(Relatively) Speedy Introduction to C

Rudiments

- History
- Features
- How do I use C tools?
- 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 of the UNIX kernel's code was a goal
- 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 C11
  - GNU toolchain will be our workhorse (gcc version 9)

```c
/*
 * 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
  - develop a network protocol
  - develop a database management system
  - write a compiler for another language
- It is ubiquitous: where you find UNIX you usually find C
- It provides a 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 (but some scenarios can be checked at compile-time)

How do I use C tools?

- Write an application

```
$ cat > hello.c
#include <stdio.h>
int main() {
    printf("Hello, world!\n");
}
^D
```

- Compile the source file into an object file

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

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

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

```
$ gcc hello.o -o hello -lm  # Version which links in math libraries
```

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 -std=c11 -Wall hello.c -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

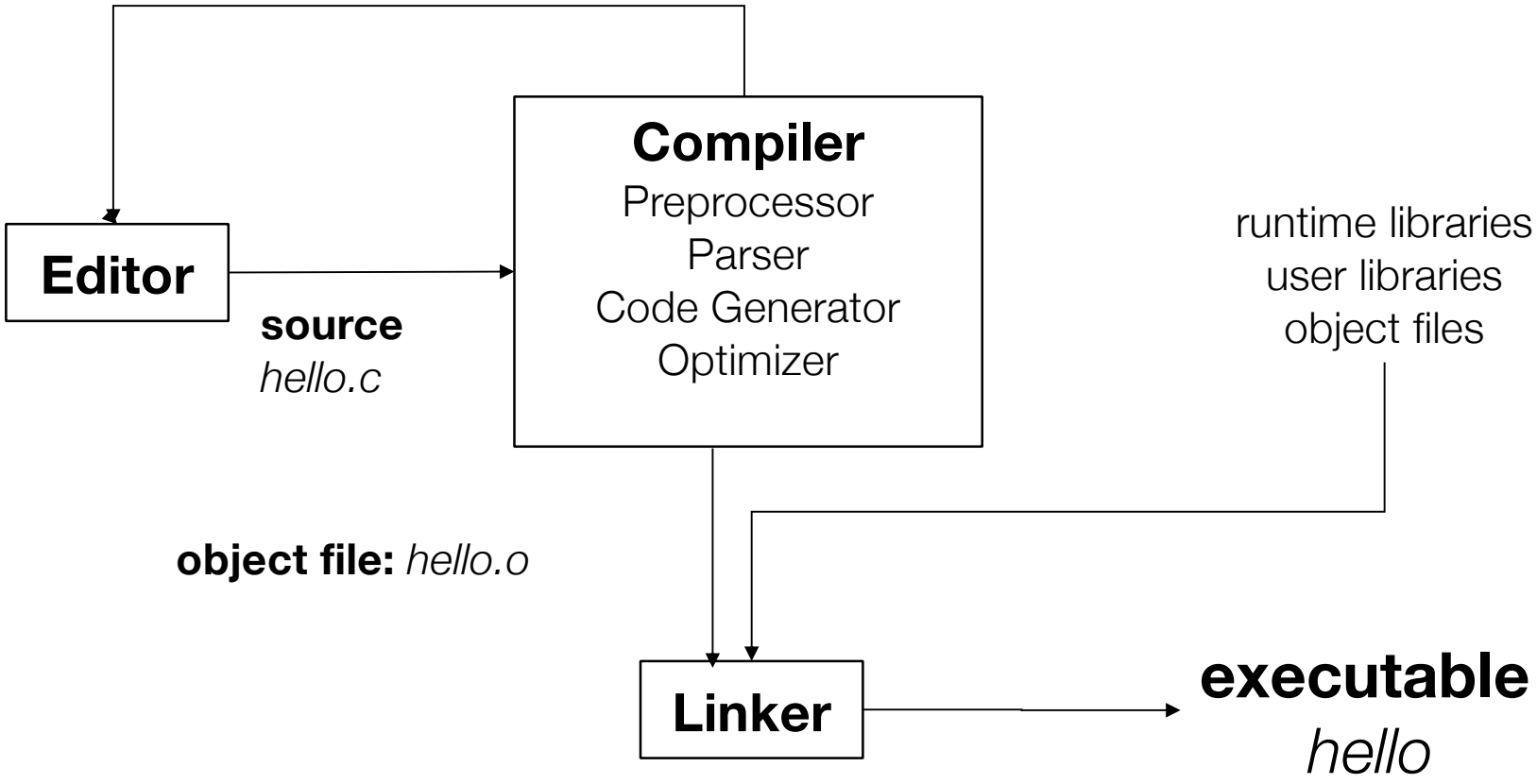
How do I use C ?

- 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 ?


Compiler
Preprocessor
Parser
Code Generator
Optimizer
Editor
source
hello.c
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 `snake_case_variable_names` rather than `someCamelCaseVariableNames`

C data types

- These behave largely as you expect from other languages
  - Java integers, floats, etc.
- Because of the C language problem domain, lots of other additional terms
  - Modifiers, specifiers, storage “classes” (which are not like Java classes)
  - These terms can cause confusion...
  - ... but in this course you are not expected to master all of the terms

type	modifiers (precision / range)
char	signed, unsigned
int	signed, unsigned, short, long, long long
float	
double	long

type	purpose / intent
struct	(for heterogeneous aggregate types)
{arrays}	(for homogeneous aggregate types)
enum	(assign names to integral constants)
union	(tricky to use, but nice when needed)

storage	purpose / intent
static	controls variable “linkage”
extern	controls variable “linkage”
auto	(now assumed as default)
register	(rarely used as compiler does it better)

qualifier	purpose / intent
const	compiler enforces non-modification
volatile	compiler avoids optimizing access

Literals: examples

```
/* Character constants in 8-bit ASCII */
char ch = 'A';
char bell = '\a';
char formfeed = '\f';

/* But chars are also just 8-bit bytes */
char c = 65;  /* Same as 'A' */
```

```
/* Integer literals */
int a = 10;
int b = 0x1CE;
int c = 0777;

unsigned int x = 0xfffU;
long int y = 2L;
```

```
/* Floating-point literals */
float x = 3.14159f;
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
```

Example

```
#include <stdio.h>

int main() {
    char person_A[50] = "Anakin Skywalker";
    char *person_B = "Darth Vader";

    printf("%s; %s\n", person_A, person_B);

    person_A[1] = '\0';
    printf("%s\n", person_A);

    person_B[1] = '\0';
    printf("%s\n", person_B);
}
```

```
$ ./fubar
Anakin Skywalker; Darth Vader
A
Segmentation fault (core dumped)
```

C data types

- We will not go into all of the C type system in exhaustive detail ...
- ... but rather will examine – via examples – the way data types in used in practice.
- Deep knowledge is essential for some programmers, though!
  - For example: those who write C compilers!
- Our focus in this course is getting you comfortable with using C data types in a straightforward way during your problem solving.
  - We will return to different type-system elements and their explanation when they are needed to understand the bigger picture.

Introduction to C Programming (cont)

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

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?

- Plain-vanilla C **does not** have a boolean type
  - C11 does have <stdbool.h>, but it does not help you understand how truth and falsity work in C.
- 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 treated as **false**, otherwise it is treated as **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 after the switch-statement's closing brace

Example: char case labels

```
#include <ctype.h>
#define TRUE 1
#define FALSE 0
...

