Introduction to C Programming

- History
- Features
- How do I use C ?
- Programming style
- C data types
  - Basic data types
- Literals
- Storage class
- Scalar variable definitions

History

- 1972 : Dennis Ritchie
  - developed as a convenient way of accessing the machine instruction set
  - produced efficient machine code
- 1973 : Ritchie and Ken Thompson
  - rewrite the UNIX kernel using C
  - portability was a requirement
- 1977 : Ritchie and Brian Kernighan
  - “The C Programming Language”
  - K&R dialect of C
- AT&T releases PCC : Portable C Compiler
  - *de facto* “standard” starts to break down as vendors begin to “extend” their C compilers in non-portable ways

History (2)

- 1983 : James Brodie (Motorola) applies to X3 committee of ANSI to draft a C standard
  - ANSI (American National Standards Institute)
  - results in X3J11 – C Programming Language Committee
- 1985 : AT&T (Bjarne Stroustrup) and first release of C++
  - (But that's another story)
- 1987,1989
  - ANSI Standard C defined simultaneously with ISO
  - ISO (International Standards Organization)
    - Committee JTC1 SC22 WG14
- we will be focusing on a version referred to as ANSI C
  - GNU toolchain will be our workhorse

```
/*
 * mywc.c: not-quite-so-robust version of “wordcount"
 */

#include <ctype.h>
#include <stdio.h>
#include <string.h>
#include <stdlib.h>

#define MAX_LINE_LEN 256


int main (int argc, char **argv) {
          FILE *infile;
          char line[MAX_LINE_LEN];

          int  num_chars = 0;
          int  num_lines = 0;
          int  num_words = 0;

          char *c;

          if (argc < 2) {
                    fprintf(stderr, "usage: %s filename\n", argv[0]);
                    exit(1);
          }

          infile = fopen(argv[1], "r");
          if (infile == NULL) {
                    fprintf(stderr, "%s: cannot open %s", argv[0], argv[1]);
                    exit(1);
          }

          /* continued on next slide with same indentation */
          /* continued from previous slide */

          while (fgets(line, MAX_LINE_LEN-1, infile) != NULL) {
                    num_lines += 1;
                    num_chars += strlen(line);
                    if (strncmp(line, "", MAX_LINE_LEN) != 0) {
                              num_words++;
                    }
                    for ( c = line; *c; c++) {
                              /* Not quite good enough!! */
                              if (isspace(*c)) {
                                        num_words++;
                              }
                    }
          }

          fclose(infile);

          printf ("%s: %d %d %d\n", argv[1],
                    num_lines, num_words, num_chars);

          return 0;  /* return the success code */

}
```

Features

- a "general purpose" language
  - equally usable for applications programming and systems programming, for example:
    - develop a network protocol
    - develop a database management system
    - write a compiler for another language (C++, Eiffel, …)
- it's ubiquitous: where you find UNIX you usually find C
- it provides the basis for understanding other languages, most notably C++

Features

- Most C toolchains have a relatively small footprint
  - popular choice for developing **embedded systems**
  - operating systems research and development
  - good choice for systems programs that one expects to port
- Compile-time features
  - ANSI-compliant compilers provide extensive compile-time diagnostics
  - ANSI-compliant compilers provide a continuum of optimizations; from **none** to **conservative** to **aggressive**

Features

- Run-time features (i.e., “pluses”):
  - easy to adapt a C compiler’s output (executables) to the execution environment on a platform: Windows, Mac, UNIX
- Run-time features missing (i.e., also could be considered as “efficiency pluses”!):
  - no native array access bounds checking
  - no native null-pointer checks (use a custom library for this)
  - no native checks on uninitialized variables (some scenarios can be checked at compile-time)

How do I use C?

- Write an application

```
$ vim hello.c
#include <stdio.h>
int main() {
    printf("Hello, World!\n");
    return (0);
}
```

- Compile the source file into an object file

```
$ gcc -ansi -Wall -c hello.c
```

- Link the object file to the “Standard C Runtime Library” to produce an executable (hello)

```
$ gcc -o hello hello.o
         OR
$ gcc -o hello -lm hello.o   # link in the math library
```

How do I use C?

- Much terser syntax going from source code straight to executable (assuming executable needs to link a single object file)

```
$ gcc hello.c -o hello
```

- Assuming we want to also include debugging symbols:

```
$ gcc -g hello.c -o hello
```

- Specify some warning flags:

```
$ gcc -g hello.c -ansi -Wall -o hello
```

How do I use C ?

- Run the executable:

```
$ ./hello
Hello, World!
```

- Basic rules:
  - all C stand-alone programs must have at most one function named "`main()`"
  - keywords are always lowercase; you cannot use a keyword as an identifier
  - statements must be terminated with a semicolon

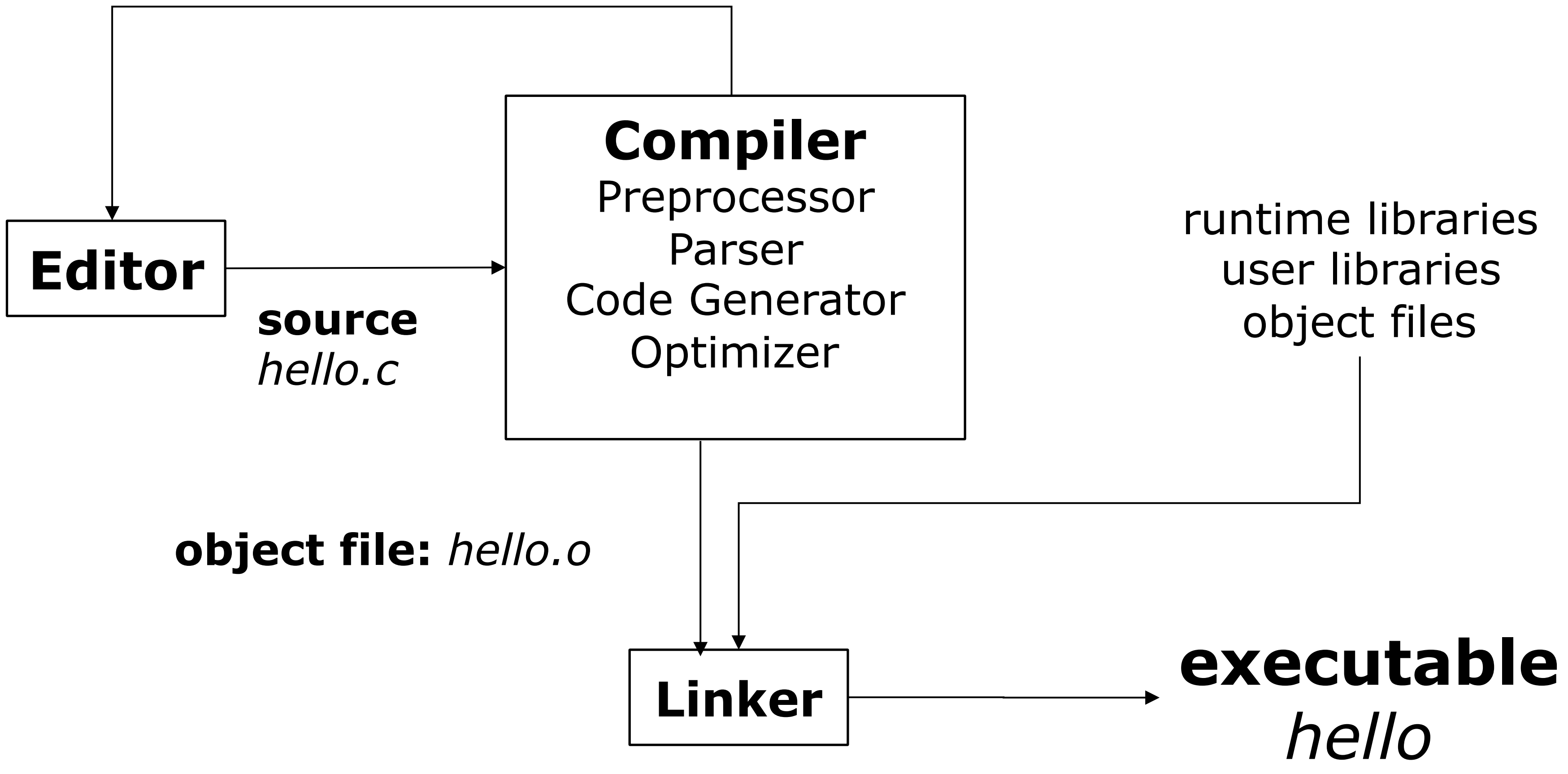
How do I use C ?

