Introduction to C

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Outline

- Goals
- History
- Basic syntax
- Makefiles
- Additional syntax

Goals

- To write simple C programs
- To understand and modify existing C code
- To write and use makefiles

C History

- Developed by Dennis Ritchie at Bell Labs in 1969-73
  - Originally designed for system software
  - Impetus was porting of Unix to a DEC PDP-11
    - PDP-11 had 24kB main memory!
- See The C Programming Language by Kernighan & Ritchie (2nd ed.) (aka “K & R”)
- Official ANSI standard published in 1989
  - Updated in 1999
- C++ (1983)
  - Author: Bjarne Stroustrup (Bell Labs), 1979, “C with classes”

Compiled vs. Interpreted Languages

- Interpreted languages
  - when you type something, e.g., “x=y+z”, it is immediately converted to machine language and executed
  - examples: MATLAB, Python, R
  - advantage
    - interactive, allows fast development
  - disadvantage
    - generally uses more CPU/memory/time for given task

Compiled (cont'd)

- Compiled languages
  - examples: C, C++, Fortran
  - **source code** is written using a text editor
    - source code does nothing by itself – it's just text
  - source code must be processed through a **compiler**, which
    - checks for correct **syntax** and **semantics**
    - translates source code into **assembly**, then assembles (or calls assembler) to produce **machine** code
    - passes machine code to linker, which creates **executable**
      - this is the file that you actually run
      - example: .exe file in Windows
      - default name in Unix/Linux: a.out

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C syntax

- C is case-sensitive
- Spaces, linefeeds, etc., don’t matter except within character strings.
- Source lines generally end with semicolons
- Comments
  - notes for humans that are ignored by the compiler
  - C: enclosed by /* */
  - C++: // at beginning of comment
    - many C compilers also accept this syntax
  - Official advice: use them liberally (so you can still understand your program next year [or next week, depending on your age])

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Variables

- Variables are **declared** to have a certain **type**.
- Common types include:
  - int
    - “integer”
      - number with no decimal places: -56, 857436
  - float, double
    - “floating-point”
      - number with decimal: 1.234, 4.0, 7.
    - float: single precision, 32 bits*, ~7 significant digits
    - double: double precision, 64 bits*, ~16 significant digits
  - complex, double complex (since C99)

*on most computers

Variables (cont'd)

- char
  - "character"
  - enclosed in *single* quotes
  - 'x', '$'
  - *character string* is string of chars enclosed in *double* quotes
    - "This is a character string."

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Functions

- Source code largely consists of **functions**
  - each one performs some task
  - you write some of them
  - some are supplied, typically in libraries
- every code contains at least one function, called **main**
- functions often, though not always, return a value, e.g.:
  - int, float, char, etc.
  - default return value is int
  - To explicit about returning no value, declare as void

Functions (cont'd)

- functions may, but do not have to, take arguments
  - arguments are inputs to the function
    - e.g.,   y = sin(x)
- code blocks, including entire functions, are enclosed within "curly brackets" { }
- main function is defined in source code as follows:

type declaration   function name   function arguments (we have no arguments here but still need parentheses)

```
int main( ) {
    function statements
}
```

Functions (3)

- Style note: some people like to arrange the brackets like so:

```
int main( )
{
    function statements
}
```

- Either way is fine
  - Friendly advice: be consistent!
- Emacs advertisement: a good editor can do automatic indentation, help you find matching brackets, etc.

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How to say “hello, world”: printf

- printf is a function, part of C’s standard input/output library, that is used to direct output to the screen, e.g.,

  printf(“my string”);

- The above syntax does not include a line feed. We can add one with:

  printf(“my string\n”);

  where \n is a special character representing LF

printf and stdio.h

- Some program elements, such as library functions like printf, are declared in **header files**, aka “include files.”
- Syntax*:

  #include <stdio.h> or

  #include “stdio.h”
- The contents of the named file are presented to the compiler as if you had placed them directly in your source file. In the case of printf, “stdio.h” informs the compiler about the arguments it takes, so the compiler can raise a warning or error if printf is called incorrectly. More will be said about this later.

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*Note that the #include statement does ***not*** end with ‘**;**’

Exercise 1

- Write a “hello world” program in an editor
- Program should print a character string
- General structure of code, in order:
  - include the file “stdio.h”
  - define main function
  - use printf to print string to screen
- Save it to the file name hello.c

Compilation

- A compiler is a program that reads source code and converts it to a form usable by the computer/CPU, i.e., machine code.
- Code compiled for a given type of processor will not generally run on other types
  - AMD and Intel are compatible
- We’ll use gcc, since it’s free and readily available

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Compilation (cont'd)

- Compilers have numerous options
  - See gcc compiler documentation at http://gcc.gnu.org/onlinedocs/
  - gcc is part of the "GNU compiler collection," which also includes a C++ compiler (g++), Fortran compiler (gfortran), etc.
- For now, we will simply use the –o option, which allows you to specify the name of the resulting executable

Compilation (3)

- In a Unix window:

  ```
  gcc –o hello hello.c
  ```

  - “hello” is name of executable file (compiler output)
  - “hello.c” is source file name (compiler input)
- Compile your code
- If it simply returns a Unix prompt it worked
- If you get error messages, read them carefully and see if you can fix the source code and re-compile

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Compilation (4)

- Once it compiles correctly, type the name of the executable

  hello

  at the Unix prompt, and it will run the program
  - should print the string to the screen

