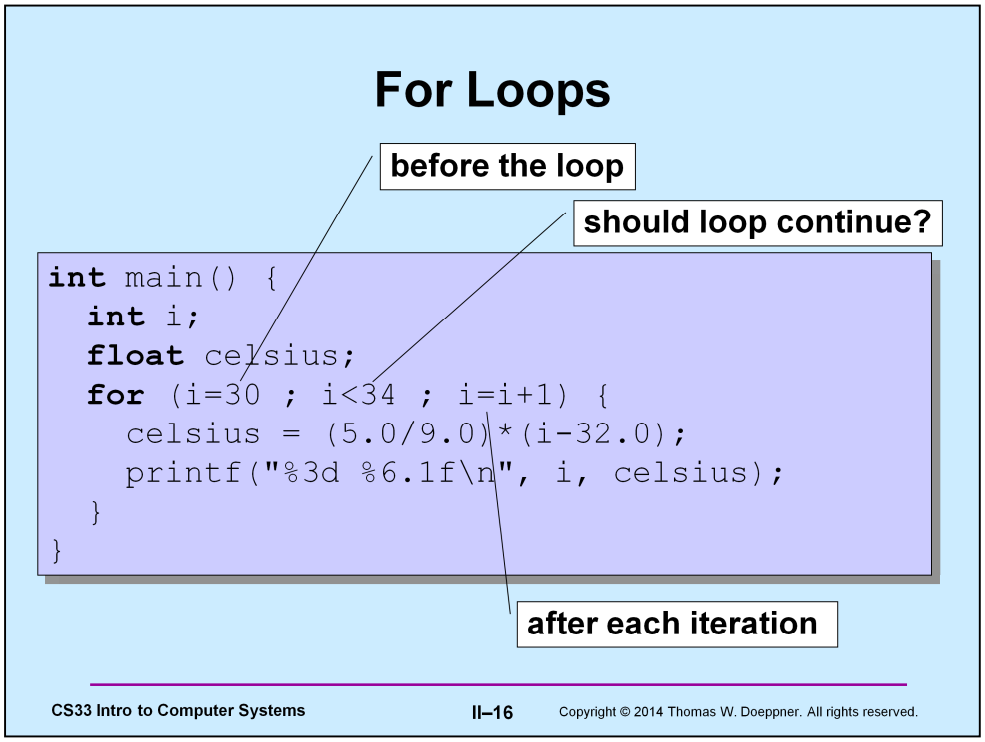
Formatting instructions

- **%6d: decimal integers at least 6 characters wide**
- **%6f: floating point at least 6 characters wide**
- **%6.2f: floating point at least 6 wide, 2 after the decimal point**

printf Again

```
int main() {
  int i;
  float celsius;
  for(i=30; i<34; i++) {
    celsius = (5.0/9.0)*(i-32.0);
    printf("%3d %6.1f\n", i, celsius);
  }
}
```

```
$ ./a.out
 30   -1.1
 31   -0.6
 32    0.0
 33    0.6
```



Note that the "should loop continue" test is done at the beginning of each execution of the loop. Thus, if in the slide the test were "i<30", there would be no executions of the body of the loop and nothing would be printed.

Some Primitive Data Types

int
- integer: 16 bits or 32 bits (implementation dependent)

long
- integer: either 32 bits or 64 bits, depending on the architecture

long long
- integer: 64 bits

char
- a single byte

float
- single-precision floating point

double
- double-precision floating point

The sizes of integers depends on the underlying architecture. In the earliest versions of C, the *int* type had a size equal to that of pointers on the machine. However, the current definitions of C apply this rule to the *long* type. The *int* type has a size of 32 bits on pretty much all of today's computers.

For the sunlab computers, a *long* is 64 bits.