- Basic rules (continued):
  - Comments are delimited by `/* … */`

```
/* Everything between "slash star" and
    "star slash" is a comment, even if it
    spans several lines. Be careful not
    to nest comments; some compilers are
    unable to handle them. */
```

  - Single line comments are not ANSI C (//)
- **Upcoming labs:**
  - introduce the GNU toolchain
  - aspects of the C execution model

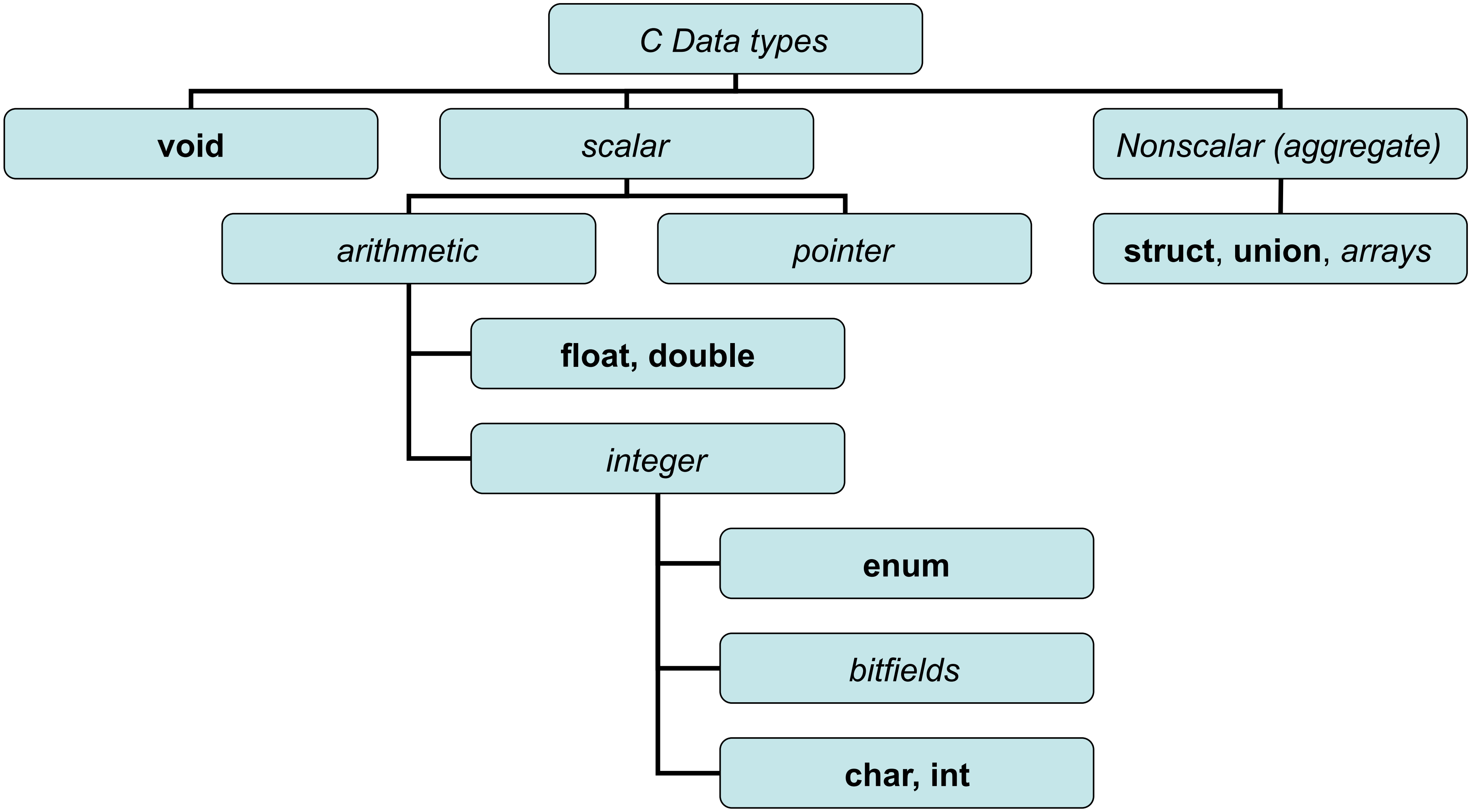
How do I use C ?


Editor
source
hello.c
Compiler
Preprocessor
Parser
Code Generator
Optimizer
runtime libraries
user libraries
object files
object file: *hello.o*
Linker
executable
hello

A word about formatting style

- Any amount of white space is considered a single space
  - tabs and spaces can be used liberally
- White space improves code readability
- Commenting is important as a maintenance tool
- Use tabbing in conjunction with curly braces (`{ , }`) to indicate different levels of nested functions.
- In C, type declarations must appear at the beginning of a scope
- Scope begins and ends with curly braces (`{ , }`)
- Use **underscores_for_variables** rather **thanCamelCaps**

C Data Types


C Data types
void
scalar
Nonscalar (aggregate)
arithmetic
pointer
struct, **union**, *arrays*
float, double
integer
enum
bitfields
char, int

Basic Data Types

C	Java
`char`	`char`
`int`	`int`
`enum`	`enum`
`float`	`float`
`double`	`double`
`--`	`Boolean`

Type qualifiers

- C supports four type qualifiers; keywords which qualify certain scalar arithmetics:
  - `long` , `short` : affect the range of an integer or floating point numbers
  - `signed`, `unsigned`: just that, indicates that an integer is signed or unsigned

Qualified Basic Types

Basic type	Qualified basic type

`char`	`char`
	`signed char`
	`unsigned char`

`int`	`int`
	`short int`
	`long int`
	`long long int`
	`unsigned int`
	`unsigned short int`
	`unsigned long int`
	`unsigned long long int`

`double`	`long double`

Aggregate Data Types (three kinds)

- `struct` types: one mechanism to declare user-defined types
  - like records in Pascal/Modula/Oberon
  - we'll look at these later
  - **significantly different from Java classes!!**
- array types: you can define an array of any scalar or aggregate type
  - describe these later
- `union` types: similar to structs, but members are overlaid (sharing storage)

Literals

- Character constants (8-bit ASCII):

```
char ch = 'A', bell = '\a',
     formfeed = '\f';
```

- Numeric literals
  - Integer:

```
int a = 10, b = 0x1CE, c = 0777;
unsigned int x = 0xffU;
long int y = 2L;
```

  - Floating point:

```
float x = 3.1415F;
double x = 1.25, y = 2.5E10, z = -2.5e-10;
long double x = 3.5e3L;
```

Danger! String literals

- String literals

```
char *s = "unable to open file\n";
```

- We will get to C strings in due course, but here is an early warning:
  - The variable "**s**" above might appear to act like a string…
  - … but it is actually a variable holding an address to a "static string table"
  - This part of the process's memory is read-only!

Example

```
#include <stdio.h>

int main() {
    char s[50] = "abcdefghijklmnopqrstuvwxyz";
    char *t = "zyxwvutsrqponmlkjihgfedcba";

    printf("message s is: '%s'\n", s);
    s[0] = ' ';
    s[1] = ' ';
    printf("modified message s is: '%s'\n", s);

    printf("message t is: '%s'\n", t);  /* next two lines will fail */
    t[0] = ' ';
    t[1] = ' ';
    printf("modified message s is: '%s'\n", t);
}
```

```
$ ./staticstring
message s is: 'abcdefghijklmnopqrstuvwxyz'
modified message s is: '  cdefghijklmnopqrstuvwxyz'
message t is: 'zyxwvutsrqponmlkjihgfedcba'
Bus error: 10
```

Storage classes

- C provides the following four storage classes:
  - **auto**: applies only to variables declared at function scope
  - **register**: a hint to the compiler to place a variable in a CPU register
  - **static**: internal linkage, and static storage allocation
  - **extern**: external linkage, not a definition
- Storage classes are used to modify a variable declaration or definition
- Current practice:
  - avoid using "auto" or "register"
  - use "static" and "extern" to control variable visibility, and these will be the only storage classes we will use in this course

Scalar Variable Definitions

- Declaring variables
  - general definition syntax:

```
<type> <name>;
```

  - definition with initialization:

```
<type> <name> = <value>;
```

  - with a storage class modifier:

```
<storage class> <type> <name>;
<storage class> <type> <name> = <value>;
```

Scalar Variable Definitions

- Examples:

```
extern int tics;

double long int x = 4L;
int a, b, c;
unsigned int a, b = 0x1fU;

char c = 'A';
static unsigned char esc = '\0x27';

double pi;
long double ptime;
enum { red, green, blue } colour;
```

Introduction to C Programming (cont)

- C arrays in a bit more detail
- Control flow
- A bit about functions
- User defined types
  - type definitions **`(typedef)`**
  - enumerations **`(enum)`**
  - Aggregate data type: structures **`(struct)`**
- Simple I/O

C Arrays

- An array is a group of data elements of the same type, accessed using the same identifier; e.g., `x[3], x[11]`
- Arrays may be statically or dynamically allocated. Static arrays cannot grow at runtime. Dynamic arrays can grow at runtime (using standard library functions).
- Arrays may be multidimensional; e.g., `x[row][column]`
- Access to the elements of an array is accomplished using integer indices
- If an array is dimensioned to hold `size` elements, the elements are indexed from `0` up to `size-1`
- **C provides no array bounds checking**, so accessing elements beyond index `size-1`, or below index `0` can cause a segmentation fault
- Static arrays can be auto-initialized at runtime

C Arrays (2)

- syntax for a one-dimensional array declaration:
  `<storage class> <type> <identifier>[<size>]`
  e.g. `double vector[3];`
  `char   buffer[256];`
- `<size>` must be known at compile time
- `<size>` **is not a part of an array data structure**. Programmer has to manage correct access to array!