Declarations

- different variable types have different internal representations, so CPUs use different machine instructions for int, float, etc.
- must tell compiler the type of every variable by *declaring* them
- example declarations:

```
int  i,  jmax,  k_value;
float  xval,  elapsed_time;
char  aletter, bletter;
```

Arithmetic

- +, -, *, /
  - No power operator (see next bullet)
- Math functions declared in math.h
  - pow(x,y) raises x to the y power
  - sin, acos, tanh, exp, sqrt, etc.
  - for some compilers, need to add –lm flag (that’s a small el) to compile command to access math library
  - complex functions declared in complex.h
- Exponential notation indicated by letter “e”

  e.g., 4.2×10^3 is expressed as 4.2e3

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Arithmetic (cont'd)

- Computer math
  - The equals sign is used for assignment:
    - Value of variable on left is replaced by value of expression on right
    - Many legal statements are algebraically nonsensical, e.g.,
      `i = i + 1;`

Arithmetic (3)

- ++ and -- operators
  - These are equivalent:

```
i = i+1;
i++;
```

  - Available as prefix or postfix operator
    - j = i++; // assign value of i to j, then increment i
    - j = ++i; // increment i, then assign value to j
- += assignment
  - These are equivalent:

```
x = x + 46.3*y;
x += 46.3*y;
```

Arithmetic (4)

- Pure integer arithmetic *truncates* result!

```
5/2 = 2
2/5 = 0
```

- Can convert types with *cast* operator

```
float xval;
int i, j;
xval = (float) i / (float) j;
```

A Little More About printf

- To print a value (as opposed to a literal string), must specify a format
- For now we will use %f for a float and %d for an int
- Here’s an example of the syntax:

  printf(“My integer value is %d and my float value is %f \n”, ival, fval);
- The values listed at the end of the printf statement will be embedded at the locations of their respective formats.

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Exercise 2

- Write program to convert Celcius temperature to Fahrenheit and print the result.
  - Hard-wire the Celcius value to 100.0
    - We'll make it an input value in a subsequent exercise
  - Don't forget to declare all variables
  - Here's the equation (which you will need to modify appropriately [hint, hint!] for your program):

$$F = (9/5)C + 32$$

scanf

- reads from keyboard
- 2 arguments
  - character string describing format, e.g.,
    - %d for integer
    - %f for float
  - address* of variable into which to put keyboard input
- example

```
int ival;
scanf("%d", &ival);
```

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*see next slide

Address-of Operator

- Every variable has an address in which it is stored in memory
- In C, we sometimes need to access the address of a variable rather than its value
  - Will go into more details when we discuss pointers
- Address-of operator & returns address of specified variable
  - &ival returns the address of the variable ival
  - rarely need to know actual value of address, just need to use it

Exercise 3

- Modify Celcius program to read value from keyboard
  - Prompt for Celcius value using printf
  - Read value using scanf
  - Rest of program can remain the same as last exercise

Arrays

- Declare arrays using [ ]

```
float  x[100];
char  a[25];
```

- Array indices start at zero
  - Declaration of x above creates locations for x[0] through x[99]
- Multi-dimensional arrays are declared as follows:

```
int  a[10][20];
```

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Character arrays

- Can’t directly assign character array values:

```
char w[100];
w = “hello”;
```

$\Big\}$ This is wrong!

- Need to use strcpy function
  - declared in string.h

```
strcpy(w, ”hello”);
```

Character arrays (cont'd)

- Character strings (char arrays) always end with the null character (\0)
  - You usually don't have to worry about it as long as you dimension the string 1 larger than its maximum possible length

```
char name[5];
strcpy(name, ”Fred”);
```

} works

```
char name[4];
strcpy(name, ”Fred”);
```

} bug: might or might not work, (depending on what follows 'name' in memory – might corrupt other variables)

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For Loop

- for loop repeats calculation over range of indices

```
for(i=0;  i<n;  i++) {
        a[i] = sqrt( pow(b[i],2)  +  pow(c[i],2)  );
}
```

- for statement has 3 parts:
  - initialization
  - completion condition (i.e., if true, keep looping)
  - what to do *after* each iteration

while

- while is a simpler alternative to for:

```
int i = 0;
while (i < n) {
   a[i] = sqrt( pow(b[i],2)  +  pow(c[i],2)  );
   i++;
 }
```

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do

- do is like while, but executes the loop before testing the condition:

```
int i = 0;
do {
   a[i] = sqrt( pow(b[i],2)  +  pow(c[i],2)  );
   i++;
 } while (i < n);
```

- Note that after the first iteration, the logic of do is identical to while.

break

- break immediately exits the enclosing loop:

```
int i = 0;
while (1) {
   a[i] = sqrt( pow(b[i],2)  +  pow(c[i],2)  );
   i++;
   if (i >= n) break;
 }
```

continue

- continue immediately jumps to the top of the enclosing loop:

```
for (i=0;i<maxindex;i++) {
   if (a[i] == b[i]) continue;
   printf(“Mismatch of a and b at index %d\n”,i);
   break;
 }
```