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;

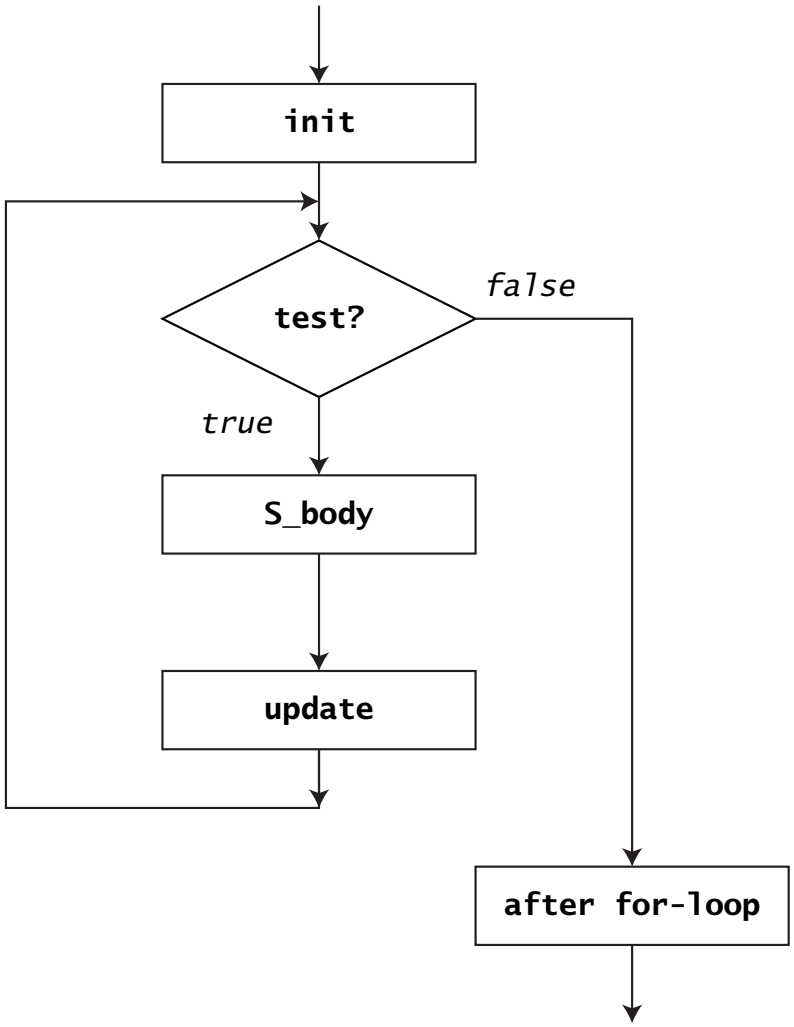
do {
    ch = getchar();
    if (ch == BLANK)
        cnt += 1;
} while (ch != '\n');
```
```

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



Examples

```
int i, sum;

sum = 0;

for (i = 1; i <= 20; i++) {
    sum += i;
}

printf ("Sum of first 20 integers is: %d\n", sum);
```

```
int i, sum;

for (i = 1, sum = 0; i <= 20; ++i, sum += i);  /* Possibly works! */

printf ("Sum of first 20 integers is: %d\n", sum);
```

```
while (1) {

    /* do something */

}
```

```
for (;;) {

    /* do something */

}
```

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);
    }
}
```

```
/* ... a bunch of code intervenes ... */

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

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

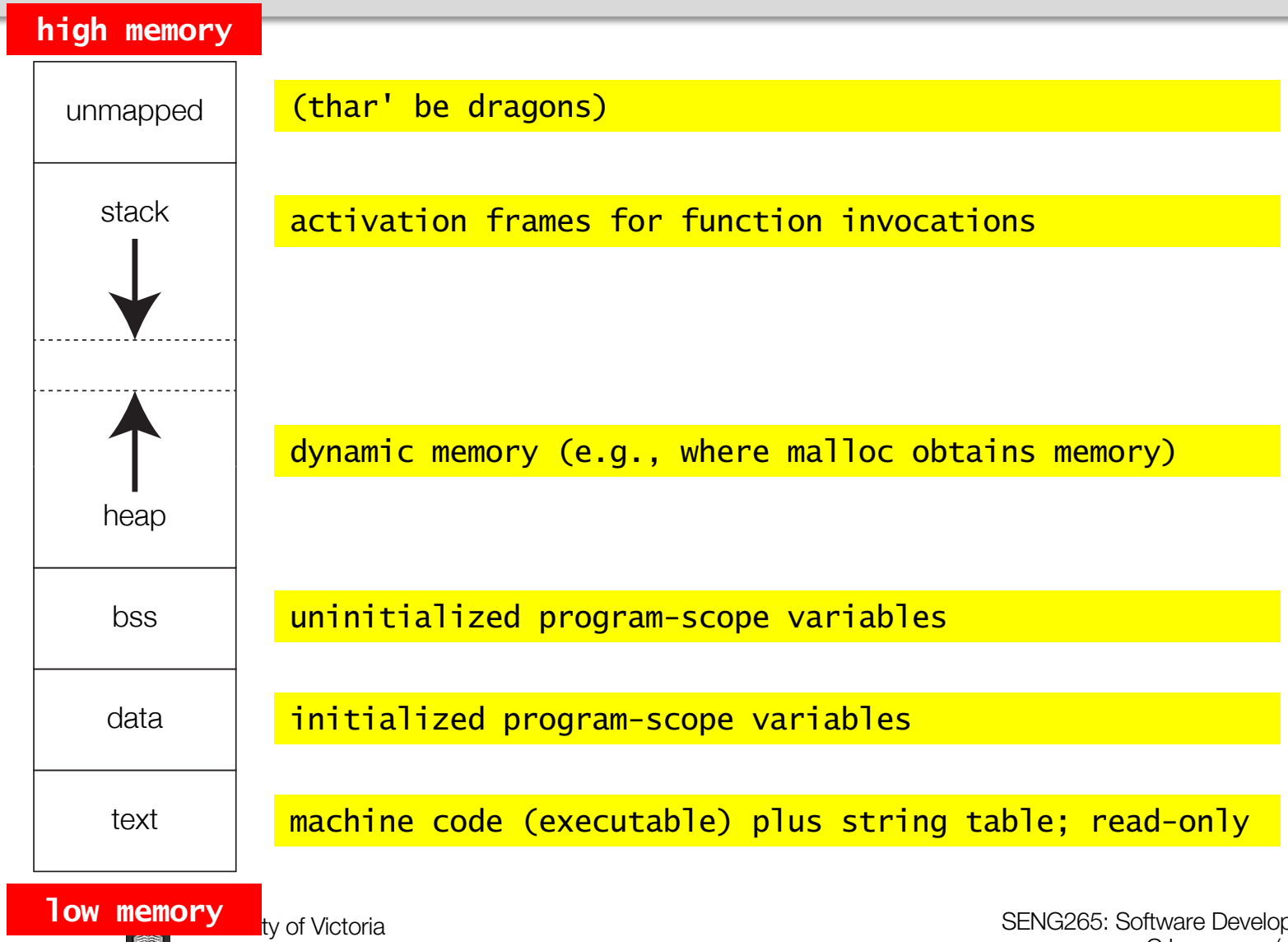
Addresses and Pointers

- Remember these points:
  a) All variables refer to data.
  b) All data resides in memory.
  c) Every memory location has an address.
  d) 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 an aggregate data type**, e.g. a location within a C string (which is stored in 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 (address) 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