- Examples:

```
double f[3] = {0.1, 2.2, -100.51};

int freq[10] = {20,12}; /* freq[0] = 20,
                           freq[1] = 12,
                           freq[2] = 0,
                              ...
                           freq[9] = 0 */
```

C Statements

-
  ```
  S = S; S;
    | x = e
    | f(e1,…,en)
    | if (bexpr) {S} [else if {S}] [else {S}]
    | switch(e) { case e1: S case e2: S … default: S }
    | while (bexpr) {S}
    | do {S} while (bexpr)
    | for (e1; bexpr; e2) {S}
    | break
    | continue
    | return e
    | ε
  ```
- where,
  - ***S*** is a statement
  - ***e,e1,en*** are general expressions
  - ***bexpr*** is a boolean expression
  - **ε** is the empty or null statement

Control Flow

- five basic flow control statements:
  - **`if-then`**, **`if-then-else`** (conditional)
  - **`switch`** (multi-branch conditional)
  - **`while`** loops (iteration, top-tested)
  - **`do-while`** loops (iteration, bottom-tested)
  - **`for`** loops (iteration)
- Other control flow constructs:
  - "**`goto`**", there are many reasons not to use this, so we won't (use "**`continue`**" and "**`break`**" instead);
  - "**`setjmp/longjmp`**", special functions provided by the standard library to implement non-local return from a function – these also won't be used in this course

Control Flow: true & false?

- C does not have a boolean type
- However, to build conditional (boolean) expressions we can use the following operators:
    - relational operators: `>, <, >=, <=`
    - equality operators: `==, !=`
    - logical operators: `&&, ||, !`
- Any expression that evaluates to zero is **false**, otherwise it is **true**

Control Flow: beware = vs ==

- the assignment operator ("`=`") and equality operator ("`==`") have different meanings
  - legal (but possibly not what you intended):

```
int a = 20;
if (a = 5) {
    S;
}
```

- One extreme approach is to write conditionals like this:
  - `if (5 == a) { ...`
- Best approach overall: use compiler to catch this
  - The "-Wall" flag works well here.

if

```
/* A bexpr is a C expression which, if it zero, is interpreted as false.
 * Otherwise it is interpreted as true.
 */

/* case 1: if */
if (bexpr) {
    S;
}

/* case 2: if-else*/
if (bexpr) {
    S;
} else {
    notS;
}


/* case 3: multiway if */
if (bexpr1) {
    S;
} else if (bexpr2) {
    T;
} else if (bexpr3) {  /* Can keep on chaining more "else if" clauses */
    U;
} else {
    V;
}
```

switch

```
switch (intexpr) {
   case int_literal_1:
        S1;
        break;

   case int_literal_2;
       S2;
       break;

   /* potentially many other cases */

   default:
       Sdefault;
       break;
}
```

- Syntax:
  - **`intexpr`** is an "integer expression"
  - **`intlit`** is an integer literal (i.e., it must be computable at compile time)
  - **`if (intexpr == intlit)`** execute Sn;
  - **`break`** continues execution at the closing brace

Example: `char` case labels

```c
#include <ctype.h>

...

int isvowel(int ch) {
        int res;

        switch(toupper(ch)) {
        /* Note that character literals are also considered
         * integer expressions in C!
         */
             case 'A':
             case 'E':
             case 'I':
             case 'O':
             case 'U':
                 res = TRUE;
                 break;
             default:
                 res = FALSE;
        }

        return res;
}
```

Control Flow (`while`)

-
  ```
  while (bexpr) {
       S;
  }
  ```
- iteration, top-tested
- keywords: **`continue`**, **`break`** have significance here
  - **`continue`**: start the next loop iteration by checking the while conditional
  - **`break`** : exit the loop immediately, resume at first instruction after the while body

```
char buf[50];
int pos = 0;

if (fgets(buf, 50, stdin) == NULL) {
    /* report an error and exit */
}

while(buf[pos] != '\0') {
    if (isvowel(buf[pos])) {
        putchar(toupper(buf[pos]));
    } else {
        putchar(buf[pos]);
    }
    pos += 1;
}
```

Control Flow (`do while`)

-
  ```
  do {
       S;
  } while (bexpr);
  ```
- iteration, bottom-tested
- keywords: **`continue`**, **`break`** also have significance here

```
int ch, cnt = 0;

do {
    ch = getchar();
    if (ch == BLANK)
        cnt += 1;
    } while (ch != '\n');
```

Control flow (`for`)

```
for (init; test; update) {
        S_body;
}
```

1. `init` is evaluated, usually variable initialization
2. `test` is evaluated
   a) if `test` is false, leave for-loop
   b) if `test` is true, `S_body` is executed
   c) after `S_body` is executed, `update`is evaluated, return to step 2

- iteration, top-tested
- keywords: `continue`, `break` have significance here

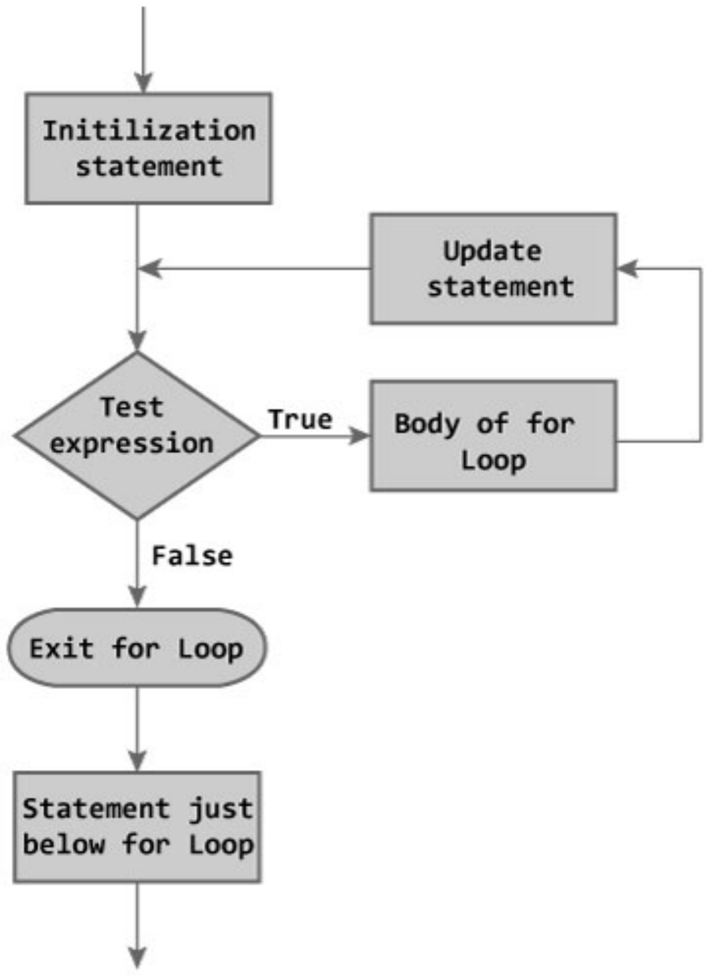


Diagram from http://www.programiz.com/sites/tutorial2program/files/for-loop.jpg

Functions

- A program is made up of one or more functions, one of which is `main()`
- Program execution always begins with `main()`
- When program control encounters a function name, the function is invoked
  - program control passes to the function
  - the function is executed
  - control is passed back to the calling function

Functions

- function syntax:

```
[<storage class>] <return type>
    name (<parameters>) {
       <statements>
}
```

- parameter syntax:

```
<type> varname , <type> varname> , …
```

- type `void`:
  - if `<return type>` is `void` the function has no return value
  - if `<parameters>` is `void` the function has no parameters
  - e.g., `void f(void);`

Functions

- example:

```
int main(int argc, char *argv[]) {
    printf("Hello, world!\n");
    return 0;
}
```

- example:

```
double fmax(double x, double y) {
    if (x > y) {
        return x;
    } else {
        return y;
    }
}
```

Parameter passing

- C implements **call-by-value** parameter passing:

```
/* Formal parameters: m, n */

int maxint(int m, int n) {
   if (m > n) {
      return m;
   } else {
      return n;
   }
}
```

```
/* ... more code ... */

void some_function() {
    int a = 5;
    int b = 10;
    int c;

    /* Actual parameters: a, b */
    c = maxint (a, b);
    printf ("maximum of %d and %d is: %d", a, b, c);
}
```

Parameter passing

- **Call-by-value semantics** copies actual parameters into formal parameters.

```
int power2( double f ) {
    if (f > sqrt(DBL_MAX)) {
        return 0;  /* Some sort of error was detected... */
    } else {
        return (int) (f * f);
    }
}
```

```
/* ... some more code intervenes ... */

void some_other_function() {
    double g = 4.0;
    int h = power2(g);

    printf( "%f %d \n", g, h );
}
```