Exercise 4

- Write program to:
  - declare two float vectors of length 3
  - prompt for first vector and read values
  - prompt for second vector and read values
  - calculate dot product
  - print the result

$$c = \sum_{i=1}^{3} a_i \times b_i$$

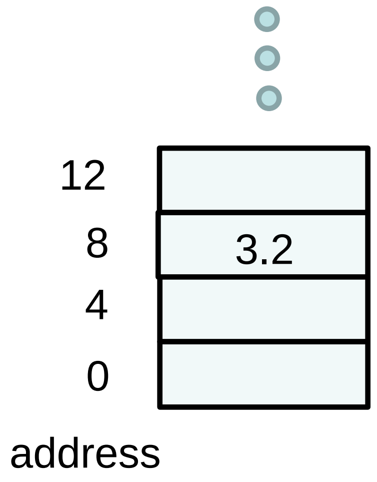
- Possible to use “redirection of standard input” to avoid retyping each time:
  - % echo 1 2 3 4 5 6 | dotprod

Pointers

- When you declare a variable, a location of appropriate size is reserved in memory
- When you set its value, the value is placed in that memory location

```
float x;

x = 3.2;
```



Pointers (cont'd)

- A pointer is a variable containing a memory *address*
- Declared using *

```
float *p;
```

- Often used in conjunction with address-of operator &

```
float x, *p;
p = &x;
```

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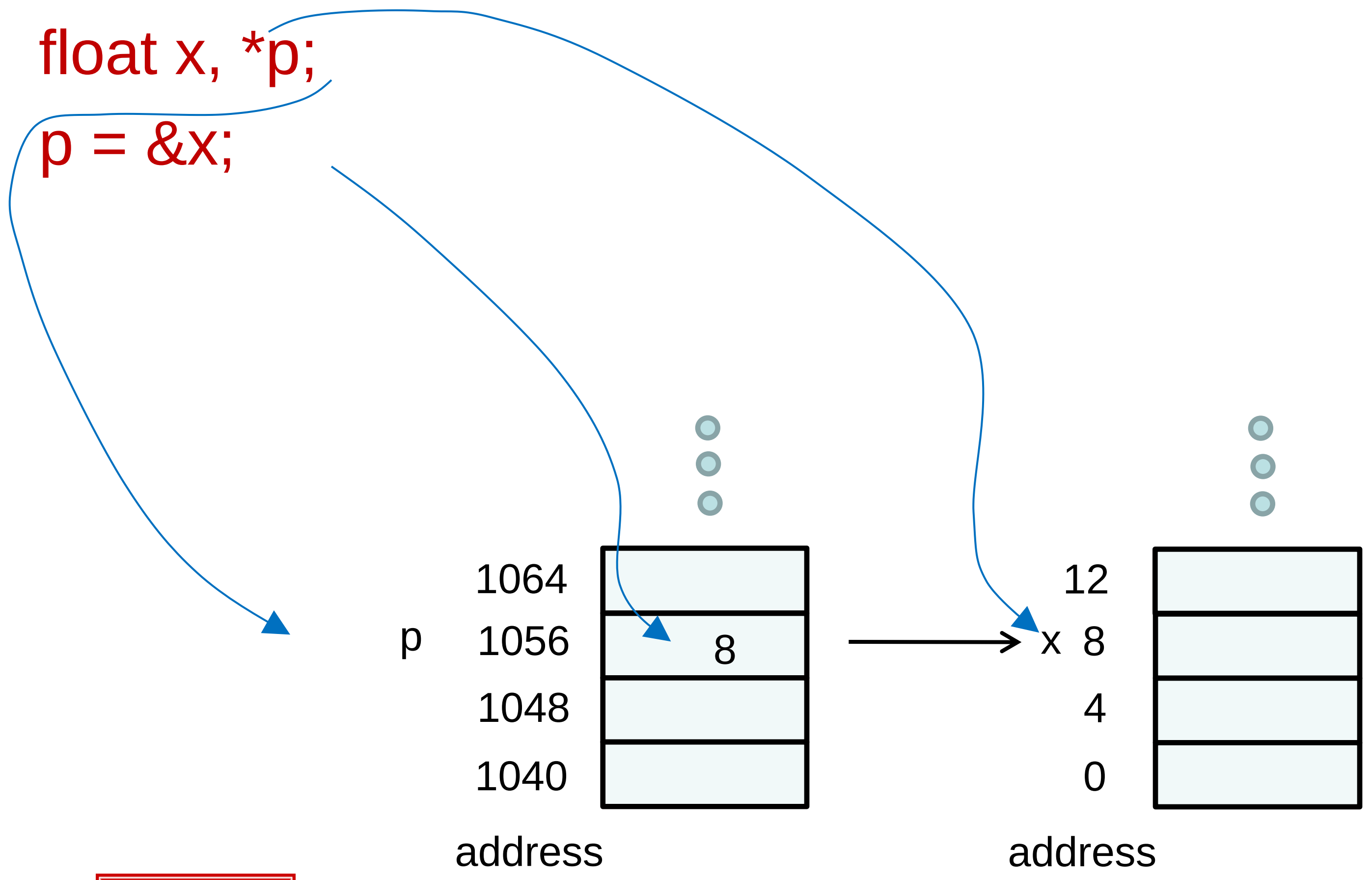
Pointers (3)

```
float x, *p;
p = &x;
```



Pointers (4)

- Depending on context, * can also be the *dereferencing operator*
  - Value stored in memory location pointed to by specified pointer

    *p = 3.2; // “the place pointed to by p gets 3.2”
- Common newbie error

```
double *p;
*p = 3.2;
```

Wrong! – p contains an unknown address

```
float x, *p;
p = &x;
*p = 3.2;
```

correct

Pop quiz: what is the value of x after this code runs?