Notation (declaration)

- **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'	is a variable	that holds an address	**to an 'int'**
'f'	is a variable	that holds an address	**to a 'double'**

Notation (expression)

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

***y** "read y – which contains the address to some variable – and then go to that address in order to read what is there" (**dereferencing**)

- Remember that * can appear in a **variable declaration**
- **However, * 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

- A little bit trickier with arrays of pointers

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

"st is a variable that holds ten addresses to char"

- 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;

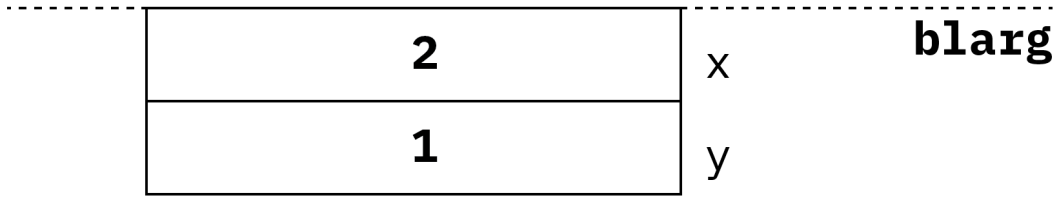
    swap(x, y);
    printf("x = %d, y = %d\n", x, y); /* x = 2, y = 1 */
}
```

```
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 */
}
```

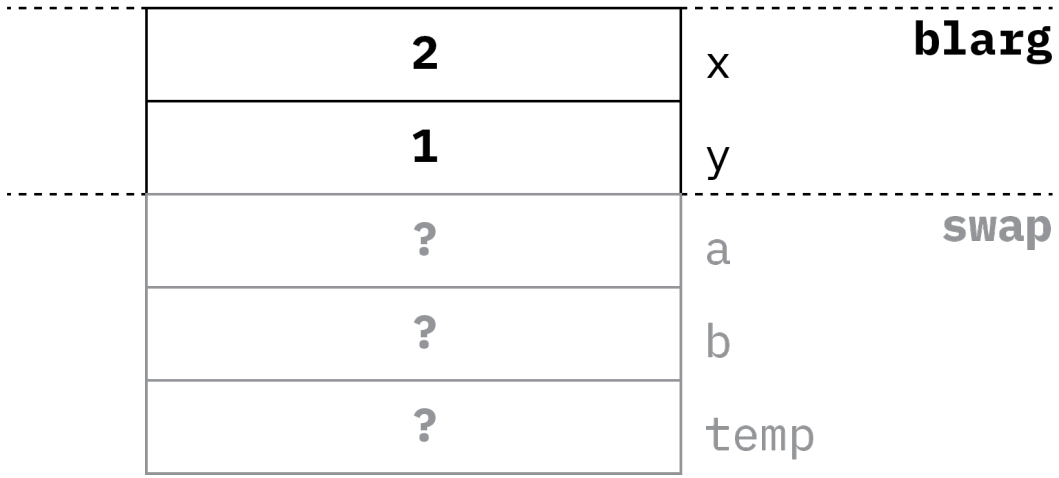


```
void swap(int a, int b) {
        int temp = a;
        a = b;
        b = temp;
}
```

```
/* ... 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 */
}
```

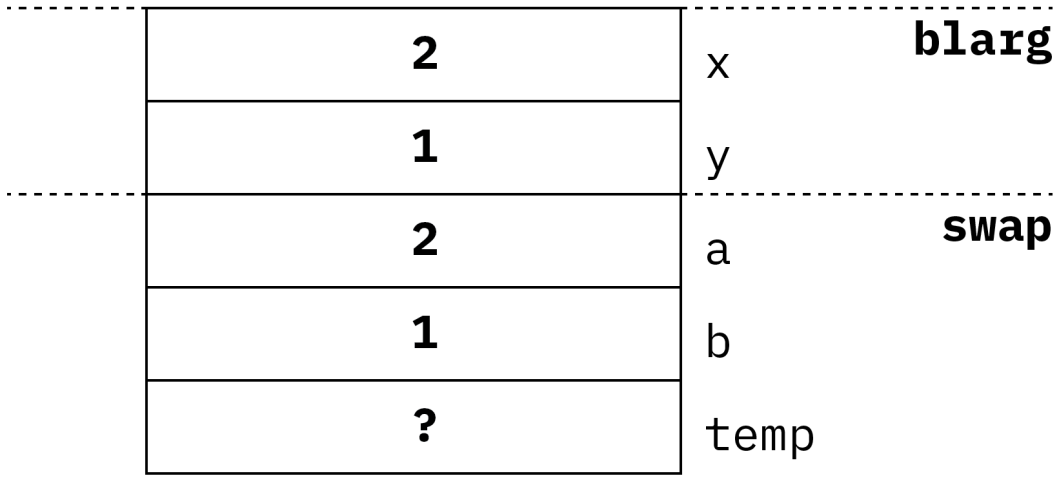


```c
void swap(int a, int b) {
        int temp = a;
        a = b;
        b = temp;
}
```

```c
/* ... 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 */
}
```

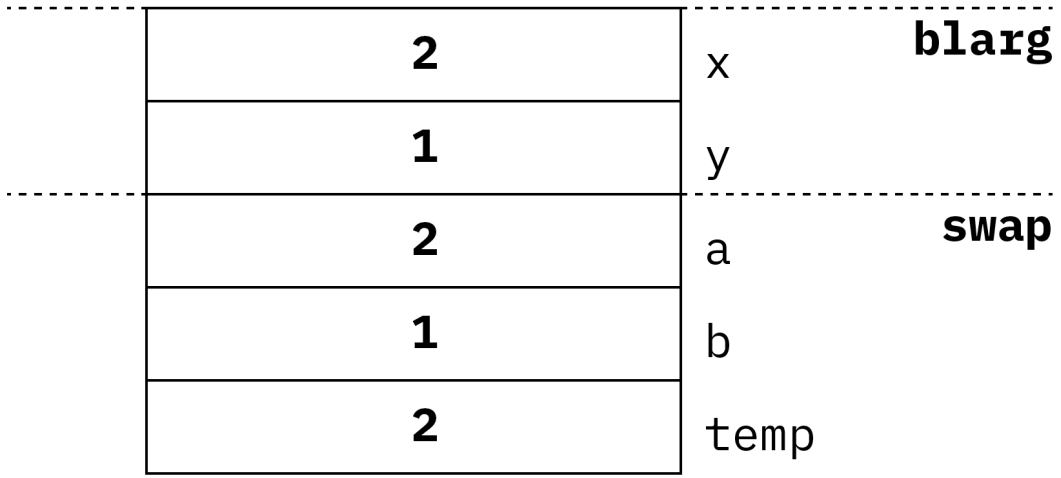