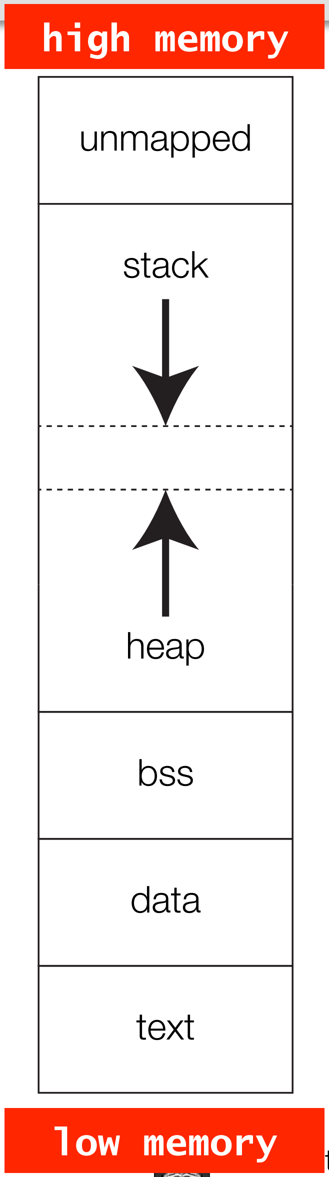
Addresses and Pointers

- Remember these details:
  - All variables are data!
  - All data resides in memory!
  - Every memory location has an address!
  - C exposes these details for us to use in our programs
- Some language systems hide these details from us
  - Java, C#, Python
- But others keep these details visible

Pointer variables

- Holds the **address of a memory location** storing a value of **some data type**
  - Usually contains the address of a **named variable**
  - Sometimes an **anonymous variable** on the heap
- Often is an address **within a aggregate data type**, e.g. a location within a C string (which is a character array)
- Can be used as a formal function parameter to receive the address of a variable (an ersatz "call-by-reference" mechanism)
  - Here the actual parameter (addresses) is copied to formal parameter (pointers)
- **To obtain an address**: use the **& symbol**
- **To use an address**: use the *** symbol** (outside of a variable declaration)

Memory model



(thar' be dragons)

activation frames for function invocations

dynamic memory (e.g., where malloc obtains memory)

uninitialized program-scope variables

initialized program-scope variables

machine code (executable) plus string table; read-only

Notation

`&x` “get the address of memory location used to store the variable x” (**referencing**)

`*x` “read x – which contains the address to some variable – and then go to that address in order to read what is there” (**dereferencing**)

- Note that `*` can appear in a **variable declaration**
- **However, it has a different meaning in a declaration!**

```
double f = 30.0;
double *g = &f;
printf("%lf  %lf\n", f, *g);
```

Addresses and Pointers

- Compare the following two code fragments

```
int x = 1;
int y = x;
x = 2;
printf("y is %d\n", y); /* “y is 1” */
```

```
int x = 1;
int *y = &x;
x = 2;
printf("*y is %d\n", *y); /* “*y is 2” */
```

- In other words, **`x`** is a synonym for **`*&x`**

Notation

- **Pointer variables** are declared in terms of other types (scalar and nonscalar)
- More accurate to read the simpler variable declarations **right-to-left**

```
int *a;
double *f;
```

- A little bit trickier with arrays of pointers

```
char *st[10];
```

- Note: In declarations the `*` is **beside** and **logically attached** to the variable name
  - Declaration syntax is meant to remind programmer of the result of **dereferencing** the variable

Pointers

- Why do we need pointers?
- **Call-by-value** works well for passing parameters into functions, but:
  - What if we want values to be modified in the call function?
  - What if want to pass a large struct as a function argument?
- Functions can only return a single value in `return` statements; what if we need multiple values changed (but don't want to write a struct for this)?
  - **Call-by-reference-like** semantics would get around the limitation of a "single return value".
  - **However, C only has call-by-value semantics!**
  - (C++ has call-by-value and call-by-reference)

Example

- swap function:

```
void swap(int a, int b) {
        int temp = a;
        a = b;
        b = temp;
}
```

```
/* ... some code here ... */

void blarg() {
    int x = 2;
    int y = 1;

    swap(x, y);
    printf("x = %d, y = %d\n", x, y); /* x = 2, y = 1 */
}
```

Example (2)

- Notice that the values in Example (1) were **not swapped**
- Integers "a" and "b" were swapped within the scope of **`swap()`**, but the results are not visible in to calling function
- Must use pointers to swap as shown below:

```
void swap(int *a, int *b) {
    int tmp = *a;
    *a = *b;
    *b = tmp;
}
```

```
/* ... some code here ... */

void blarg() {
    int x = 2;
    int y = 1;

    swap(&x, &y);
    printf("x = %d, y = %d\n", x, y); /* x = 1, y = 2 */
}
```

Invalid pointers

- **C does not implicitly check the validity of a pointer!**
  - The address could be to a region of memory holding complete and total garbage...
  - ... but C will dereference the (garbage) address if told to do so.
- **It is your responsibility** to ensure that a pointer contains a valid memory address
  - avoiding **dangling pointers**
  - avoid dereferencing a pointer when you're not sure of "where it has been"
- Example, what happens?:

```
int *x = NULL;
printf("%d\n", *x);
```

  - sometimes the runtime system reports use of null pointer
  - `NULL` is defined in both “stdio.h” and “stdlib.h”

Pointers and arrays

- Recall that arrays are an aggregate data type where each data element has the same "type":

```
    int grades[10];
    struct date_record info[50];
    char buffer[100];
```

- All elements in an array occupy contiguous memory locations
- To get the address of any data element, we can use **&**:

```
    5th element of "grades": &grades[4]
    1st element of info: &info[0]
    last element of "buffer": &buffer[99]
```

Pointers and arrays

- an important array location is usually that of the first element
- in C, an array variable name without the subscript represents the first element; recall that each element is a character

```
char  buffer[100];
char *cursor;

cursor = &buffer[0]; /* these two lines ... */
cursor = buffer;     /* ... have the same effect. */
```

Pointers and arrays (3)

- Can use pointer variables and array names (sometimes) interchangeably to access array elements:

```
int X[4];
int *p = &X[0];
p = X; /* okay */
p++;   /* okay */
X = p; /* illegal */
X++;   /* illegal */
X[1] ~ *(p + 1);
X[n] ~ *(p + n);
```

- Declarations: the following function declarations are equivalent:

```
1.extern double func(double X[]);
2.extern double func(double *X);
```

  - Format #1 is often preferred as it does conveys more information

Call-by-value: caution!

- Call-by-value parameter passing semantics is straightforward to understand for:
  - scalar types (e.g., int, float, char, etc.)
  - structs
- It is a bit trickier with arrays
  - Call-by-value is still used with arrays...
  - ... but what is copied (actual parameter to formal parameter) is the **address of the array's first element!**
  - This will make more sense in 15 slides.
  - Just be aware the C **does not copy** the value each element in the array from the actual parameter to the formal parameter...
- Java implements **call-by-value** for primitive types and **call-by-sharing** for object parameters.

What is a "string"?

- "Strings" as a datatype known in Java **do not exist** in C
- Memory for strings is **not automatically allocated** on assignment.
- Concatenation via the "+" operator **is not possible**.
- The boundaries between strings **are not enforced** by the C runtime.

```
String name;
```

```
char *name;

/*
 * time passes
 */

name = "Donald Trump";
```

```
char *prefix = "/home/yuuuuuge";
char *full;

/* ... */

full = prefix + "/" + "bin/tacos.sh";
```

```
char name[10], address[10], code[5];
/* ... */
strcpy(code, "1234");
/* ... */
strcpy(address, "abcdefghijklmnopq");
/* ... */
printf("%s\n", code);
```

Strings are character arrays

- A C string is stored in a character array
- The start of a string is an address to a char
  - **The start of the string need not be identical with the start of an array!**
- The end of a string is indicated with a **null character** ('\0')
- The size of a string **need not necessarily be the same size** as the character array in which it is stored.
- C strings are often manipulated using special functions
  - `strncpy()`
  - `strcmp()`
  - `strncat()`
  - `strtok()`
- C strings are sometimes accessed `char` by `char`
- C strings are difficult to use at first
  - But you always have access to their underlying representation
- Mourn, and move on.