Pointers (5)

- The name of an array is actually a pointer to the memory location of the first element
  - a[100]
  - “a” is a pointer to the first element of the array
- These are equivalent:

```
x[0] = 4.53;
*x = 4.53;
```

Pointers (6)

- If p is a pointer and n is an integer, the syntax p+n means to advance the pointer by n *locations**
- These are therefore equivalent:

```
x[4] = 4.53;
*(x+4) = 4.53;
```

*i.e., for most machines, 4*n bytes for a float, and 8*n bytes for a double

Pointers (7)

- In multi-dimensional arrays, values are stored in memory with *last* index varying most rapidly:*

  (a[0][0], a[0][1], a[0][2], …)
  - Opposite of MATLAB, Fortran, R, et al.
- The two statements in each box are equivalent for an array declared as int a[5][5]:

```
a[0][3] = 7;
*(a+3) = 7;
```

```
a[1][0] = 7;
 *(a+5) = 7;
```

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* referred to as ”row-major order”

sizeof

- Some functions require size of something in bytes
- A useful function – sizeof(*arg*)
  - The argument *arg* can be a variable, an array name, a type
  - Returns no. bytes in arg

```
float x, y[5];
sizeof(x)          ( 4)
sizeof(y)          (20)
sizeof(float)      ( 4)
```

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Dynamic Allocation

- Suppose you need an array, but you don’t know how big it needs to be until run time.
- Tried and true method - use malloc function:

  malloc(*n*)

  - n is no. *bytes* to be allocated
  - returns pointer to allocated space
  - declared in stdlib.h
- Many C compilers now accept “float f[n]”, where ‘n’ is determined at runtime.

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Dynamic Allocation (cont'd)

- Declare pointer of required type

  float *myarray;

- Suppose we need 101 elements in array:
  - myarray = malloc(101*sizeof(float));
- free releases space when it's no longer needed:

  free(myarray);

Exercise 5

- Modify dot-product program to handle vectors of any length
  - Prompt for length of vectors (printf)
  - Read length of vectors from screen (scanf)
  - Dynamically allocate vectors (malloc)
  - Prompt for and read vectors (printf, scanf)
    - use for loop
  - Don’t forget to include stdlib.h, which contains a declaration for the malloc function
  - Note that the vectors will be declared as pointers, not fixed-length arrays

if/else

- Conditional execution of block of source code
- Based on relational operators

<	less than
>	greater than
==	equal
<=	less than or equal
>=	greater than or equal
!=	not equal
&&	and
||	or

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if/else (cont’d)

- Condition is enclosed in parentheses, and code block is enclosed in curly brackets:

```
if (x > 0.0  && y > 0.0) {
     printf(“x and y are both positive\n”);
     z = x + y;
}
```

- Note: curly brackets are optional if there is only a single statement in the code block (but this is a notorious source of bugs):

```
if (x > 0.0  && y > 0.0)
  z = x + y;
```

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if/else (3)

- Can have multiple conditions by using else if

```
if( x > 0.0  && y > 0.0 ) {
    z = 1.0/(x+y);
} else if( x < 0.0  &&  y < 0.0 ) {
    z = -1.0/(x+y);
} else {
    printf(“Error condition\n”);
}
```

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switch

- For multi-way branches on constant integer values:

```
int j; …
switch (j) {
case 0:
  printf(“Here, j = 0”\n);
  break;
case 100:
  printf(“Here, j = 100\n”);
  break;
default:
   printf(“Here, j != 0 && j != 100\n”);
   break;
}
```

Exercise 6

- In dot product code, check if the magnitude of the dot product is less than 10^{-6} using the absolute value function fabsf. If it is, print a warning message.
  - With some compilers you need to include math.h for the fabsf function. You should include it to be safe.
  - With some compilers you would need to link to the math library by adding the flag –lm to the end of your compile/link command.

Functions

- C functions return a single value
- Return type should be declared (default is int)
- Argument types must be declared
- Sample function *definition*:

```
float sumsqr(float x, float y) {
    float z;
    z = x*x + y*y;
    return z;
}
```

Functions (cont’d)

- Use of sumsqr function:

```
a = sumsqr(b,c);
```

- Call by *value*
  - when function is called, copies are made of the arguments
  - copies are accessible within function
  - after function exits, copies no longer exist

Functions (3)

```
b = 2.0;  c = 3.0;
a = sumsqr(b, c);
printf(“%f\n”, b);      ⟵  will print 2.0

float sumsqr(float x, float y) {
    float z;
    z = x*x + y*y;
    x = 1938.6;         ⟵  this line has no effect on b
    return z;
}
```

Functions (4)

- If you want to change argument values, pass pointers

```
int swap(int *i,  int *j) {
    int k;
    k = *i;
    *i = *j;
    *j = k;
    return 0;
}
```

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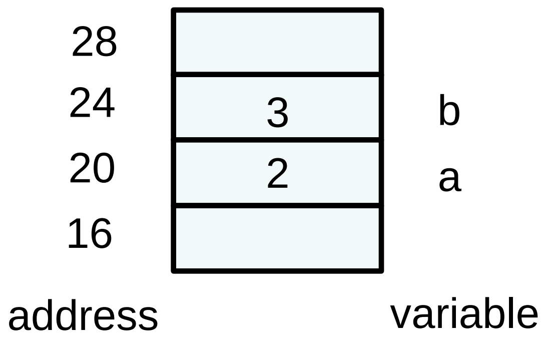
Functions (5)

- Let’s examine the following code fragment:

```
int a, b;
a = 2;  b = 3;
swap(&a, &b);
```