```
void swap(int a, int b) {
        int temp = a;
        a = b;
        b = temp;
}
```

```
/* ... 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 */
}
```

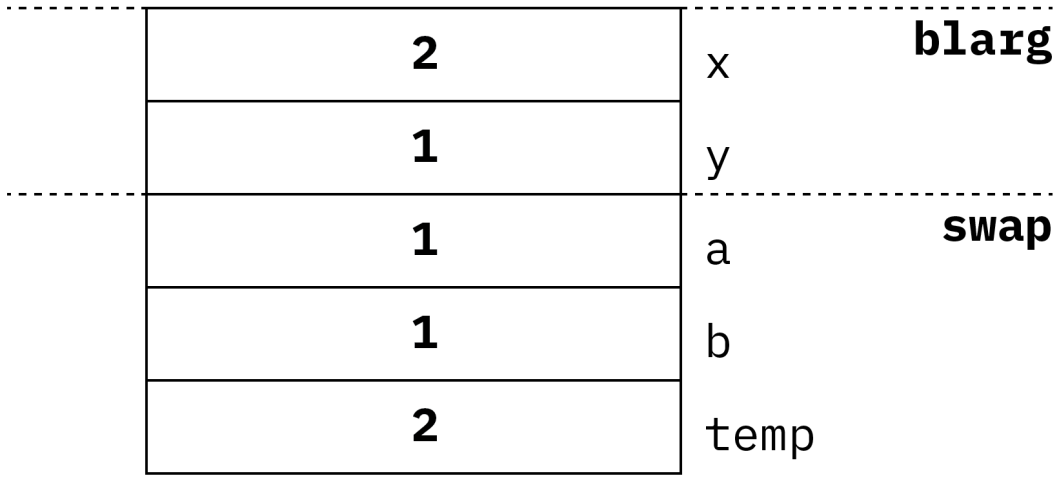


```
void swap(int a, int b) {
        int temp = a;
        a = b;
        b = temp;
}
```

```
/* ... 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 */
}
```

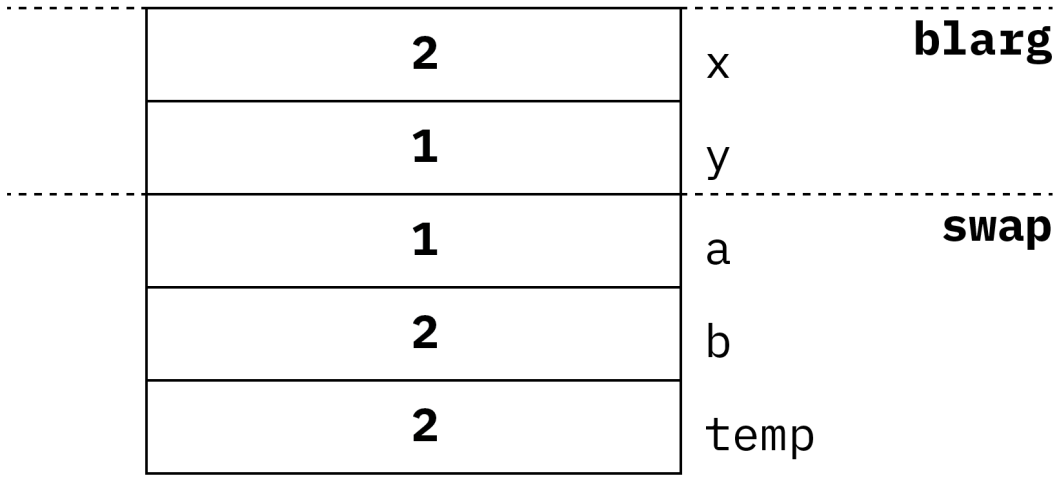


```
void swap(int a, int b) {
        int temp = a;
        a = b;
        b = temp;
}
```

```
/* ... 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 */
}
```

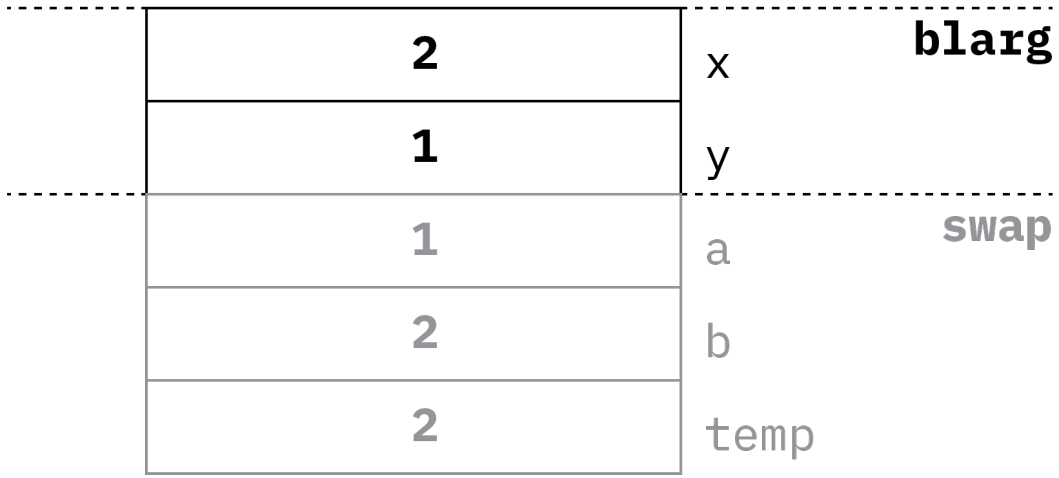


```
void swap(int a, int b) {
        int temp = a;
        a = b;
        b = temp;
}
```

```
/* ... 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 */
}
```

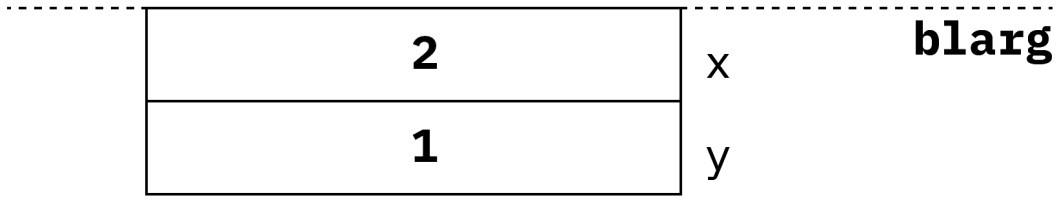


```
void swap(int a, int b) {
        int temp = a;
        a = b;
        b = temp;
}
```

```
/* ... 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

- 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;