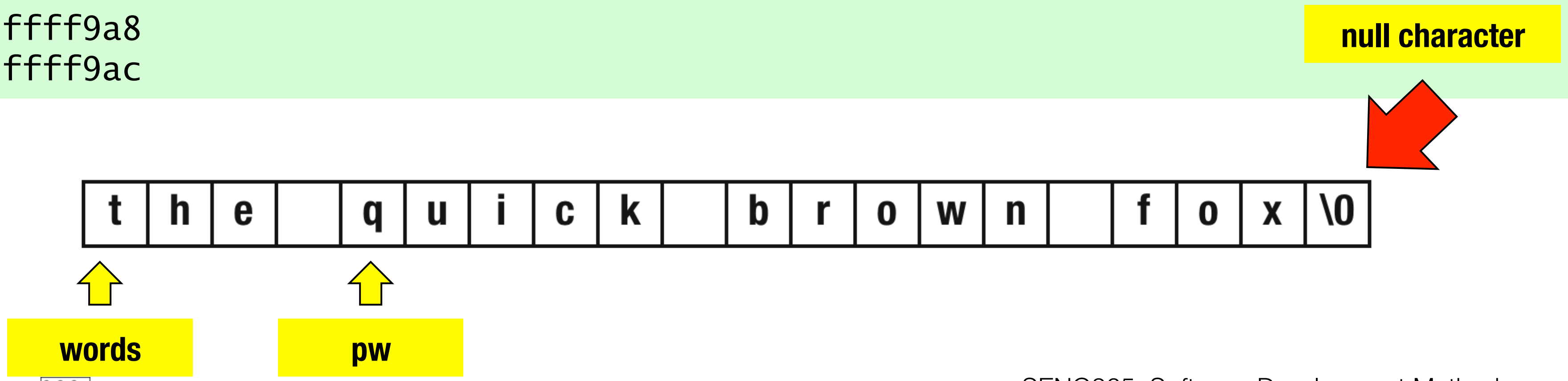
Example

```
char words[20];
char *pw;

/* ... */
strncpy(words, "the quick brown fox", 20);
pw = &words[0];  /* That's the same as writing "pw = words;". */
pw += 4;

printf ("%s\n%s\n", words, pw);
printf ("%x\n%x\n", words, pw);
```

```
the quick brown fox
quick brown fox
bffff9a8
bffff9ac
```



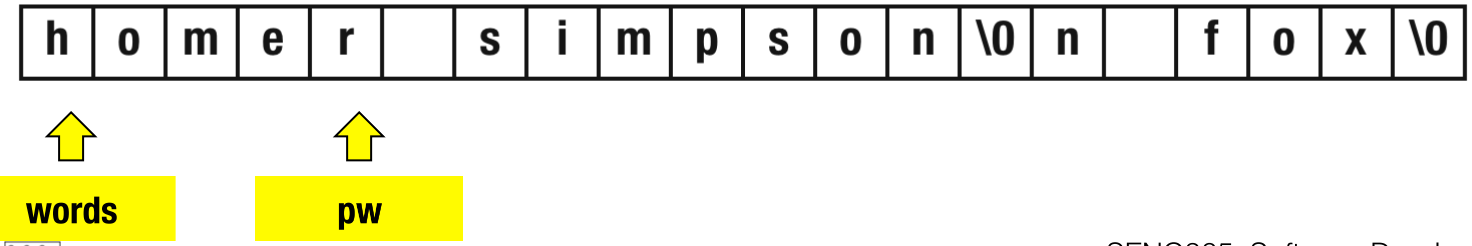
Example

```
/* ... continued from previous slide ... */

strncpy(words, "homer simpson", 20);

printf ("%s\n%s\n", words, pw);
printf ("%x\n%x\n", words, pw);
```

```
homer simpson
r simpson
bffff9a8
bffff9ac
```



Always be aware of array-ness!

- Always be aware that C strings are, underneath, really just C char arrays
- To store a string in your program:
  - **You must have enough room in some character array** for all the string's characters **plus** one extra character for the null
  - Therefore correct program behavior often boils down to declaring (and later in the course, allocating) char arrays which have correct sizes for your purposes
- Must be scrupulous about specifying "maximum" sizes
  - Note the third parameter of "strncpy"
- Also use "strncat" to append a string to an already existing string

Example

```
char words[20];
char first[10];
char second[10];

strncpy(first, "aaaaa", 10);
strncpy(second, "bbbbb", 10);

strncpy(words, first, 20);
strncat(words, " ", 2);
strncat(words, second, 10);

printf("%s\n", words);
```

```
aaaaa bbbbb
```

Strings

- In C, we can manipulate pointers in many ways
- This can help us when working with strings

`char *cp = buffer`	same as	`cp = &buffer[0]`
`cp + n`	same as	`&buffer[n]`
`*(cp + n)`	same as	`buffer[n]`
`cp++`	same as	`cp = cp + 1`
`*cp++`	same as	`*cp, cp++`

C string functions

string.h: C string functions

- **`strncpy(char *dest, const char *src, int length):`**
  - copies the contents of string **`src`** to the array pointed to by **`dest`**. **`src and dest`** should not overlap.
- **`strncmp(const char *s1, const char *s2, int length):`**
  - compares the two strings **`s1`** and **`s2`**, returning a negative, zero, or positive integer if **`s1`** is lexicographically <, ==, > **`s2`**.
- **`strlen(const char *s):`**
  - compute the length of string **`s`** (not counting the terminal null character (**`'\0'`**)).

Do not use strcpy!

- strcpy() takes only two parameters:
  - destination char array
  - source char array
- If the string in the source array is longer than the size of the destination array:
  - then strcpy() will write over the end of destination array…
  - … and this is what happens in a buffer overflow attack
- What kind of bad things can happen?
  - Overwrite data in the activation frame
  - Cause function to return to a different location
  - read: https://en.wikipedia.org/wiki/Buffer_overflow

File input and output

- C, like most languages, provides facilities for reading and writing files
- files are accessed as **streams** using `FILE` objects
- the `fopen()` function is used to open a file; it returns a pointer to info about the file being opened

```
FILE *data = fopen("input.txt", "r");
```

- streams `FILE *stdin`, `FILE *stdout`, and `FILE *stderr` are automatically opened by the O/S when a program starts

File I/O

- open modes (text): "r" for reading, "w" for writing, and "a" for appending
- open modes (binary): "rb" for reading, "wb" for writing, and "ab" for appending
- the **`fclose()`** function is used to close a file and flush any associated buffers
- use **`fgetc()`** to read a single character from an open file (file was opened in "r" mode)
- similarly, **`fputc()`** will output a single character to the open file (file was opened in "w" mode)

File I/O

```c
/* charbychar.c
 * Echo the contents of file specified as the first argument,
 * char by char. */

#include <stdio.h>
#include <stdlib.h>

int main(int argc, char *argv[]) {
    int ch, num_char;

    if (argc < 2) {
        fprintf(stderr, "You must provide a filename\n");
        exit(1);
    }

    FILE *data_fp = fopen(argv[1], "r");

    if (data_fp == NULL) {
        fprintf(stderr, "unable to open %s\n", argv[1]);
        exit(1);
    }

    num_char = 0;
    while ((ch = fgetc(data_fp)) != EOF) {
        num_char++;
        printf("%c", ch);
    }
    fclose(data_fp);

    fprintf(stdout, "Number of characters: %d\n", num_char);
    return 0;
}
```

```c
/* linebyline.c
 * Echo the contents of file specified as the first argument, line by line. */

#include <stdio.h>
#include <stdlib.h>
#define BUFLEN 100

int main(int argc, char *argv[]) {
    char buffer[BUFLEN];
    int num_lines;

    if (argc < 2) {
        fprintf(stderr, "You must provide a filename\n");
        exit(1);
    }

    FILE *data_fp = fopen(argv[1], "r");

    if (data_fp == NULL) {
        fprintf(stderr, "unable to open %s\n", argv[1]);
        exit(1);
    }

    num_lines = 0;
    while (fgets(buffer, sizeof(char) * BUFLEN, data_fp)) {
        num_lines++;
        printf("%d: %s", num_lines, buffer);
    }
    fclose(data_fp);  /* There is a little bug in the loop! */

    return 0;
}
```

I/O functions

- **`FILE *fopen(char *filename, char *mode)`**
  - open file corresponding to filename
  - mode can be "r" or "rw" or "rw+" (depending on flavour of Unix)
  - if an error occurs when opening file, function returns 0 (NULL)
- **`char *fgets(char *buf, int n, FILE *stream)`**
  - read at most **`n-1`** characters from **`stream`** and copy to location **`buf`**; input terminates when newline encountered or n-1 characters input. Appends a null character to end of buffer.
  - returns **`NULL`** if error or end-of-file encountered
  - set **`stream`** to **`stdin`** to accept input from standard input
- **`int scanf( char *format, […] )`**
  - read formatted data from standard input
  - returns **`EOF`** when end-of-file encountered, otherwise it returns the number of fields successfully converted
  - format specifiers encoded in **`format`** (variable # of arguments)

I/O functions

- **standard output (stdout)**
- **`int printf( char *format, […])`**
  - print formatted output to standard output
  - returns the number of characters printed
  - the format specifiers are encoded in the string **`format`**
  - takes a variable number of arguments
- Examples:
  - `printf("My name is %s\n", name); /* char array */`
  -
    ```
    printf("My name is %s and my age is %d\n", name, age);
    /* name is a char array, age is an int */
    ```
  -
    ```
    printf("The temperature today is %f\n", temp_celsius);
    /* temp_celsius is a float */
    ```
  -
    ```
    printf("%d/%d/%d", year, month, day);
    /* year, month and day are ints; there is no newline */
    ```

I/O functions

- `int fprintf( FILE *stream, char *format, […])`
  - like printf, but output goes to (already opened) stream
- `int fputc( int c, FILE *stream)`
  - outputs a single character (indicated by ASCII code in c) to (already opened) stream
  - note that the character is stored in an integer
  - idea here is the character is a number from 0 to 255
  - (if you pass a char as the first parameter, the function will still work)
- `int fclose(FILE *stream)`
  - closes the stream (i.e., flushes all OS buffers such that output to file is completed)
  - dissociates the actual file from the stream variable
  - returns 0 if file closed successfully.

More raw I/O (less text oriented)

- function **`fread()`** reads n elements of a fixed size from an open stream
  - `extern size_t fread( void *buf, size_t size, size_t n, FILE *stream );`
  - returns the number of elements read
- function **`fwrite()`** writes n elements of a fixed size to an open stream
  - `extern size_t fwrite( void *buf, size_t size, size_t n, FILE *stream );`
  - returns the number of elements written

C string programming idioms

- "programming idiom"
  - "means of expressing a recurring construct in one or more programming languages"
  - use of idioms indicates language fluency
  - also assumes some comfort with the language
- idioms also imply terseness
  - expressions using idioms tend to be the "ideal" size
  - "terseness" can even have an impact as machine-code level
- non-string example: infinite loop

A C-language idiom: Infinite loop

```
/*
 * Not the ideal technique
 */

while (1) {
    some_function();
    if (someflag == 0) {
        break;
    }
    some_other_function();
}
```

Loop must always perform a check at the start of the loop.