- Memory after setting values of a and b



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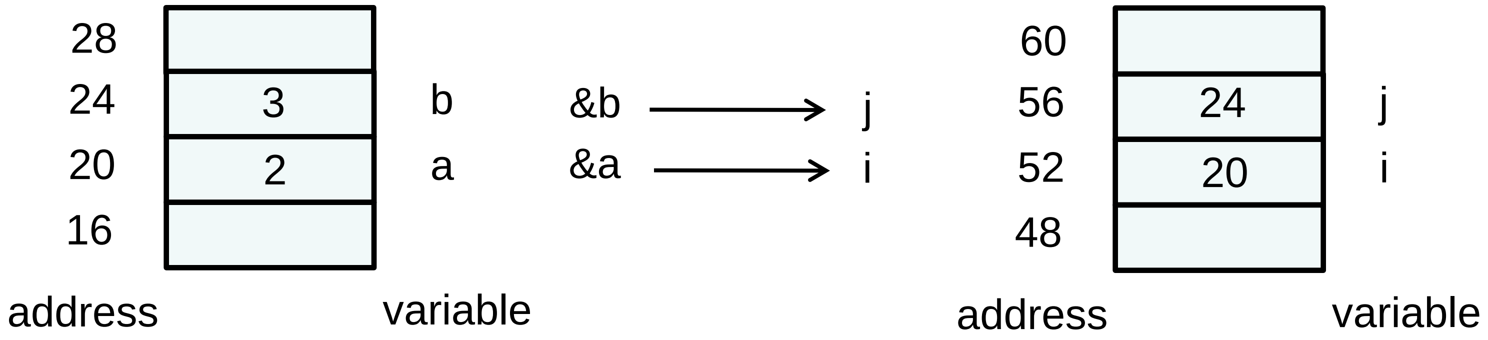
Functions (6)

- When function is called, copies of arguments are created in memory

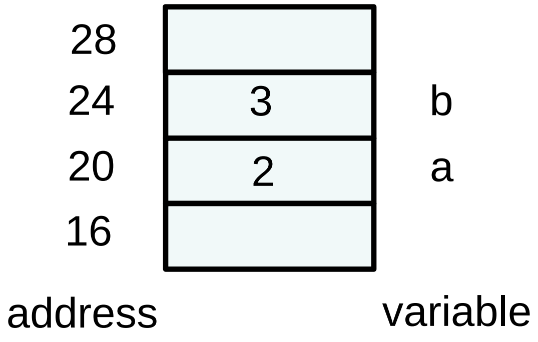
swap(&a, &b); ⟶ int swap(int *i, int *j){ ... }



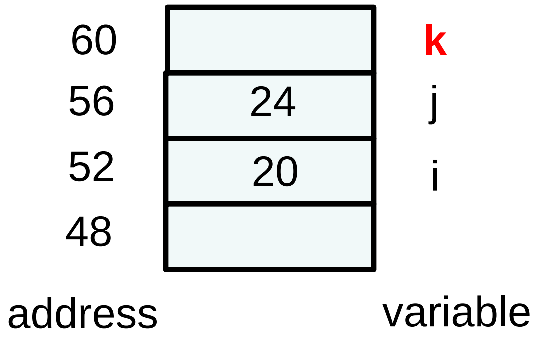
- i, j are pointers to ints with values &a and &b

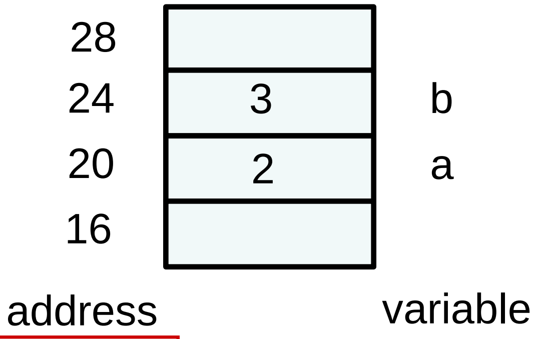
Functions (7)

- What happens to memory for each line in the function?

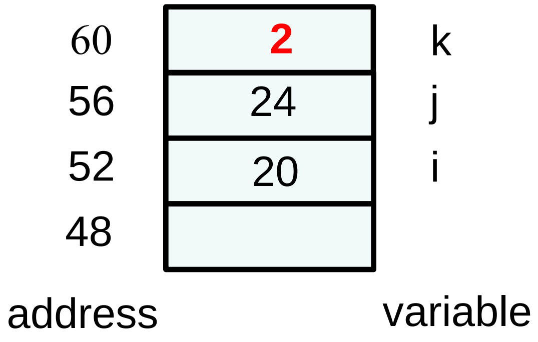


int k;

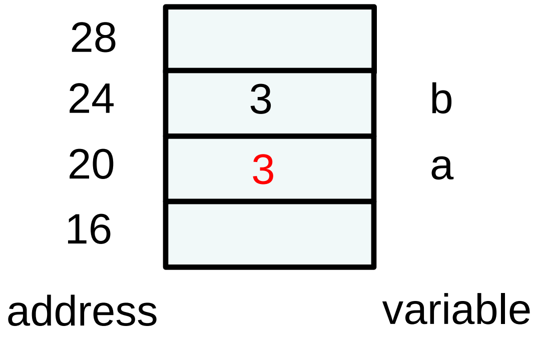




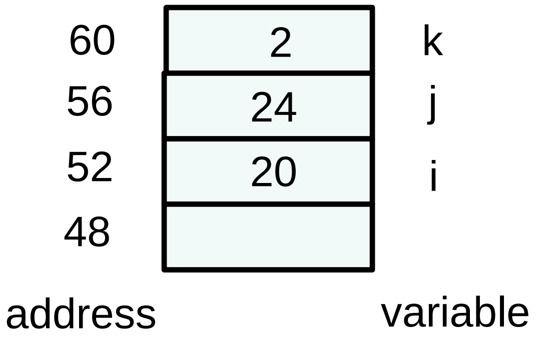
k = *i;