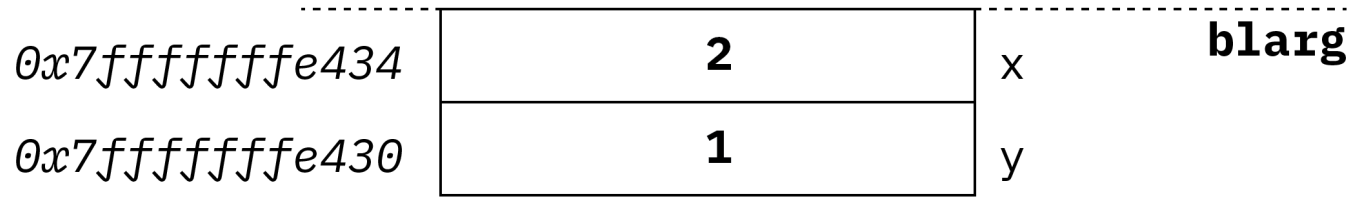
    swap(&x, &y);
    printf("x = %d, y = %d\n", x, y);
}
```

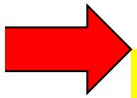
```
void swap(int *a, int *b) {
    int temp = *a;
    *a = *b;
    *b = temp;
}
```

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

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

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



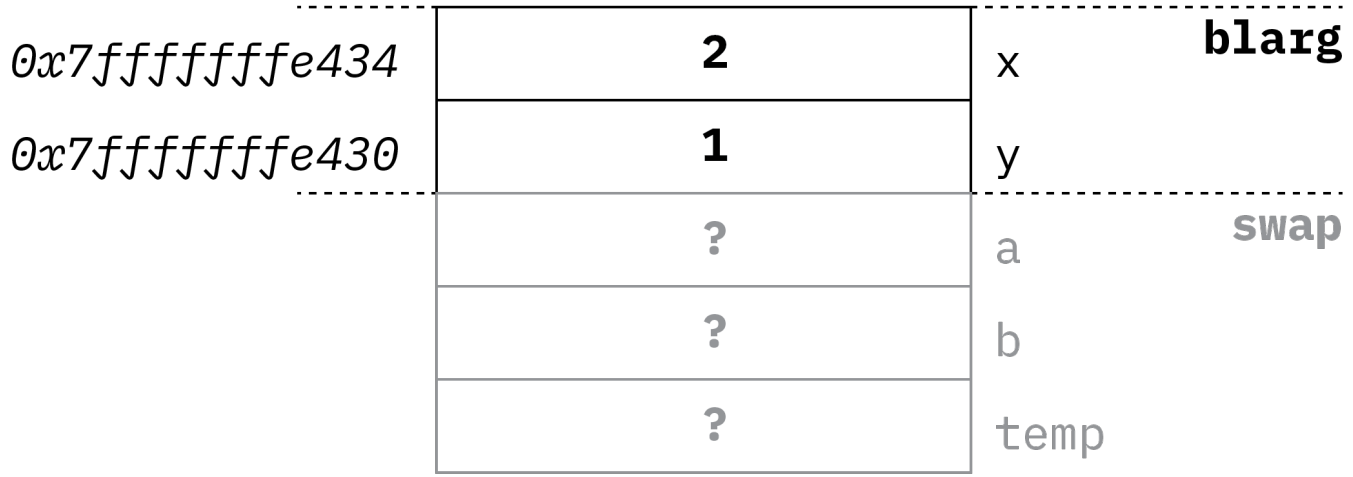


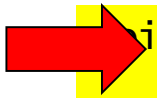
```
void swap(int *a, int *b) {
    int temp = *a;
    *a = *b;
    *b = temp;
}
```

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

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

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



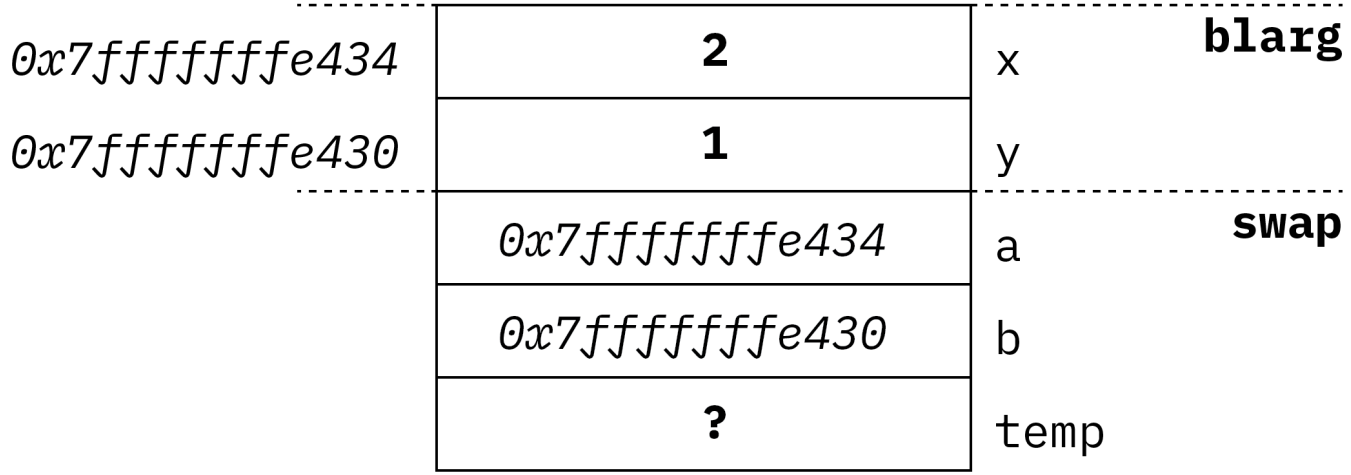


```
void swap(int *a, int *b) {
    int temp = *a;
    *a = *b;
    *b = temp;
}
```

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

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

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

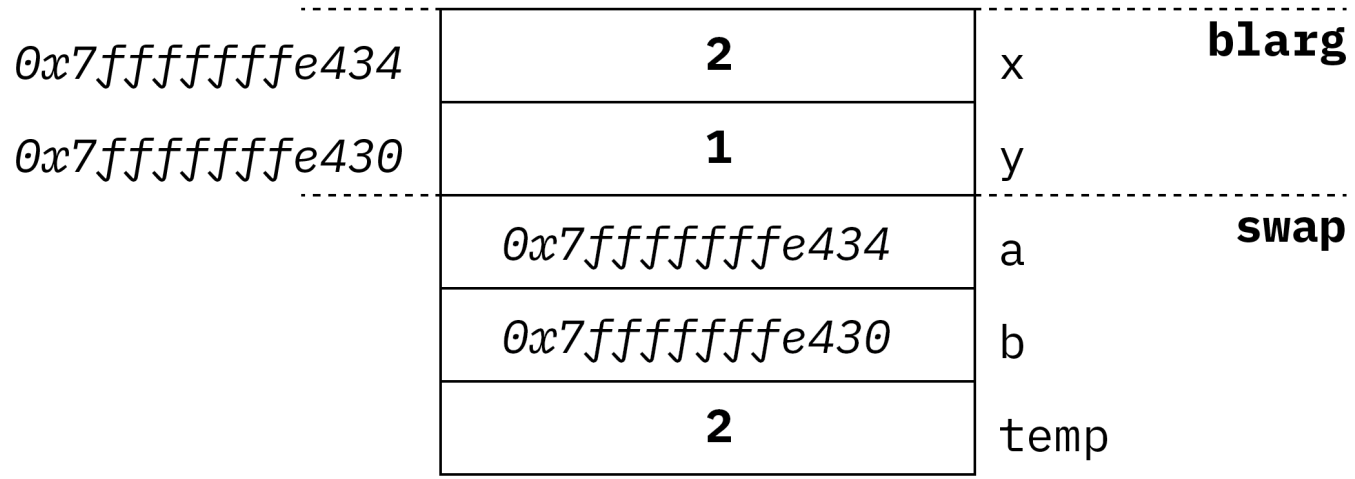