What is the size of my int?

```
int main() {
  int i;
  printf("%d\n", sizeof(i));
}
```

```
$ ./a.out
4
```

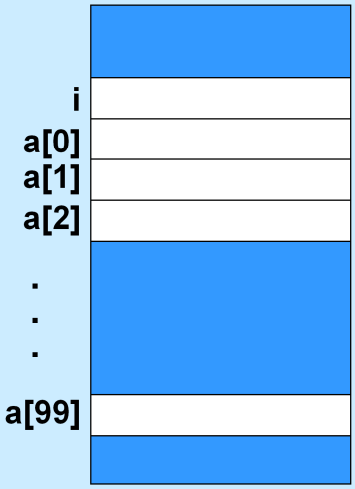
sizeof

- **return the size of a variable in bytes**
- **very very very very very very important function in C**

Note that the argument to *sizeof* need not be a variable, but could be the name of a type. For example, “sizeof(int)” is legal and returns 4 on most machines.

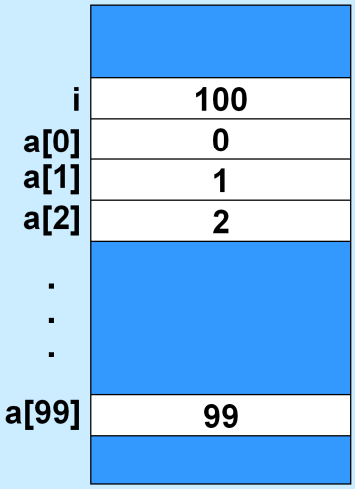
Arrays

```
int main() {
    int a[100];
    int i;
}
```



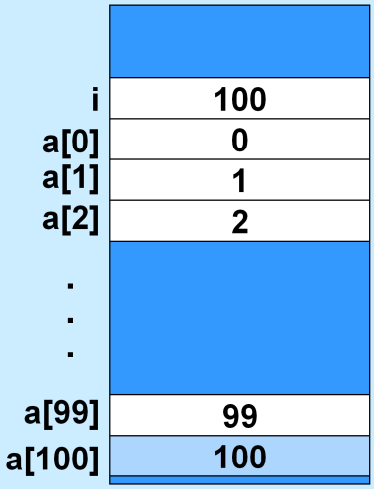
Arrays

```
int main() {
   int a[100];
   int i;
   for(i=0;i<100;i++)
     a[i] = i;
}
```



Array Bounds

```
int main() {
   int a[100];
   int i;
   for(i=0;i<=100;i++)
     a[i] = i;
}
```



Arrays in C

C Arrays = Storage + Indexing

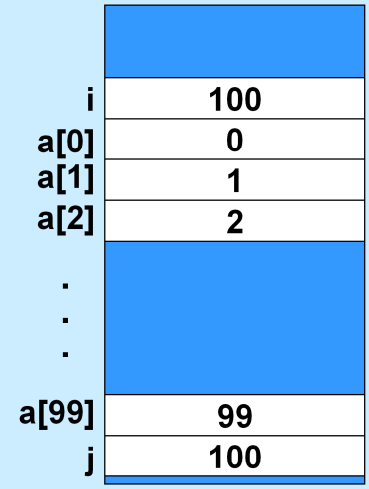
- no bounds checking
- no initialization

WELCOME TO THE JUNGLE

Welcome to the Jungle

```
int main() {
   int j=8;
   int a[100];
   int i;
   for(i=0;i<=100;i++)
     a[i] = i;
   printf("%d\n", j);
}
```

```
$ ./a.out
100
```

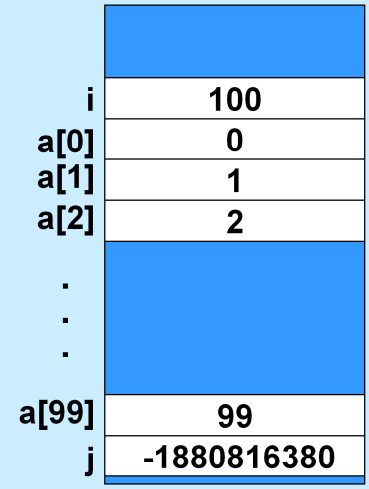


Note how j is both declared and initialized in the same statement.