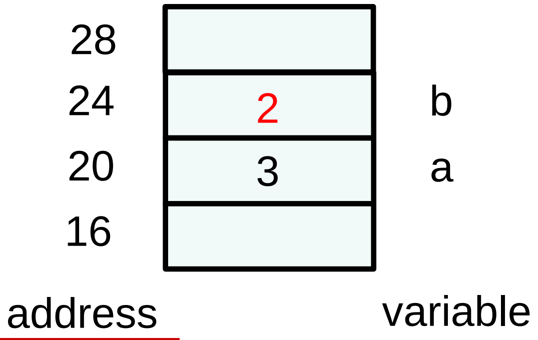


Functions (8)

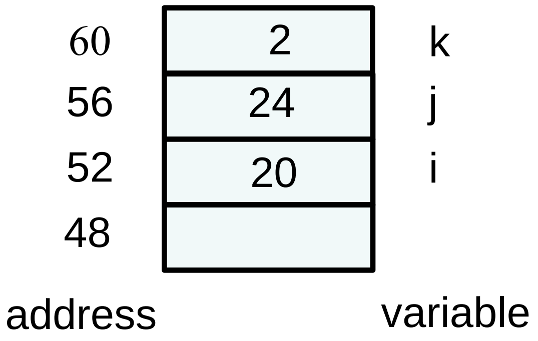


*i = *j;





*j = k;



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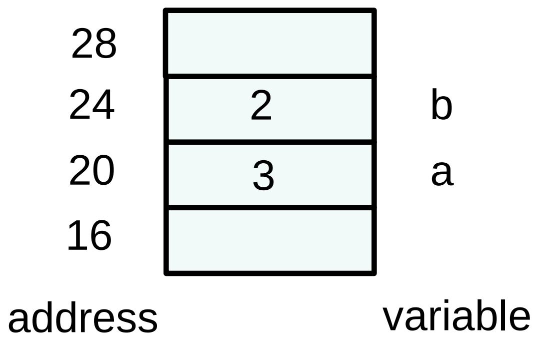
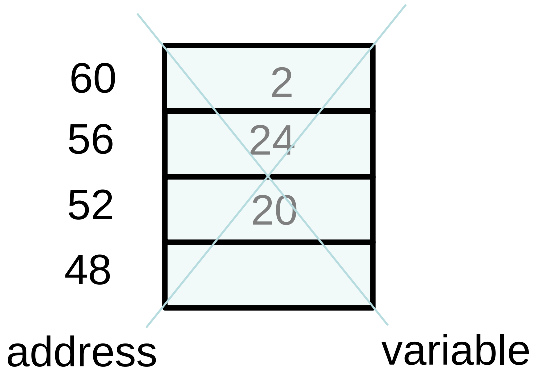
Functions (9)



return 0;



Exercise 7

- Modify dot-product program to use a function to compute and return the dot product
  - The function definition should go after the includes but *before* the main program in the source file
  - Arguments can be an integer containing the length of the vectors and a pointer to each vector
  - Function should only do dot product, no i/o
  - Do not give function same name as executable
    - I called my executable “dotprod” and the function “dp”

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Function Prototypes

- C compiler checks arguments in function calls
  - number
  - type
- Multiple files are compiled separately, so if function definition and function call are not in same file, need means of determining proper arguments, etc.
  - this is done through *function prototypes*

Function Prototypes (cont'd)

- Prototype looks like 1st line of function definition
  - return type
  - name
  - argument types

```
float dp(int n,  float *x,  float *y);
```

- Argument names are optional:

```
float dp(int,  float*,  float*);
```

Function Prototypes (3)

- Prototypes are often contained in include files

```
/* mycode.h contains prototype for myfunc */
#include “mycode.h”
int main(){
…
myfunc(x);
…
}
```

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Basics of Code Management

- Large programs usually consist of multiple files
- Some programmers create a separate file for each function
  - Easier to edit
  - Can recompile one function at a time
- Files can be compiled, but not linked, using –c option; then object files can be linked later

```
gcc –c mycode.c
gcc –c myfunc.c
gcc –o mycode mycode.o myfunc.o
```

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Exercise 8

- Put dot-product function and main program in separate files
- Create header file
  - function prototype
  - .h suffix
  - include at top of file containing main
- Compile, link, and run

Makefiles

- Make is a Unix utility to help manage codes
- When you make changes to files, make will
  - automatically deduce which files have been modified and compile them
  - link latest object files
- *Makefile* is a file that tells the *make* utility what to do
- Default name of file is “makefile” or “Makefile”
  - Can use other names if you’d like
- See documentation here: http://www.gnu.org/software/make/manual/make.html

Makefiles (cont'd)

- Makefile contains different sections with different functions
  - The sections are *not* executed in order
- Comment character is #
  - As with source code, use comments freely

Makefiles (3)

- Simple sample makefile

```
### suffix rule
.SUFFIXES:
.SUFFIXES: .c .o
.c.o:
        gcc  -c   $*.c

### compile and link
myexe:  mymain.o   fun1.o   fun2.o   fun3.o
        gcc   –o    myexe   mymain.o   fun1.o   fun2.o   fun3.o
```

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Makefiles (4)

- Most makefiles contain one or more *rules*:

```
target:  prerequisites
                 recipe
```

- The target is a goal, oftentimes the name of an executable (but can be any name)
- Prerequisites are files the target depends on
  - E.g., executable requires object files
- Recipe generally contains means of producing target
- May have multiple targets in a makefile
  - First target is default

Makefiles (5)

- Have to tell how to create one file type from another with a *suffix rule*

```
.c.o:
	gcc  -c  $*.c
```

- The first line indicates that the rule tells how to create a .o file from a .c file
- The second line tells *how* to create the .o file
- $* is automatically set to the “stem” of the .o filename
- The big space before gcc is a tab, and you must use it!