```
void swap(int *a, int *b) {
    int temp = *a;
    *a = *b;
    *b = temp;
}
```

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

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

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

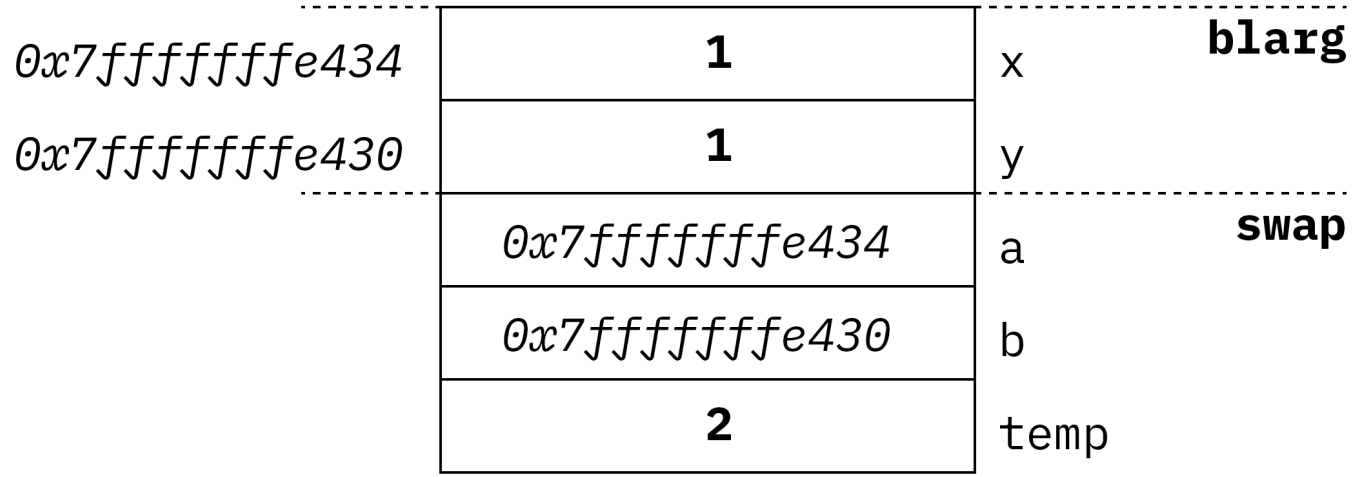


```
void swap(int *a, int *b) {
    int temp = *a;
    *a = *b;
    *b = temp;
}
```

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

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

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

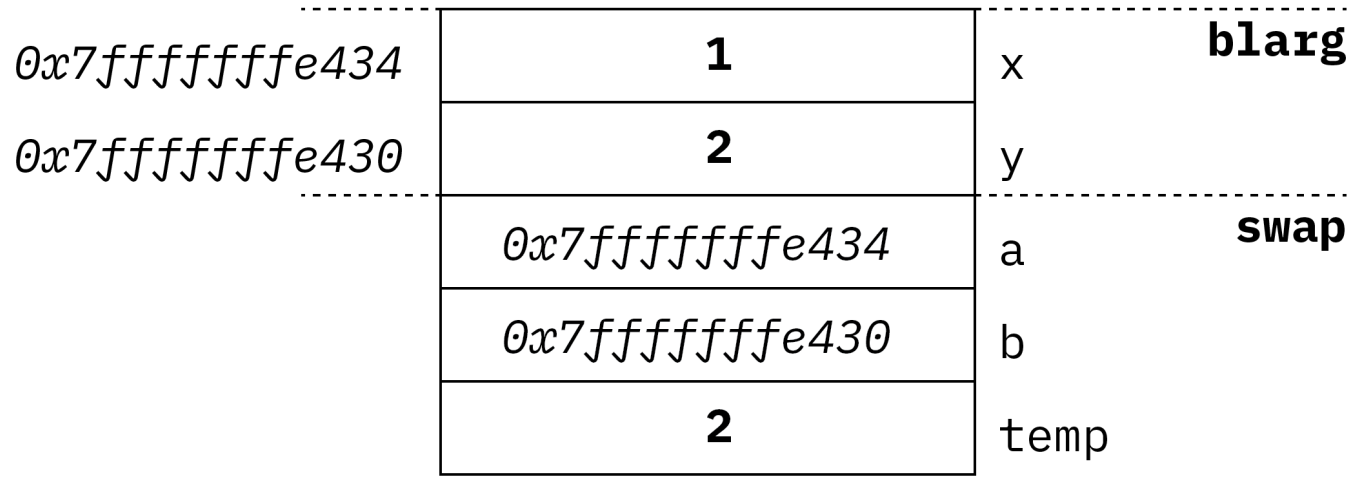


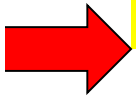
```
void swap(int *a, int *b) {
    int temp = *a;
    *a = *b;
    *b = temp;
}
```

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

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

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



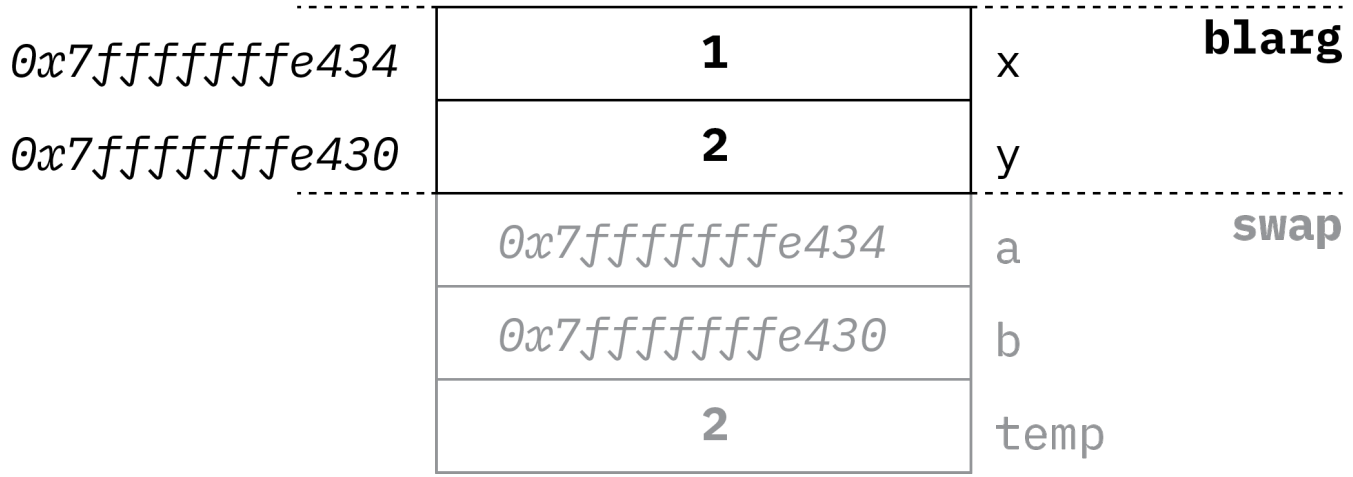