Welcome to the Jungle

```
int main() {
   int j;
   int a[100];
   int i;
   for(i=0;i<100;i++)
     a[i] = i;
   printf("%d\n", j);
}
```

```
$ ./a.out
-1880816380
```



Welcome to the Jungle

```
int main() {
  int a[100];
  int i;
  a[-3] = 25;
  printf("%d\n", a[-3]);
}
```

```
$ ./a.out
25
```


Note that this code is not guaranteed to work!

Welcome to the Jungle

```
int main() {
  int a[100];
  int i;
  a[-3] = 25;
  a[11111111] = 6;
  printf("%d\n", a[-3]);
}
```

```
$ ./a.out
Segmentation fault
```

What is a segmentation fault?

- **attempted access to an invalid memory location**

Sometimes the error message is “bus error.” Both terms (segmentation fault and bus error) come from the original C/Unix implementation on the PDP-11. A segmentation fault resulted from accessing memory that might exist, but for which the accessor has no permission. A bus error results from trying to use an address that makes no sense.

Function Definitions

```
int fact(int i) {
  int k;
  int res;
  for(res=1,k=1; k<=i; k++)
    res = res * k;
  return res;
}

int main() {
  printf("%f\n", fact(5));
  return 0;
}
```

main

- **is just another function**
- **starts the program**

All functions

- **have a return type**

Note the use of the comma in the initialization part of the for loop: the initialization part may have multiple parts separated by commas, each executed in turn.

Compiling It

```
$ gcc –o fact fact.c
$ ./fact
120
```


Function Definitions

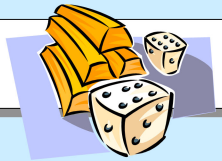
```
int main() {
  printf("%f\n", fact(5));
  return 0;
}
float fact(int i) {
  int k;
  float res;
  for(res=1,k=1; k<=i; k++)
    res = res * k;
  return res;
}
```


Note that not only has the definition of *main* been placed before the definition of *fact*, but that *fact* has been changed so that it now returns a *float* rather than an *int*.

Function Definitions

```
$ gcc –o fact fact.c
main.c:27: warning: type mismatch with previous implicit declaration
main.c:23: warning: previous implicit declaration of 'fact'
main.c:27: warning: 'fact' was previously implicitly declared to return
'int'
```

```
$  ./fact
1079902208
```



If a function, such as *fact*, is encountered by the compiler before it has encountered a declaration or definition for it, the compiler assumes that the function returns an int. This rather arbitrary decision is part of the language for “backwards-compatibility” reasons — so that programs written in older versions of C still compile on newer (post-1988) compilers.

Function Declarations

```
float fact(int i);

int main() {
  printf("%f\n", fact(5));
  return 0;
}
float fact(int i) {
  int k;
  float res;
  for(res=0,k=1; k<=i; k++)
    res = res * k;
  return res;
```

Declares the function

```
$ ./fact
120.000000
```

Here we have a declaration of *fact* before its definition. (If the two are different, gcc will complain.)

Methods

- C has functions
- Java has methods
  - methods implicitly refer to objects
  - C doesn't have objects
- Don't use the "M" word
  - TAs will laugh at you


```
for (;;)
  printf("C does not have methods!\n");
```

Function Declarations

fact.h

```
float fact(int i);
```

fact.c

```
#include "fact.h"
int main() {
  printf("%f\n", fact(5));
  return 0;
}
float fact(int i) {
  int k; float res;
  for(res=1,k=1; k<=i; k++)
    res = res * k;
  return res;
}
```

The Preprocessor

#include

- **calls the preprocessor to include a file**

What do you include?

- **your own *header* file:**
  #include "fact.h"
  - **look in the current directory**
- **standard *header* file:**
  #include <assert.h>
  #include <stdio.h>
  - **look in a standard place**

Contains declaration of *printf* (and other things)

The rules for the distinction between using double quotes and angle brackets are a bit vague. What's shown here is common practice, which should be the rule.

Note that the preprocessor directives (such as #*include*) must start in the first column.

Note that one must include *stdio.h* if using *printf* (and some other routines) in a program.

On most Unix (including Linux and OS X) systems, the "standard place" for header files is the directory /usr/include.