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Makefiles (6)

- Define all file suffixes that may be encountered

```
.SUFFIXES:  .c  .o
```

- To override make's built-in list of suffixes, first use a null .SUFFIXES: line:

```
.SUFFIXES:
.SUFFIXES:  .c  .o
```

Makefiles (7)

- Revisit sample makefile

```
### suffix rule
.SUFFIXES:
.SUFFIXES: .c .o
.c.o:
        gcc  -c   $*.c

### compile and link
myexe:  mymain.o   fun1.o   fun2.o   fun3.o
        gcc   –o   myexe   mymain.o   fun1.o   fun2.o   fun3.o
```

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Makefiles (8)

- When you type “make,” it will look for a file called “makefile” or “Makefile”
- searches for the first target in the file
- In our example (and the usual case) the object files are prerequisites
- checks suffix rule to see how to create an object file
- In our case, it sees that .o files depend on .c files
- checks time stamps on the associated .o and .c files to see if the .c is newer
- If the .c file is newer it performs the suffix rule
  - In our case, compiles the routine

Makefiles (9)

- Once all the prerequisites are updated as required, it performs the recipe
- In our case it links the object files and creates our executable
- Many makefiles have an additional target, “clean,” that removes .o and other files

```
clean:
        rm  –f  *.o
```

- When there are multiple targets, specify desired target as argument to make

```
make clean
```

Makefiles (10)

- Also may want to set up dependencies for header files
  - When header file is changed, files that include it will automatically recompile
- example:

```
myfunction.o:  myincludefile.h
```

  - if time stamp on .h file is newer than .o file and .o file is required in another dependency, will recompile myfunction.c
  - no recipe is required

Exercise 9a

- At terminal prompt, copy sample makefile:
  - scc1% cp /tmp/Makefile .
- Modify so it works with the filenames you are using.
- Use **make** to build your code using the new makefile.

Exercise 9b

- Type **make** again
  - should get message that it’s already up to date
- Clean files by typing **make clean**
  - Type **ls** to make sure files are gone
- Type **make** again
  - will rebuild code
- Update time stamp on header file
  - **touch dp.h**
- Type **make** again
  - should recompile main program, but not dot product function

Addendum: Makefile macros

- Macros* can be used in makefiles to make textual substitutions:

```
OBJECTS=dotprod.o dp.o
dotprod: $(OBJECTS)
```

- Possible to make flexible Makefile template, with small number of macros at top and boilerplate following. (See next slide, and also /tmp/Makefile2.)

*GNU documentation uses the term “variables” for macros

Addendum: Makefile macros (cont'd)

```
OBJECTS=dp.o dotprod.o
INCLUDE_FILES=dp.h
EXECUTABLE=dotprod

.SUFFIXES:
.SUFFIXES: .c .o
%.o: %.c
	gcc -c $<
$(EXECUTABLE): $(OBJECTS)
	gcc -o $@  $(OBJECTS)
$(OBJECTS): $(INCLUDE_FILES)
clean:
	rm –f *.o $(EXECUTABLE)
```

Note: GNU "pattern rule" is being used instead of older "suffix rule"

C Preprocessor

- Initial processing phase before compilation
- Directives start with #
- We’ve seen one directive already, #include
  - inserts specified file in place of directive
- Another common directive is #define

  #define *NAME text*
  - *NAME* is any name you want to use
  - *text* is the text that replaces *NAME* wherever it appears in source code

C Preprocessor (cont’d)

- #define often used to define global constants

```
#define NX   51
#define NY 201
…
float x[NX][NY];
```

- Also handy to specify precision

```
#define REAL double
…
REAL x, y;
```

C Preprocessor (3)

- #define can also be used to define a macro with substitutable arguments

```
#define  ind(m,n)   (m + NY*n)
k = 5*ind(i,j);   ⟶   k = 5*(i + NY*j);
```

- Be careful to use ( ) when required!
  - without ( ) above example would come out wrong

$$\xrightarrow{\quad} k = 5*i + NY*j \; \} \text{wrong!}$$

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Exercise 10

- Modify dot-product code to use preprocessor directives to declare double-precision variables.
  - In dp.h, use #define to set REAL to double
  - In dp.h, use #define to set SCANFORMAT to “%lf” (including quotes)*
  - Add #include “dp.h” to dp.c
  - In all files, change occurrences of float to REAL.
  - In dotprod.c, change scanf “%f” format strings to SCANFORMAT.
  - In Makefile, add dependency of dp.o on dp.h.

