Introduction to the C Programming Language

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Table of Contents

Introduction

- Why Learn C?

Why Learn C?

- Compact, fast, and powerful
- “Mid-level” Language
- Standard for program development (**wide acceptance**)
- It is everywhere! (**portable**)
- Supports modular programming style
- Useful for all applications
- C is the native language of UNIX
- Easy to interface with system devices/assembly routines
- C is terse

C Program Structure

- Canonical First Program
- Header Files
- Names in C
- Comments
- Symbolic Constants

Canonical First Program

- The following program is written in the C programming language:

```
#include <stdio.h>
main()
  {
     /* My first program */
     printf("Hello World! \n");
  }
```

- **C is case sensitive**. All commands in C must be lowercase.
- **C has a free-form line structure**. **End of each statement must be marked with a semicolon**. Multiple statements can be on the same line. ***White space*** is ignored. Statements can continue over many lines.

Canonical First Program

```
#include <stdio.h>
main()
  {
     /* My first program */
     printf("Hello World! \n");
  }
```

- The C program starting point is identified by the word `main()`.
- This informs the computer as to where the program actually starts. The parentheses that follow the keyword `main` indicate that there are no arguments supplied to this program (this will be examined later on).
- **The two braces, { and }, signify the begin and end segments of the program.** In general, braces are used throughout C to enclose a block of statements to be treated as a unit. ***COMMON ERROR: unbalanced number of open and close curly brackets!***

Canonical First Program

```
#include <stdio.h>
main()
  {
     /* My first program */
     printf("Hello World! \n");
  }
```

- The purpose of the statement `#include <stdio.h>` is to allow the use of the `printf` statement to provide program output. For each function built into the language, an associated ***header*** file must be included. Text to be displayed by `printf()` must be enclosed in double quotes. The program only has the one `printf()` statement.
- `printf()` is actually a function (procedure) in C that is used for printing variable's values and text. Where text appears in double quotes `""`, it is printed without modification. There are some exceptions however. This has to do with the `\` and `%` characters. These characters are modifiers, and in this code the `\` followed by the `n` character represents a ***newline*** character.

Canonical First Program Output & Comments

- Thus the program prints

```
Hello World!
```

- And the cursor is set to the beginning of the next line. As we shall see later on, the letter that follows the `\` character will determine what special printing action is taken (i.e., a tab, backspace, clear line, etc.)

```
/* My first program */
```

- Comments can be inserted into C programs by bracketing text with the `/*` and `*/` delimiters. As will be discussed later, comments are useful for a variety of reasons. Primarily they serve as *internal documentation* for program structure and functionality.

Header Files

- **Header files contain declarations of functions and variables** which can be incorporated into any C program by using the pre-processor `#include` statement. Standard header files are provided with each compiler, and cover a range of areas: string handling, mathematics, data conversion, printing and reading of variables, etc.
- To use any of the standard functions, the appropriate header file should be included. This is done at the beginning of the C source file. For example, to use the function **`printf()`** in a program, the line

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

  should be at the beginning of the source file, because the declaration for **`printf()`** is found in the file `stdio.h`. All header files have the extension **`.h`** and generally reside in the `/usr/include` subdirectory. Some examples:

  ```
  #include <string.h>
  #include <math.h>
  #include "mylib.h"
  ```

- The use of angle brackets `<>` informs the compiler to search the compiler's include directories for the specified file. The use of the double quotes `""` around the filename informs the compiler to start the search in the current directory for the specified file.

Names in C

- Identifiers in C **must begin with a character or underscore**, and may be followed by any combination of characters, underscores, or the digits 0-9.

```
summary      exit_flag                  i
Jerry7       Number_of_moves            _id
```

- You should ensure that you use **meaningful (but short) names** for your identifiers. The reasons for this are to make the program easier to read and self-documenting. For example, compare these two lines of code:

```
x = y * z;
distance = speed * time;
```

- Some users choose to adopt the **convention** that variable names are all lower case while symbolic names for constants are all upper case.
- **Keywords** are reserved identifiers that have strict meaning to the C compiler. C only has 29 keywords. Example keywords are:

```
if, else, char, int, while
```

Comments

- The addition of comments inside programs is desirable. These may be added to C programs by enclosing them as follows,

```
/*
Computational Kernel: In this section of code we implement the
   Runge-Kutta algorithm for the numerical solution of the
   differential Einstein Equations.
*/
```

- Note that the `/*` opens the comment field and the `*/` closes the comment field. Comments may span multiple lines. Comments may not be nested one inside the another.

```
/* this is a comment. /* this comment is inside */ wrong */
```

- In the above example, the first occurrence of `*/` closes the comment statement for the entire line, meaning that the text wrong is interpreted as a C statement or variable, and in this example, generates an error.

Why use comments?

- Documentation of variables and functions and their usage
- Explaining complex sections of code
- Describes the program, author, date, modification changes, revisions…

Best programmers comment as they write the code, not after the fact.

Symbolic Constants

- Symbolic constants are names given to values that cannot be changed. Implemented with the `#define` preprocessor directive.

```
#define N 3000
#define FALSE 0
#define PI 3.14159
#define FIGURE "triangle"
```

- Note that preprocessor statements begin with a `#` symbol, and are NOT terminated by a semicolon. Traditionally, preprocessor statements are listed at the beginning of the source file.
- Preprocessor statements are handled by the compiler (or preprocessor) before the program is actually compiled. All `#` statements are processed first, and the **symbols** (like `N`) which occur in the C program **are replaced by their value** **(3000)**. Once these substitutions has taken place by the preprocessor, the program is then compiled.
- By convention, preprocessor constants are written in UPPERCASE. This acts as a form of internal documentation to **enhance program readability and reuse**.
- In the program itself, values cannot be assigned to symbolic constants.

