CS 33

Introduction to Computer Systems

What You'll Learn

- Programming in C
- Data representation
- Programming in x86 assembler language
- High-level computer architecture
- Optimizing programs
- Linking and libraries
- Basic OS functionality
- Memory management
- Network programming (Sockets)
- Multithreaded programming (POSIX threads)

Prerequisites: What You Need to Know

- Ability to program in some reasonable language (e.g., Java)
  - CS15 or CS18

What You'll Do

- Eleven 2-hour labs
- Twelve one- to two-week programming assignments
  - most will be doable on OSX as well as on SunLab machines
- No exams!
- Clickers used in class
  - not anonymous: a small portion of your grade
  - full credit (A) for each correct answer
  - partial credit (B) for each wrong answer
  - NC for not answering
  - one to three or so questions per class

Gear-Up Sessions

- Optional weekly sessions
  - handle questions about the week's assignment and course material
  - Thursdays, 7pm – 9pm
  - Barus-Holley 166

Collaboration Policy

- Learn by doing
  - get your hands dirty!
- You may:
  - discuss the requirements
  - discuss the high-level approach
- Write your own code
- Debug your own code
- Get stuck
  - others may help you find bugs
  - may not give you solutions or test cases
- Acknowledge (in README) those who assist you

Textbook

- *Computer Systems: A Programmer's Perspective,* 2nd Edition, Bryant and O'Hallaron, Prentice Hall 2011
  - 3rd Edition is also ok
  - very definitely required

If Programming Languages Were Cars …

- Java would be an SUV
  - automatic transmission
  - stay-in-lane technology
  - GPS navigation
  - traction control
  - gets you where you want to go
    - » safe
    - » boring

- Racket would be a Tesla
  - you drive it like an SUV
    - » definitely cooler
    - » but limited range

If Programming Languages Were Cars …

- C would be a sports car
  - manual everything
  - dangerous
  - fun
  - you really need to know what you're doing!

U-Turn Algorithm (Java and Racket Version)

1. Switch on turn signal
2. Slow down to less than 3 mph
3. Check for oncoming traffic
4. Press the accelerator lightly while turning the steering wheel pretty far in the direction you want to turn
5. Lift your foot off the accelerator and coast through the turn; press accelerator lightly as needed
6. Enter your new lane and begin driving

U-Turn Algorithm (C Version)

1. Enter turn at 30 mph in second gear
2. Position left hand on steering wheel so you can quickly turn it one full circle
3. Ease off accelerator; fully depress clutch
4. Quickly turn steering wheel either left or right as far as possible
5. A split second after starting turn, pull hard on handbrake, locking rear wheels
6. As car (rapidly) rotates, restore steering wheel to straight-ahead position
7. When car has completed 180° turn, release handbrake and clutch, fully depress accelerator