#define

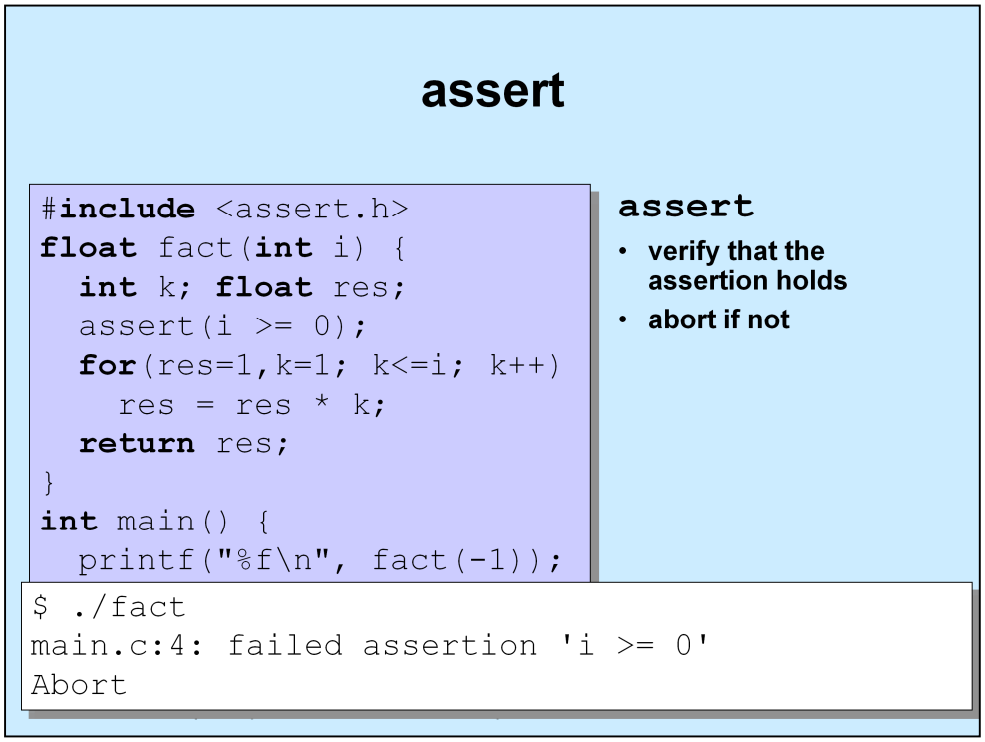
```
#define SIZE 100
int main() {
   int i;
   int a[SIZE];
}
```

#define

- **defines a substitution**
- **applied to the program by the preprocessor**

#define

```
#define forever for(;;)
int main() {
   int i;
   forever {
     printf("hello world\n");
   }
}
```

The assert statement is actually implemented as a macro (using #define). One can "turn off" asserts by defining (using #define) NDEBUG. For example,

#include <assert.h>

…

#define NDEBUG

…

assert(i>=0);

In this case, the assert will not be executed, since NDEBUG is defined. Note that one also can define items such as NDEBUG on the command line for gcc using the –D flag. For example,

gcc –o prog prog.c –DNDEBUG

Has the same effect as having "#define NDEBUG" as the first line of prog.c.

Parameter passing

Passing arrays to a function

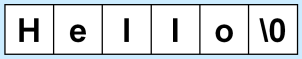
```
int average(int a[], int s) {
   int i; int sum;
   for(i=0,sum=0; i<s; i++)
     sum += a[i];
   return sum/s;
}
int main() {
   int a[100];
   …
   printf("%d\n",average(a,100));
}
```

- Note that I need to pass the size of the array
- This array has no idea how big it is

Strings (or something like them)

Strings are arrays of characters terminated by '\0' (“null”)

- **the '\0' is included at the end of string constants**
  - `"Hello"`



Strings

```
int main() {
   printf("%s\n","Hello");
   return 0;
}
```

```
$ ./a.out
Hello
```


Strings

```
void printString(char s[]) {
   int i;
   for(i=0; s[i]!='\0'; i++)
      printf("%c", s[i]);
}
int main() {
   printString("Hello");
   printf("\n");
   return 0;
}
```