*scanf format
  “%f” for 4-byte floats
  “%lf” (long float) for 8-byte floats

Structures

- Can create a compound data structure, i.e., a group of variables under one name

```
struct grid{
   int param;
   float x[100][100], y[100][100], z[100][100];
};
```

- Note semicolon at end of definition

Structures (cont'd)

- To declare a variable as a struct

```
struct  grid  mygrid1;
```

- Components are accessed using **.**

```
mygrid1.param = 20;
mygrid1.x[0][0] = 0.0;
```

- Or, with struct pointer, access using ->

```
struct grid *mygrid1;
mygrid1 = malloc(sizeof(struct grid));
mygrid1->param = 20;
mygrid1->x[0][0] = 0.0;
```

typedef

- Typedef can be used to create synonyms for data types. It is often used with struct declarations, e.g.:

```
struct rvec {
  int veclen;
  float *vec;
};
typedef struct rvec Rvec;
…
Rvec vec1, vec2;
```

Exercise 11

- Define struct *rvec* with 2 components, and place in dp.h
  - vector length (int)
  - pointer to REAL vector
- Modify dot-product code to use *rvec* structure
  - Declare two rvec structs in main
  - If you like, in the interest of minimizing editing, do not modify the dp function. Just call it with the appropriate elements of the two structs.

i/o

- Often need to read from and write to files rather than screen
- Files are opened with a *file pointer* via a call to the fopen function
- File pointer is of type FILE, which is defined in stdio.h
- If fopen fails, NULL is returned.

i/o (cont'd)

- fopen takes 2 character-string arguments
  - file name
  - mode

"r"	read
"w"	write
"a"	append

```
FILE *fp;
fp = fopen("myfile.d", "w");
```

i/o (3)

- Write to file using fprintf
  - Need stdio.h
- fprintf arguments:
  1. File pointer
  2. Character string containing what to print, including any formats
     - %f for float or double
     - %d for int
     - %s for character string
  3. Variable list corresponding to formats

i/o (4)

- Example:

  fprintf(fp, “x = %f\n”, x);
- Read from file using fscanf
  - arguments similar to fprintf, but, as with scanf, must supply addresses of variables:
    - fscanf(fp, “%f”, &x);
  - Returns integer equal to # items read (or EOF if error)
- When finished accessing file, close it

  fclose(fp);

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Exercise 12

- Modify dot-product code to read inputs, e.g.,

  3 1 2 3 4 5 6
- (size of vector and values for both vectors) from file "inputfile". You can use a #define for the name; a better approach will be shown in a later exercise.
  - In main function, declare FILE pointer variable fp
  - Use fopen to open file and assign value to fp, and use if to ensure that fp is not equal to 0 (and exit if is).
  - Use fscanf to read file.
  - Note: you no longer need the prompts (printfs) for the vector size and vector data, so comment them out or remove them.

Addendum: standard file streams

- stdin
  - “standard input” //default = keyboard
- stdout
  - “standard output” //default = screen
- stderr
  - “standard error” //default = screen
- Can separate standard program output from error messages:

```
printf(“%f %f %f\n”, x,y,z);
….
fprintf(stderr,  “Error opening %s.\n”,  filename);
```

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Binary i/o

- Binary data generally require much less disk space than ascii data
- [optional in Linux as of C89]: use “b” suffix on mode

```
fp = fopen(“myfile.d”, “wb”);
```

- Use fwrite, fread functions (which take same arguments)

```
float x[100];
fwrite( x,   sizeof(float),   100,   fp )
        ↗         ↑            ↗       ↖
pointer to   no. bytes in    no. of    file pointer
1st element  each element    elements
```

  - Note that there is no format specification
    - We’re strictly writing binary, not ASCII, data

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Command-Line Arguments

- It’s often useful to pass input values to the executable on the command line, e.g.,

  mycode 41.3 “myfile.d”

- Define *main* with two arguments:

  int main(int argc, char *argv[ ])

  1. argc is the number of items on the command line, *including name of executable*
     - “argument count”
  2. argv is an array of character strings containing the arguments
     - “argument values”
     - argv[0] is pointer to executable name
     - argv[1] is pointer to 1st argument, argv[2] is pointer to 2nd argument, etc.

Command-Line Arguments (cont’d)

- Arguments are character strings, often want to convert them to numbers
- Some handy functions – atoi, atof
  - atoi converts string to integer
  - atof converts string to *double*
  - They are declared in stdlib.h
  - Example:

    ```
    ival = atoi(argv[2])
    ```

    to convert the 2nd argument to an integer

Command-Line Arguments (3)

- Often want to check the value of argc to make sure the correct number of command-line arguments were provided
- If wrong number of arguments, can stop execution with exit statement
  - Can exit with status, e.g.:

    exit(1);
  - View status by echoing '$?':
    - % echo $?

      1

Exercise 14

- Modify dot-product code to accept input filename on command line.
- Declare a character string variable and use strcpy to make copy of argv[1]
  - And remember to #include <string.h> at the top of the file.
- Add test on argc to ensure one command-line argument was provided
  - argc should equal 2 (since the executable name counts)
  - if argc is not equal to 2, print message and exit to stop execution

References

- Lots of books available
  - Kernighan & Ritchie, “The C Programming Language”
- gcc
  http://gcc.gnu.org/onlinedocs/gcc-4.5.1/gcc/
- If you’d like to move on to C++
  - Good C++ book for scientists:
    - Barton and Nackman, “Scientific and Engineering C++”
  - Quick and dirty C++ book:
    - Liberty, “Teach Yourself C++ in 21 Days”

Survey

- Please fill out the course survey at

http://scv.bu.edu/survey/tutorial_evaluation.html

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