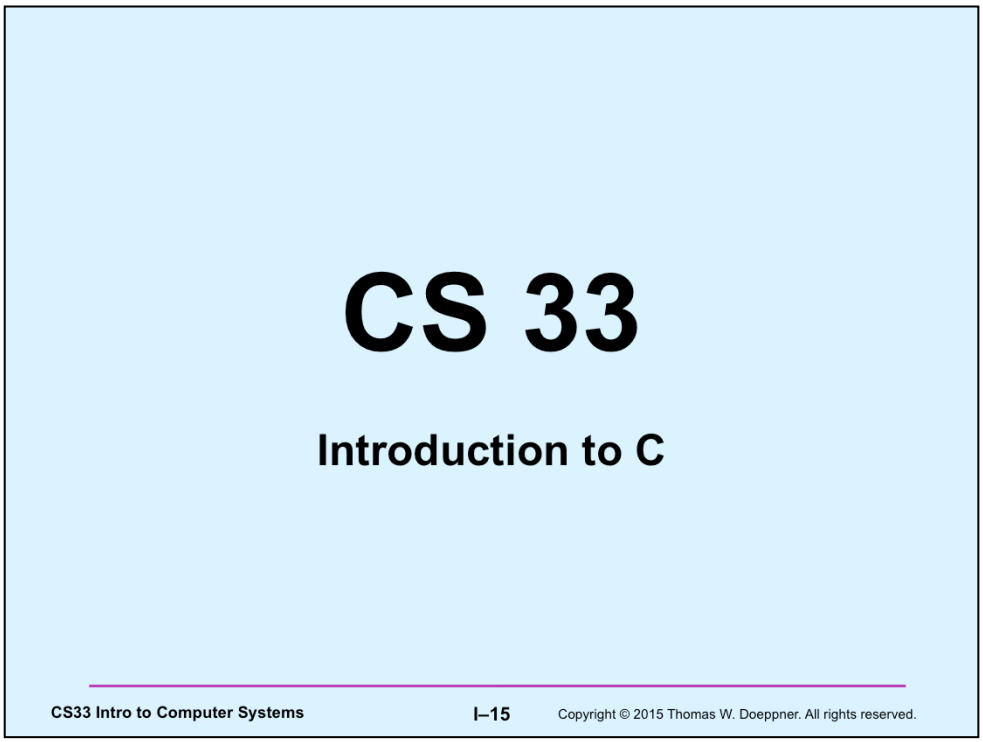
History of C

- Early 1960s: CPL (Combined Programming Language)
  - developed at Cambridge University and University of London
- 1966: BCPL (Basic CPL): simplified CPL
  - intended for systems programming
- 1969: B: simplified BCPL (stripped down so its compiler would run on minicomputer)
  - used to implement earliest Unix
- Early 1970s: C: expanded from B
  - motivation: they wanted to play "Space Travel" on minicomputer
  - used to implement all subsequent Unix OSes

See http://en.wikipedia.org/wiki/C_programming_language.

More History of C

- 1978: Textbook by Brian Kernighan and Dennis Ritchie (K&R), 1st edition, published
  - de facto standard for the language
- 1989: ANSI C specification (ANSI C)
  - 1988: K&R, 2nd edition, published, based on draft of ANSI C
- 1990: ISO C specification (C90)
  - essentially ANSI C
- 1999: Revised ISO C specification (C99)
- 2011: Further revised ISO C specification (C11)
  - too new to affect us



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=gnu99]
  - -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=gnu99
    - » 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

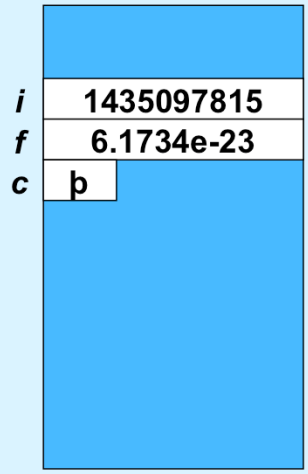
Declarations in C

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

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

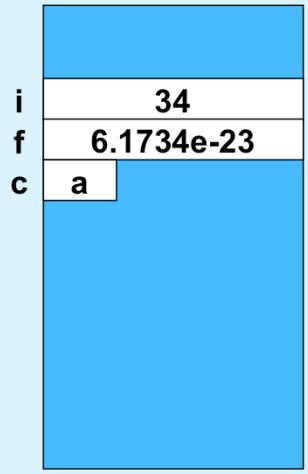
Declarations in C

```
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
```