Tells C that this function does not return a value

Swapping

Write a function to swap two entries of an array

```
void swap(int a[], int i, int j) {
   int tmp;
   tmp = a[j];
   a[j] = a[i];
   a[i] = tmp;
}
```


Selection Sort

```
void selectsort(int array[], int length){
  int i, j, min;
  for (i = 0; i < length; ++i){
    /* find the index of the smallest item from i onward */
    min = i;
    for (j = i; j < length; ++j)
      if (array[j] < array[min])
        min = j;
    /* swap the smallest item with the i-th item */
    swap(array, i, min);
  }
  /* at the end of each iteration, the first i slots have the i
     smallest items */
}
```

Swapping

Write a function to swap two ints

```
void swap(int i, int j) {

}
int main() {
   int a = 4;
   int b = 8;
   swap(a,b);
   printf("a:%d  b:%d", a, b);
}
```

Parameters are passed by value

Swapping

Write a function to swap two ints

```
void swap(int i, int j) {
  int tmp;
  tmp = j; j = i; i = tmp;
}
int main() {
   int a = 4;
   int b = 8;
   swap(a, b);
   printf("a:%d  b:%d",a,b);
}
```


```
$ ./a.out
a:4  b:8
```


Why “pass by value”?

- **Fortran, for example, passes parameters “by reference”**
- **Early implementations had the following problem (shown with C syntax):**

```
int main() {
   function(2);
   printf("%d\n", 2);
}
void function(int x) {
   x = 3;
}
```

```
$ ./a.out
3
```


Note, this has been fixed in Fortran, and, since C passes parameters by value, this has never been a problem in C.

Memory addresses

- In C
  - you can get the memory address of any variable
  - just use the magical operator &

```
int main() {
   int a = 4;
   printf("%u\n", &a);
}
```

```
$ ./a.out
3221224352
```

C Pointers

- What is a C pointer?
  - a variable that holds an address
- Pointers in C are “typed” (remember the promises)
  - pointer to an int
  - pointer to a char
  - pointer to a float
  - pointer to <whatever you can define>
- C has a syntax to declare pointer types
  - things start to get complicated …

C Pointers

p is a pointer to an int

if you follow p, you find an int

```
int main() {
   int *p;
   int a = 4;
   p = &a;
   printf("%u\n", p);
}
```

p takes the address of a

```
$ ./a.out
3221224352
```

C Pointers

```
int main() {
   int *p;
   int a = 4;
   p = &a;
   printf("%u\n" ,p);
}
```

p 3221224352

a:3221224352 4

```
$ ./a.out
3221224352
```

Can you guess what &p is?

C Pointers

- Pointers are typed
  - the type of the objects they point to is known
  - there is one exception (see later)
- Pointers are first-class citizens
  - they can be passed to functions
  - they can be stored in arrays and other data structures
  - they can be returned by functions

Swapping

What does this do?

```
void swap(int *i, int *j) {
   int *tmp;
   tmp = j; j = i; i = tmp;
}
int main() {
   int a = 4;
   int b = 8;
   swap(&a, &b);
   printf("a:%d  b:%d\n", a, b);
}
```


```
$ ./a.out
a:4  b:8
```


C Pointers

- **Dereferencing pointers**
  - **accessing/modifying the value pointed to by a pointer**

```
int main() {
   int *p;
   int a = 4;
   p = &a;
   printf("%d\n", *p);
   *p = *p + 1;
   printf("%d\n", *p);
}
```

```
$ ./a.out
4
5
```


Dereferencing C Pointers

```
int main() {
   int *p;
   int a = 4;
   p = &a;
   printf("%d\n", *p);
   *p = *p + 1;
   *p += 3;
   printf("%d\n", *p);
}
```

```
$ ./a.out
4
8
```

Swapping

```
void swap(int *i, int *j) {
   int tmp;
   tmp = *j; *j = *i; *i = tmp;
}
int main() {
   int a = 4;
   int b = 8;
   swap(&a, &b);
   printf("a:%d  b:%d\n", a, b);
}
```


```
$ ./a.out
a:8  b:4
```