```
void swap(int *a, int *b) {
    int temp = *a;
    *a = *b;
    *b = temp;
}
```

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

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

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

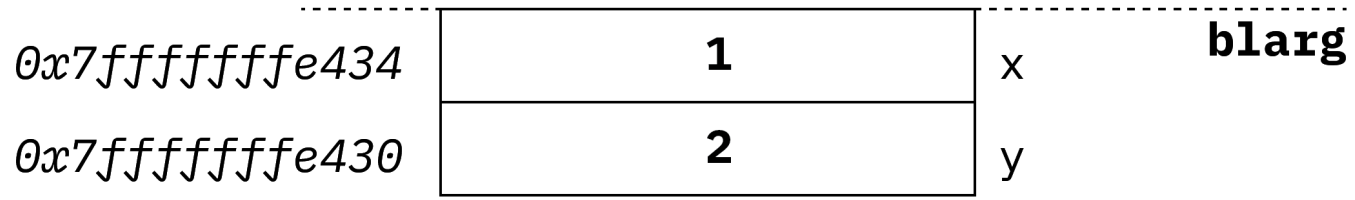


```
void swap(int *a, int *b) {
    int temp = *a;
    *a = *b;
    *b = temp;
}
```

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

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

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



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:

```
extern double func(double X[]);
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 = "Rick Sanchez";
```

```
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.

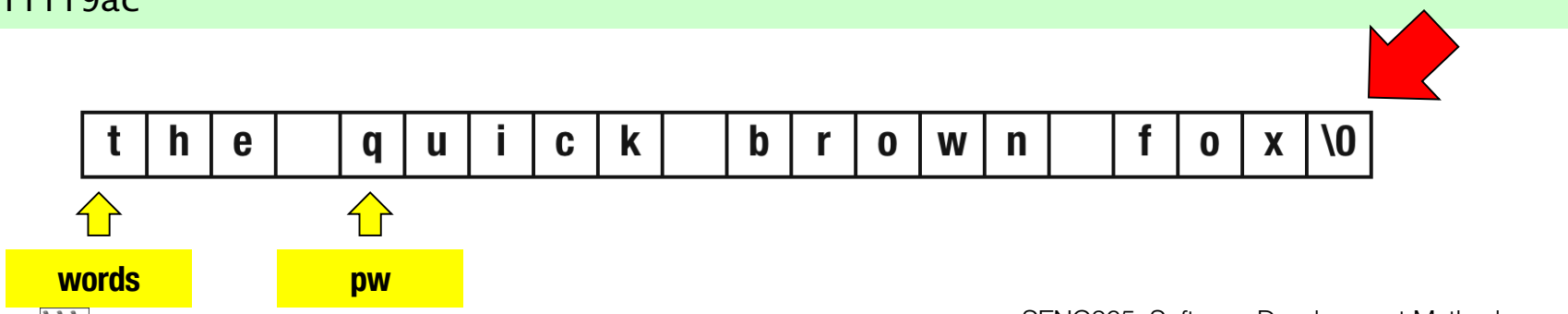
Example

```
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
```



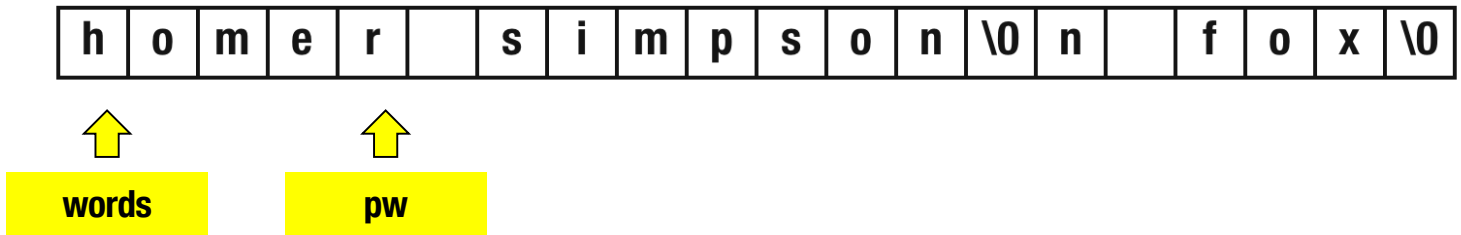
Example

```
/* ... 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
```

Example with serious problems

```
#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
```

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

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.

The constants are not stored with the array!

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?

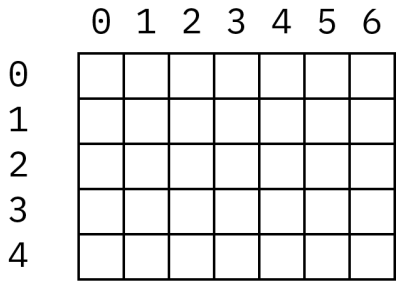
Array-ness of char arrays...

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

#define MAX_WORDS 5
#define MAX_WORD_LEN 7

char w[MAX_WORDS][MAX_WORD_LEN];

...
```



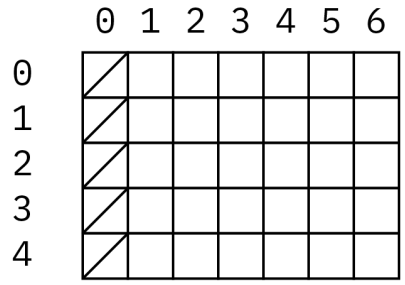
Array-ness of char arrays...

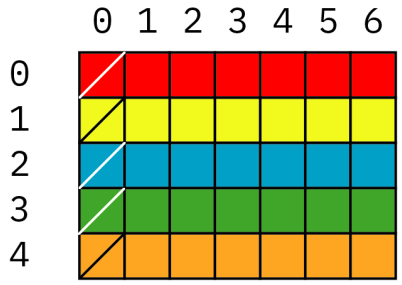
```
...