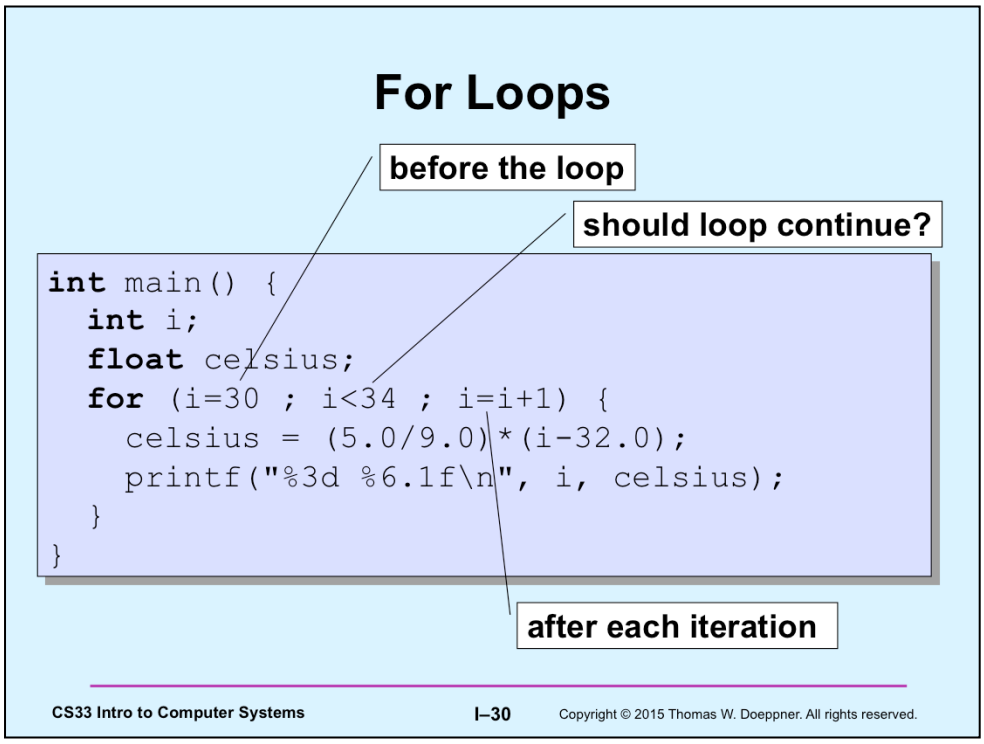
Formatting instructions

- **%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
```

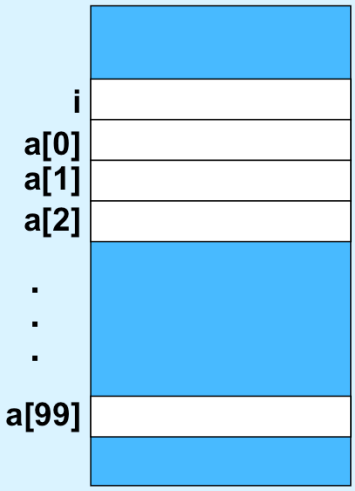
sizeof

- 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.

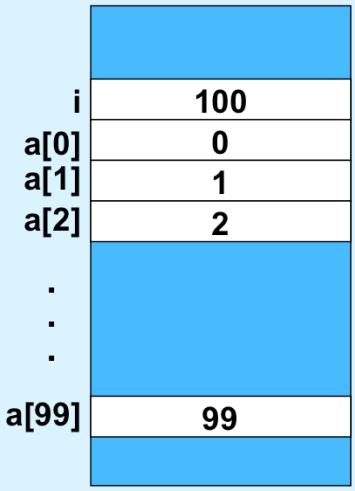
Arrays

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



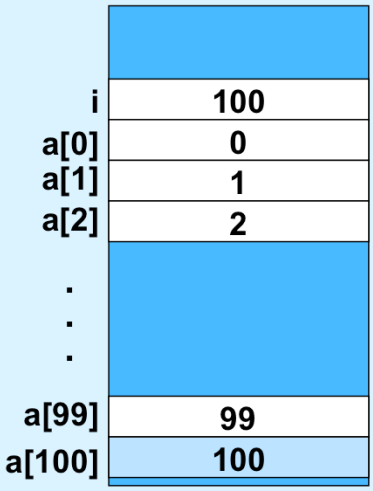
Arrays

```
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

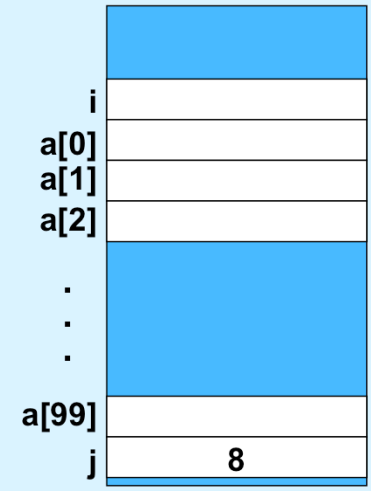
- **no bounds checking**
- **no initialization**

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
????
```



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

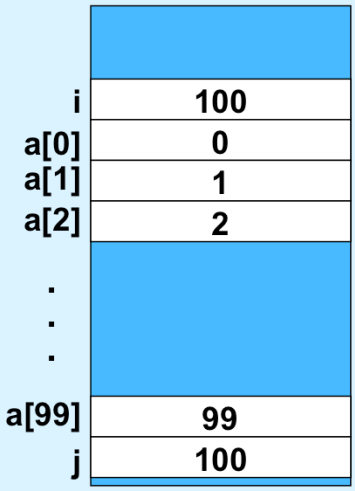
Quiz 1

- What is printed for the value of j when the program is run?
  a) 0
  b) 8
  c) 100
  d) indeterminate

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
```

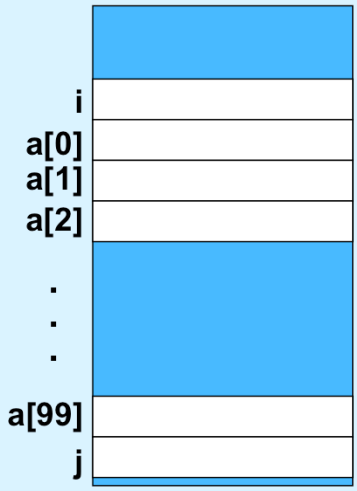


Note how j is both declared and initialized in the same statement.

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
???
```



Note that j no longer has an initial value. Note also that the for loop ends with i equal to 99.

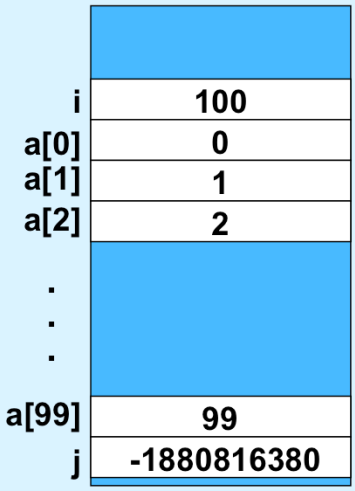
Quiz 2

- What is printed for the value of j when the program is run?
  a) 0
  b) 8
  c) 100
  d) indeterminate

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.