```
/*
 * Recommended approach ("idiomatic").
 */

for (;;) {
    some_function();
    if (someflag == 0) {
        break;
    }
    some_other_function();
}
```

There is no check at the start of the loop -- no extra instructions!

Example: Computing string length

- Note!
  - Normally we use built-in library functions wherever possible.
  - There is a built-in string-length function ("strlen").
  - These libraries functions are very efficient and very fast (and bug free)
- Algorithm:
  - Function accepts pointer to a character array as a parameter
  - Some loop examines characters in the array
  - Loop terminates when the null character is encountered
  - Number of character examined becomes the string length

First example

```
#include <string.h>
#include <stdlib.h>
#include <stdio.h>

#define MAX_STRING_LEN 100

int stringlength_1(char a_string[])
{
        int len = 0;

        while (a_string[len] != '\0') {
                len = len + 1;
        }
        return len;
}

int main(int argc, char *argv[])
{
        char buffer[MAX_STRING_LEN];

        if (argc == 1) { exit(0); }
        strncpy(buffer, argv[1], MAX_STRING_LEN);
        printf("%d\n", stringlength_1(buffer));

         exit(0);
}
```

C knows nothing about the bounds of arrays!

"char a_string[]" is the same as "char *a_string"

Each character is explicity compared against the null character. Note the single quotes!

Name of character array is passed as the parameter to stringlength_1.

"buffer" is the same as "&buffer[0]"

First example: not idiomatic

- C strings are usually manipulated via indexed loops
  - "for" statements
- "For" statements are suitable to use with loops:
  - where termination depends the size of some array
  - where termination depends upon the size of some linear structure
  - where loop tests are at loop-top and loop-variable update operations occur at the loop-end
- "While" statements are most suitable with loops:
  - where termination depends on the change of some state
  - where termination depends on some property of a complex data structure
  - where actual loop operations can possibly lengthen or shorten number of loop iterations (e.g., "worklist" algorithms)

Second example

```c
#include <string.h>
#include <stdlib.h>
#include <stdio.h>

#define MAX_STRING_LEN 100

int stringlength_2(char a_string[])
{
        int len;

        for (len = 0; a_string[len] != '\0'; len = len + 1) { }

        return len;
}

int main(int argc, char *argv[])
{
        char buffer[MAX_STRING_LEN];

        if (argc == 1) { exit(0); }
        strncpy(buffer, argv[1], MAX_STRING_LEN);
        printf("%d\n", stringlength_2(buffer));

         exit(0);
}
```

Each character is explicity compared against the null character, but this is done within the "for" header.

"For" loop itself is empty.

Second example: not idiomatic

- C strings are most often accessed via char pointers
- Accessing individual characters by array index is rare
  - Principle is that strings are usually processed in one direction or another
  - That direction proceeds char by char
- More idiomatic usage also depends upon pointer arithmetic

Third example

```
#include <string.h>
#include <stdlib.h>
#include <stdio.h>

#define MAX_STRING_LEN 100

int stringlength_3(char a_string[])
{
        char *c;
        int len = 0;

        for (c = a_string; *c != '\0'; c = c + 1) {
                len = len + 1;
        }
        return len;
}

int main(int argc, char *argv[])
{
        char buffer[MAX_STRING_LEN];

        if (argc == 1) { exit(0); }
        strncpy(buffer, argv[1], MAX_STRING_LEN);
        printf("%d\n", stringlength_3(buffer));

         exit(0);
}
```

Note that a character pointer is used (i.e., dereferenced in the control expression, and incremented in the post-loop expression).

The body of the "for" loop is not empty here as variable "len" is increment in it.

(Note: We could add "len" to our "for"-loop header and keep the body empty. What would that look like?

Fourth example

```c
#include <string.h>
#include <stdlib.h>
#include <stdio.h>

#define MAX_STRING_LEN 100

int stringlength_4(char a_string[])
{
        char *c;
        int len;

        for (len = 0, c = a_string; *c; c++, len++) { }

        return len;
}

int main(int argc, char *argv[])
{
        char buffer[MAX_STRING_LEN];

        if (argc == 1) { exit(0); }
        strncpy(buffer, argv[1], MAX_STRING_LEN);
        printf("%d\n", stringlength_4(buffer));

         exit(0);
}
```

Note the "for"-loop termination condition!

We depend here on the meaning of "true" and "false" in C.

Note use of commas in the "for"-loop header.

Last examples: more idiomatic

- Char pointers were dereferenced
  - Value of dereference directly used to control loop.
- Char pointers were incremented
  - The most idiomatic code (not shown) combines dereferencing with incrementing
  - Example: `*c++`
  - Only works because "*" has a higher precedence than "++"
  - Meaning of example: "read the value stored in variable 'c', read the memory address corresponding to that value, return the value in that address as the expression value, and then increment the address stored in variable 'c'."

And tighter still…

```
#include <string.h>
#include <stdlib.h>
#include <stdio.h>

#define MAX_STRING_LEN 100

int stringlength_5(char a_string[])
{
        char *c;

        for (c = a_string; *c; c++);

        return c - a_string;
}

int main(int argc, char *argv[])
{
        char buffer[MAX_STRING_LEN];

        if (argc == 1) { exit(0); }
        strncpy(buffer, argv[1], MAX_STRING_LEN);
        printf("%d\n", stringlength_5(buffer));

         exit(0);
}
```

Extracting words from an array

- Common problem to be solved:
  - An input line consists of individual words
  - Words are separated by "whitespace" (space character, tabs, etc.)
  - Want to get a list of the individual words
- This is called "tokenization"
  - From the word "token" used by compiler writers
  - Once streams of tokens are extracted from text, compiler operates on tokens and not the text
- We ourselves can used tokenize functionality available in the C runtime library.

tokenize.c: global elements

```
#include <stdio.h>
#include <string.h>
#include <stdlib.h>

/*
 * Compile-time constants
 */
#define MAX_WORD_LEN 20
#define MAX_WORDS    100
#define MAX_LINE_LEN 100
#define MAX_LINES    10

/*
 * Global variables
 */
int num_words = 0;
int num_lines = 0;
char lines[MAX_LINES][MAX_LINE_LEN];
char words[MAX_WORDS][MAX_WORD_LEN];

void dump_words (void);
void tokenize_line (char *);
```

The program will store lines of text.

It will also store words.

Size of global arrays is determined by the run-time constants.

<u>The constants are not stored with the array!</u>

Function prototypes…

tokenize.c: easy stuff

```
void dump_words ()
{
        int i = 0;

        for (i=0; i<num_words; i++) {
                printf("%5d : %s\n", i, words[i]);
        }

        return;
}
```

tokenize.c: easy stuff

```
int main(int argc, char *argv[])
{
        int i;

        if (argc == 1) {
                exit(0);
        }

        for (i=0; i < argc-1; i++) {
                strncpy(lines[i], argv[i+1], MAX_LINE_LEN);
                tokenize_line (lines[i]);
        }

        dump_words();

        printf("first line: \"%s\"\n", lines[0]);

        exit(0);
}
```

tokenize.c: hard stuff

```
void tokenize_line (char *input_line)
{
        char *t;

        t = strtok (input_line, " ");
        while (t && num_words < MAX_WORDS) {
                strncpy (words[num_words], t, MAX_WORD_LEN);
                num_words++;
                t = strtok (NULL, " ");
        }

         /* Question: What would now be the output from
          * this statement:
          *
          * printf("%s\n", input_line);
          *
          */
        return;
}
```

Note difference in the two calls to "strtok"

Second one uses "NULL" as the first paramteer.

Why do we use a "while" to structure the loop? Or could it be converted into a "for" loop?

Structures

- Some languages refer to these as **records**
- Aggregate data type
  - Multiple variable declarations inside a single structure
  - **Variables can be of different types**
- Structure itself becomes a **new data type**
- Example:

```
struct day_of_year {
      int   month;
      int   day;
      int   year;
     float rating; /* 0.0: sucked; 1.0: great! */
}; /* this new type is named "struct date" */
```

- Note: No methods or functions can be associated with such a datatype!

Structures

- structures are used to create new aggregate types
- declarations come in the following forms:

1. `struct { int x; int y; } id;`
   - `id` is a variable (anonymous `struct`)
2. `struct point { int x; int y; };`
   - `struct point` is a new type
3. `struct point { int x; int y; } x, y, z[10];`
   - `struct point` is a new type; `x,y,z[]` are variables
4. `typedef struct point { int x; int y; } Point;`
   - `struct point` is a new type, `Point` is a synonym

Structures

- To access members of a structure we employ the **member operator** ("**.**") denoted by, **`x.y`**, and reads: "Get the value of member y from structure x".