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

    for (i = 0; i < MAX_WORDS; i++) {
        w[i][0] = '\0';  /* same as strncpy(w[i], "", 1);  */
                         /* ... but avoid w[i] = "";       */
    }

   ...
```



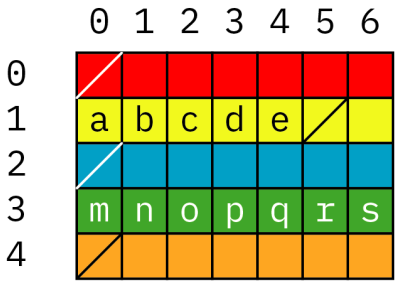


Array-ness of char arrays...

```
...

strncpy(w[1], "abcde", MAX_WORD_LEN);
strncpy(w[3], "mnopqrstuvwxyz", MAX_WORD_LEN);

...
```



Two-dimensional arrays must by laid down onto main memory (which is just a massive 1D array of bytes).

C uses “row-major” order

Array-ness of char arrays...

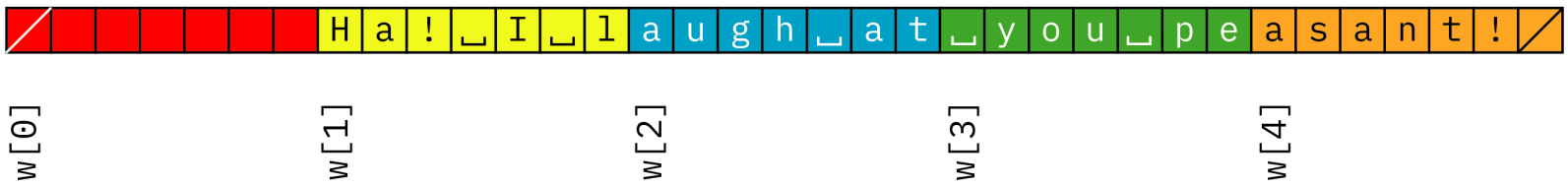
```
...

strcpy(w[1], "Ha! I laugh at you peasant!");

...
```

Before strcpy() ....

After strcpy() ....



/home/zastre/seng265/in-class/arrayness-of-words.c

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
- But we need to unpack all this a little bit more...

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
  - We'll look at `fopen()` in a moment...
- 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)

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.

File I/O

```
/* 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);
    return 0;
}
```

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 day_of_year" */
```

- 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 (with the fourth being the most flexible):

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

```c
#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);
}
```

```c
#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];
    struct body_stats_t *somebody;

    somebody = &family[0];      /* struct syntax involving pointers... */
    somebody->code = 10;
    somebody->weight = 220;
    somebody->height = 190;

    strncpy(somebody->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, somebody->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.

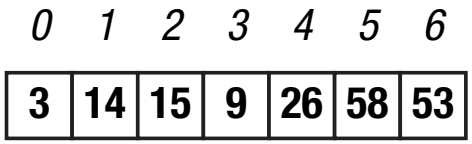
Compiler reaches this point and knows what types of parameters are accepted by print_stats.

Body of print_stats seen here and compiled.

Function pointers

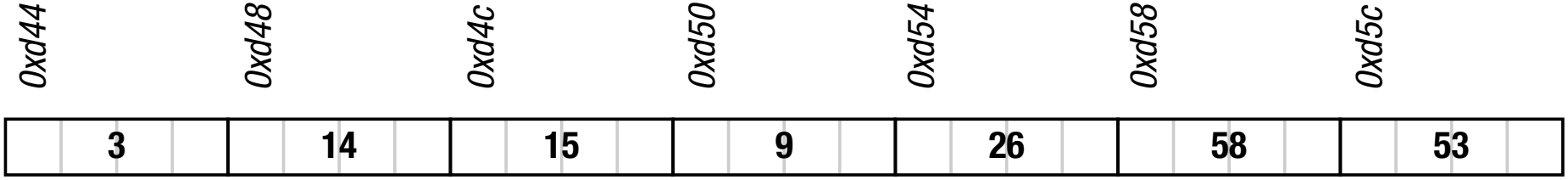
- In your travels you may see code that looks a bit like the following:
  - `foo = (*fp)(x, y)`
  - The function call is actually performed to whatever function is stored at the address in variable "fp"
- Strictly speaking:
  - A function is not a variable…
  - … yet we can assign the address of functions 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 (qsort example)




```
#define MAX_NUMBERS 7

int numbers[MAX_NUMBERS] = {3, 14, 15, 9, 26, 58, 53};
```

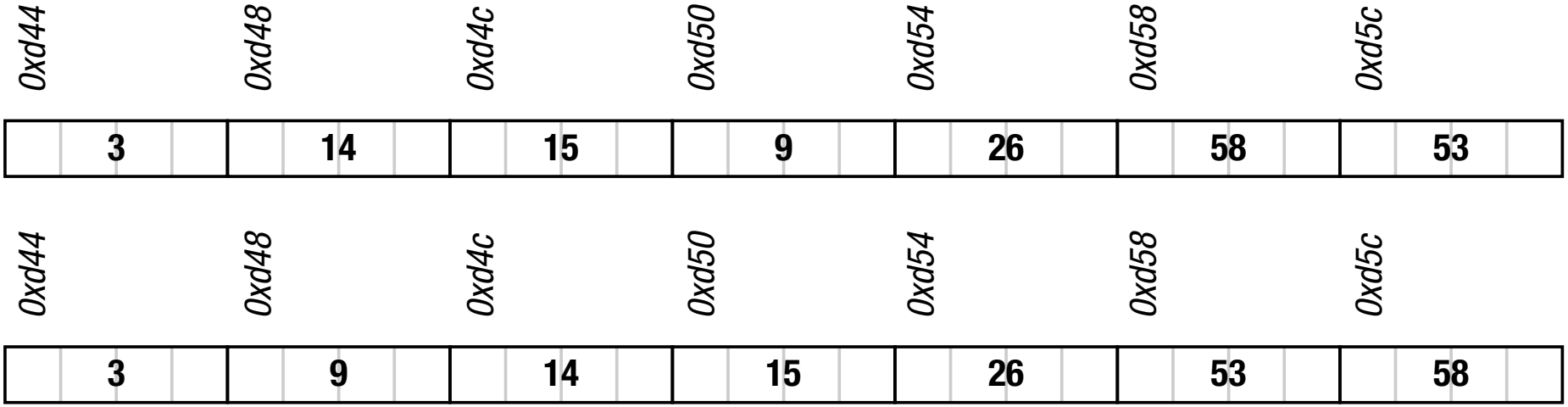


Function pointers (qsort example)

```
int main() {
    int i;
    int numbers[MAX_NUMBERS] = {3, 14, 15, 9, 26, 58, 53};

    qsort(numbers, MAX_NUMBERS, sizeof(int), compare_int);

    for (i = 0; i < MAX_NUMBERS; i++) {
        printf("%d\n", numbers[i]);
    }
}
```



Function pointers (qsort example)

```
int compare_int(const void *a, const void *b) {
    int ia = *(int *)a;
    int ib = *(int *)b;

    return ia - ib;
}
```

- qsort requires:
  - parameter 1: address of memory block to be sorted
  - parameter 2: number of elements in block to be sorted
  - parameter 3: size of each element
  - parameter 4: point to function that returns the sort order of two given elements in the block

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"
```

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