```
struct day_of_year today;
today.day = 45;     /* not a real date! */
today.month = 10;
today.year = 2014;
today.rating = -1.0; /* bad day, off the scale */
```

- arrays of **`struct`** can be defined:

```
struct day_of_year calendar[365];
calendar[180].day = 27;
calendar[180].month = 9;
calendar[180].year = 2013;
calendar[180].rating = 1.0; /* Was someone's birthday */
```

Example

```
#include <stdlib.h>
#include <stdio.h>
#include <string.h>

#define MAX_NAME_LEN 20

struct body_stats_t {
    int   code;
    char  name[MAX_NAME_LEN];
    float weight, height;
};

int main(void) {
    struct body_stats_t family[4];

    family[0].code = 10; family[0].weight = 220; family[0].height = 190;
    strncpy(family[0].name, "Michael", MAX_NAME_LEN-1);

    family[1].code = 21; family[1].weight = 140; family[1].height = 150;
    strncpy(family[1].name, "Susanne", MAX_NAME_LEN-1);

    printf("Name of member %d is %s\n", 0, family[0].name);
    printf("Name of member %d is %s\n", 1, family[1].name);

    exit(0);
}
```

Type definitions (`typedef`)

- C allows a programmer to create their own names for data types
  - the new name is a synonym for an already defined type
  - Syntax: **`typedef datatype synonym;`**
- examples:

```
typedef unsigned long int ulong;
typedef unsigned char byte;
ulong x, y, z[10];
byte a, b[33];
```

Example

```
#include <stdlib.h>
#include <stdio.h>
#include <string.h>

#define MAX_NAME_LEN 20

typedef struct body_stats_t {
    int   code;
    char  name[MAX_NAME_LEN];
    float weight, length;
} Body_stats;

void print_stats(Body_stats p) {
        printf("Member with code %d is named %s\n", p.code, p.name);
}

int main(void) {
    Body_stats family[4];

    family[0].code = 10; family[0].weight = 220; family[0].length = 190;
    strncpy(family[0].name, "Michael", MAX_NAME_LEN-1);

    family[1].code = 21; family[1].weight = 140; family[1].length = 150;
    strncpy(family[1].name, "Susanne", MAX_NAME_LEN-1);

    print_stats(family[0]);
    print_stats(family[1]);

    exit(0);
}
```

Problem!

```
/*
 * stat_stuff.c
 */
#include <stdlib.h>
#include <stdio.h>
#include <string.h>

#define MAX_NAME_LEN 20

typedef struct body_stats_t {
    int   code;
    char  name[MAX_NAME_LEN];
    float weight, length;
} Body_stats;

int main(void) {
    Body_stats family[4];

    family[0].code = 10; family[0].weight = 220; family[0].length = 190;
    strncpy(family[0].name, "Michael", MAX_NAME_LEN-1);

    family[1].code = 21; family[1].weight = 140; family[1].length = 150;
    strncpy(family[1].name, "Sus

    print_stats(family[0]);
    print_stats(family[1]);

    exit(0);
}

void print_stats(Body_stats p) {
        printf("Member with code %d is named %s\n", p.code, p.name);
}
```

Compiler will encounter a "use" of print_stats before the function is even is defined!

(Compiler output)

```
podatus:c_examples zastre$ gcc stat_stuff.c -o stat_stuff -ansi -Wall

stat_stuff.c: In function ‘main’:
stat_stuff.c:22: warning: implicit declaration of function
‘print_stats’
stat_stuff.c: At top level:
stat_stuff.c:28: warning: conflicting types for ‘print_stats’
stat_stuff.c:22: warning: previous implicit declaration of
‘print_stats’ was here
```

On the next few slides we'll learn how to fix this.

Function prototypes

- A **function declaration** provides a **prototype** for a function.
- Such a declaration includes: **optional storage class**, **function return type**, **function name**, and **function parameters**
- A **function definition** is the implementation of a function; includes: function declaration, and the function body. Definitions are allocated storage.
- A function’s **declaration** should be “seen” by the compiler before it is used (i.e., before the function is called)
  - Why? **Type checking** (of course)!
- ANSI compliant C compilers may refuse to compile your source code if you use a function for which you have not provided a declaration. The compiler will indicate the name of the undeclared function.

Function prototypes (2)

- General syntax:

  `[<storage class>] <return type> name <parameters>;`

- Parameters: types are necessary, but names are optional; names are recommended (improves code readability)
- A prototype looks like a function but without the function body...
- Examples:

```
int isvowel(int ch);
extern double fmax(double x, double y);
static void error_message(char *m);
```

Example (w/ prototypes)

```
#include <stdlib.h>
#include <stdio.h>
#include <string.h>

#define MAX_NAME_LEN 20

typedef struct body_stats_t {
    int   code;
    char  name[MAX_NAME_LEN];
    float weight, length;
} Body_stats;

void print_stats(Body_stats);

int main(void) {
    Body_stats family[4];

    family[0].code = 10; family[0].weight = 220; family[0].length = 190;
    strncpy(family[0].name, "Michael", MAX_NAME_LEN-1);

    family[1].code = 21; family[1].weight = 140; family[1].length = 150;
    strncpy(family[1].name, "Susanne", MAX_NAME_LEN-1);

    print_stats(family[0]);
    print_stats(family[1]);

    exit(0);
}

void print_stats(Body_stats p) {
        printf("Member with code %d is named %s\n", p.code, p.name);
}
```

Prototype appears at start of C program.

Compiler reaches this point and knows what types of parameters are accepted by print_stats.

Body of print_stats seen here and compiled.

Scope of Names

- The scope of a variable determines the region over which you can access the variable by its name.

- C provides four types of scope:
  - Program scope
  - File scope
  - Function scope
  - Block scope

Program Scope

- The variable exists for the program's lifetime and can be accessed from any file comprising the program.
  - To define a global variable, omit the extern keyword, and include an initializer (needed if you want a value other than 0).
  - To link to a global variable, include the extern keyword but omit an initializer
- Example:
  - Variable with program scope is declared and referenced file 1.
  - Variable with program scope is referenced in file 2.

```
/*
 * file 1
 */

int ticks = 1

void tick_tock() {
    ticks += 1;
}
```

```
/*
 * file 2
 */

extern int ticks;

int read_clock() {
    return ticks * TICKS_PER_SECOND;
}
```

File Scope

- The variable is visible from its point of declaration to the end of the source file.
- To give a variable file scope, define it outside a function with the **static** keyword

```
/*
 * file 3
 */

static long long int boot_time = 0;

void at_boot(void) {
    boot_time = get_clock();
}

...

int main(void) {
    printf("%i\n", boot_time);
}
```

```
/*
 * file 4
 */

/* THE LINE BELOW WILL FAIL
 * when the executable is constructed.
*/

extern long long int boot_time = 0;
```

Function Scope

- The name is visible from the beginning to the end of a function.
- According to the ANSI standard, the scope of function arguments is the same as the scope of variables defined at the outmost scope of a function. Shadowing of function arguments is not allowed.
- (Shadowing of global variables is permitted, however.)

```
/*
 * file 5
 */

void function_f(int x)
{
    ... = x + ...;
}
```

```
/*
 * file 6
 */

/* The variable declaration within the
 * function below will cause a compiler
 * error.
 */
void function_g (int x)
{
   int x;  /* Not possible. */
}
```

```
/*
 * file 7
 */
int sum = 0;

void function_h(int x)
{
    int sum = init_sum();  /* different! */
}
```

Block Scope

- The variable is visible from its point of declaration to the end of the block. A block is any series of statements enclosed by braces.

```
/*
 * file 7
 */

int sum;

void function_y (int X[], int n) {
    int j;

    {
        /* Start of a nested scope */

        int j;
        for (j = 0, sum = 0; j < n; j += 1) {
            sum += X[j];
        }

        /* End of a nested scope */
    }
}
```

Operators and Expressions

• arithmetic operators:	`+, -`
• multiplicative operators:	`*, /, %`
• relational operators:	`<, <=, >, >=`
• equality operators:	`==, !=`
• logical operators:	`&&, ||, !`
• bitwise operators:	`~, <<, >>,` `&, |, ^`

Operators and Expressions

- assignment operators: **`=, +=, -=, *=, /=, %=, &=, |=, ^=, <<=, >>=`**
  - **`x op= expr`** is the same as **`x = x op expr`**
- increment and decrement: **`++, --`**
- ternary (conditional) operator: **`? :`**
  - **`x = bexpr ? expr_if_true : expr_if_false;`**

Operators and Expressions

- comma operator: `x, y`
  - evaluate **`x`**, evaluate **`y`**, result is **`y`**
- cast operator: `(type) expr`
- sizeof operator: `sizeof(type)` `sizeof(var)`
- memory operators: `&x, *x, x->y, x.y, x[5]`

Operator precedence

- Expressions often use several operators
- Order in which operations performed is partially determined by operator precedence
- Also determined by associativity
- Example: "*" and "/" take precedence over "+" and "-"
- Example: "=" has lower precedence than "+", which has lower precedence "*" which has lower precedence than "*" as dereference

```
float disc;

/* ...  */
disc = b * b - 4 * a * c;

/* (b * b) - ((4 * a) * c) */
```

```
float *pf;

/* ...  */

x = y = z = temp + *pf * k;

/* (x = (y = (z =  (temp + ((*pf) * k))))) */
```

Operator precedence

- All C reference manuals will have a table of precedence
  - (or search on Google for "c operator precedence")
- Rule of thumb: From highest to lowest
  1. Primary Expression operators (e.g., "( )", "[ ]", "->", etc.)
  2. Unary operators (*, -, &, ++, etc.)
  3. Binary operators (+, -, &, &&, etc.)
  4. Ternary operator (?:)
  5. Assignment operators (=, +=, etc.)
  6. Comma
- If in doubt: **use parentheses**

Some other operators (not in Java)

- comma operator
  - `x = (e1,e2,…,en)` has the effect of `x = en`
  - `for(i=0, j=0, k=10; bexpr; i+= 1, j+=1) {S}`
- sizeof operator
  - `sizeof(type) or sizeof(variable)`
  - compile-time operator
- memory operators
  - Array element: `x[5]`
  - Member of operator (structs): `x.y, x->y`
  - “contents of” : `*x`
  - “address of”: `&x`
- casting pointer types
  - usually used to tell C to treat an anonymous type (void *) as something more accurate
  - `int a = *(int *)some_other_pointer;`

C Preprocessor

- The C preprocessor is a separate program that runs before the compiler. The preprocessor provides the following capabilities:
  - – macro processing
  - – inclusion of additional C source files
  - – conditional compilation

Macro processing

- A macro is a name that has an associated text string
  - not type checked by compiler
- Macros are introduced to a program using the **`#define`** directive

```
#define BUFSIZE 512
#define min(x,y) ((x) < (y) ? (x) : (y))
char buffer[BUFSIZE];
int x,y;
…
int z = min(x,y);
```

#include Directive

- You include the contents of a standard header or a user-defined source file in the current source file by writing an include directive:

```
#include <stdio.h>
#include <sys/file.h>
#include "bitstring.h"
```

- (Advice) The quoted form is used for your own ‘.h’ files; the angle bracket form for system ‘.h’ files.

Some Standard Headers

Header file	Contains function prototypes for …
<stdio.h>	The standard I/O library functions and constants/types used by them.
<math.h>	Double-precision math functions and constants (pi, e, ..).
<stdlib.h>	Memory allocation functions and general utility functions.
<string.h>	Functions to manipulate C strings.
<ctype.h>	Character testing and mapping functions.

Conditional Compilation

The preprocessor provides a mechanism to include/exclude selected source lines from compilation:

`#if expr`	`#ifdef expr`	`#ifndef expr`	`#if defined(expr)`
`  S1;`	`  S1;`	`  S1;`	`  S1;`
`#elif expr`	`#elif expr`	`#elif expr`	`#elif expr`
`  S2;`	`  S2;`	`  S2;`	`  S2;`
`#else`	`#else`	`#else`	`#else`
`  S3;`	`  S3;`	`  S3;`	`  S3;`
`#endif`	`#endif`	`#endif`	`#endif`

Conditional Compilation (2)

`#define DEBUG 2`
 	
`#if 1`
`// Compile S1`
` S1;`
`#else`
`// Not compiled`
` S2;`
`#endif`
 	
`#if DEBUG == 1`
` S;`
`#endif`
	`#define DEBUG`
	
	`#ifdef DEBUG`
	` S;`
	`#endif`
	
	`#if defined(DEBUG)`
	`// Compile S1`
	` S1;`
	`#else`
	`// Not compiled`
	` S2;`
	`#endif`
		`#undef DEBUG`
		
		`#ifndef DEBUG`
		` S;`
		`#endif`
		
		`#if !defined(DEBUG)`
		`// Compile S1`
		` S1;`
		`#else`
		`// Not compiled`
		` S2;`
		`#endif`

Function pointers

- In your travels you will see code that looks a bit like the following:
  - foo = (*fp)(x, y)
  - The function call is actually performed to whatever function is stored at the address in variable "fp"
- Strictly speaking:
  - A function is not a variable…
  - … yet we can assign the address of functions into pointers, pass them to functions, return them from functions, etc.
- A function name used as a reference without an argument is just the function's address
- Example: qsort's use of a function pointer

Function pointers (example)

```
/* Code here is computing compare_ints very literally --
 * can actually produce the needed result in one arithmetic
 * operation (assuming no overflows, that is...). */

int compare_ints(const void *a, const void *b) {
    int value_a = *(int *)a;
    int value_b = *(int *)b;

    if (value_a < value_b) {
        return -1;
    } else if (value_a > value_b) {
        return 1;
    } else {
        return 0;
    }
}
```

```
void some_function(int count) {
     int numbers[count];
     /* .... read values and store them into array "numbers"... */
     qsort(numbers, count, sizeof(int), compare_ints);
     /* ... values in "numbers" now in sorted order ... */
}
```

Abstract Data Types

- So far, we have described basic data types, all the standard C statements, operators and expressions, functions, and function prototypes.
- We want to introduce the concept of modularization
- Before there were object oriented languages like Java and C++, users of imperative languages used **abstract data types (ADT):**
  - an abstract data type is a set of operations which access a collection of stored data
  - in Java and C++ this idea is called **encapsulation**
- Since ANSI compilers support separate compilation of source modules, we can use abstract data types and function prototypes to **simulate modules***:*
  - this is simply for convenience
  - a C compiler does not force us to use separate files
  - allows us to implement the “one declaration – one definition” rule

Abstract Data Types (2)

- For module **`"mod"`** there are two files:
  - – **Interface module**: named **`"mod.h"`** contains function prototypes, public type definitions, constants, and when necessary declarations for global variables. Interface modules are also called header files.
    - Interface modules are accessed using the **`#include`** C preprocessor directive
  - – **Implementation module**: named **`"mod.c"`** contains the implementation of functions declared in the interface module.

Example: module bitstring

- example: **module** `bitstring`
  - Interface module: `bitstring.h` contains the declarations for data structures and operations required to support bitstring manipulation. Contains things which **must** be visible.
    - programmer's responsibility
  - Implementation module: `bitstring.c` contains implementation of bitstring operations

Interface Module: bitstring.h

```c
#ifndef BITSTRING_H
#define BITSTRING_H

typedef unsigned int Uint;
typedef enum _bool { false = 0, true = 1 } bool;

#define BITSPERBYTE      8
#define ALLOCSIZE        (sizeof(Uint)* BITSPERBYTE)
#define BYTESPERAUNIT    (sizeof(Uint))

/* -- Bit Operations */

extern void clear_bits( Uint[], Uint );
extern void set_bit( Uint[], Uint );
extern void reset_bit( Uint[], Uint );
extern bool test_bit( Uint[], Uint );

#endif
```

Implementation Module: bitstring.c

```c
#include "bitstring.h"

/* Clear a bit string */
void clear_bits( Uint bstr[], Uint naunits ) {
    Uint i;

    for ( i = 0; i < naunits; i++ )
        bstr[i] = 0;
}

/* Set a bit in a bit string */
void set_bit( Uint bstr[], Uint bit ) {
    Uint b_index = ( bit - 1 ) / ALLOCSIZE;
    Uint b_offset = ( bit - 1 ) % ALLOCSIZE;

    bstr[b_index] |= ( 1 << b_offset );
}
```

Implementation Module (2)

```
/* Reset a bit in a bit string */
void reset_bit( Uint bstr[], Uint bit ) {
    Uint b_index = ( bit - 1 ) / ALLOCSIZE;
    Uint b_offset = ( bit - 1 ) % ALLOCSIZE;

    bstr[b_index] &= (~( 1 << b_offset));
}

/* Determine the state of a bit in a bitstring */
bool
test_bit( Uint bstr[], Uint bit ) {
    Uint b_index = ( bit - 1 ) / ALLOCSIZE;
    Uint b_offset = ( bit - 1 ) % ALLOCSIZE;

    return( (bstr[b_index] & (1 << b_offset)) ? true : false );
}
```

Using the Bitstring Module

```
#include "bitstring.h"

#define NUNITS 4

int main( int argc, char *argv[] ) {
    Uint set[NUNITS];

    clear_bits(set,NUNITS);
    set_bit(set,8);
    set_bit(set,12);

    if (test_bit(set,12) == true)
        reset_it(set,12);

    return 0;
 }
```

```
$ gcc module_user.c bitstring.c -o module_user
```