Use of Symbolic Constants

- Consider the following program which defines a constant called **TAXRATE**.

```
#include <stdio.h>
#define TAXRATE 0.10
main ()   {
   … Calculations using TAXRATE …
}
```

- The whole point of using **#define** in your programs is to make them easier to read and modify. Considering the above program as an example, what changes would you need to make if the **TAXRATE** was changed to 20%?
- Obviously, the answer is one, edit the **#define** statement which declares the symbolic constant and its value. You would change it to read

```
#define TAXRATE 0.20
```

- Without the use of symbolic constants, you "hard code" the value **0.20** in your program, and this might occur several times (or tens of times).

Variables, Expressions, and Operators

- Declaring Variables
- Basic Format
- Basic Data Types: Integer
- Basic Data Types: Float
- Basic Data Types: Double
- Basic Data Types: Character
- Expressions and Statements
- Assignment Operator
- Assignment Operator Evaluation
- Initializing Variables
- Initializing Variables Example
- Arithmetic Operators
- Increment/Decrement Operators
- Prefix versus Postfix
- Advanced Assignment Operators
- Precedence & Associativity of Operators
- Precedence & Associativity of Operators Examples
- The **`int`** Data Type
- The **`float`** and **`double`** Data Types
- The **`char`** Data Type
- ASCII Character Set
- Automatic Type Conversion
- Automatic Type Conversion with Assignment Operator
- Type Casting

Declaring Variables

- A variable is a **named memory location** in which data of a certain type can be stored. The ***contents of a variable can change***, thus the name. User defined variables must be declared before they can be used in a program. It is during the declaration phase that the actual memory for the variable is reserved, a process called static memory allocation. **All variables in C must be declared before use**.
- It is common to adopt the habit of declaring variables using lowercase characters. Remember that C is case sensitive, so even though the two variables listed below have the same name, they are considered different variables in C.

```
sum              Sum
```

- The declaration of variables is done after the opening brace of main().

```
main()   {
   int sum;
```

- It is possible to declare variables elsewhere in a program, but let's start simply and then get into variations later on.

Basic Format

- The basic format for declaring variables is

```
data_type var, var, …;
```

- where ***data_type*** is one of the four basic types, an integer, character, float, or double type. Examples are

```
int i,j,k;
float length,height;
char midinit;
```

Basic Data Types: INTEGER

- **INTEGER**: These are whole numbers, both positive and negative. Unsigned integers(positive values only) are also supported. In addition, there are short and long integers. These specialized integer types will be discussed later.

- The keyword used to define integers is

```
int
```

- An example of an integer value is 32. An example of declaring an integer variable called **`age`** is

```
int age;
```

Basic Data Types: FLOAT

- **FLOATING POINT**: These are positive and negative REAL numbers which contain fractional parts. They can be written in either floating point notation or scientific notation.

- The keyword used to define float variables is

```
float
```

- Typical floating point values are 1.73 and 1.932e5 (1.932 x 10^5). An example of declaring a float variable called `x` is

```
float x;
```

Basic Data Types: DOUBLE

- **DOUBLE**: These are floating point numbers, both positive and negative, which have a higher precision than float variables.

- The keyword used to define double variables is

```
double
```

- An example of declaring a double variable called `voltage` is

```
double voltage;
```

Basic Data Types: CHARACTER

- **CHARACTER**: These are variables that contain only one character.

- The keyword used to define character variables is

```
char
```

- Typical character values might be the letter A, the character 5, the symbol “, etc. An example of declaring a character variable called `letter` is

```
char letter;
```

Expressions and Statements

- An **expression** in C is some **combination of constants, variables, operators and function calls**. Sample expressions are:

```
a + b
3.0*x - 9.66553
tan(angle)
```

- Most expressions have a value based on their contents.

- A **statement** in C is just an **expression terminated with a semicolon**. For example:

```
sum = x + y + z;
printf("Go Buckeyes!");
```

The Assignment Operator

- In C, the assignment operator is the equal sign **=** and is used to give a variable the value of an expression. For example:

```
i=0;
x=34.8;
sum=a+b;
slope=tan(rise/run);
midinit='J';
j=j+3;
```

- When used in this manner, the equal sign should be read as “gets”. Note that when assigning a character value the character should be **enclosed in single quotes**.

The Assignment Operator Evaluation

- In the assignment statement

```
a=7;
```

two things actually occur. **The integer variable a gets the value of 7**, and **the expression `a=7` evaluates to 7**. This allows a shorthand for multiple assignments of the same value to several variables in a single statement. Such as

```
x=y=z=13.0;
```

as opposed to

```
x=13.0;

y=13.0;

z=13.0;
```

Initializing Variables

- C variables may be initialized with a value when they are declared. Consider the following declaration, which declares an integer variable `count` and sets its starting value to `10`.

```
int count = 10;
```

- In general, the user should not assume that variables are initialized to some default value "automatically" by the compiler. Programmers must ensure that variables have proper values before they are used in expressions.

Initializing Variables Example

- The following example illustrates two methods for variable initialization:

```
#include <stdio.h>
main () {
   int sum=33;
   float money=44.12;
   char letter;
   double pressure;
   letter='E'; /* assign character value */
   pressure=2.01e-10; /*assign double value */
   printf("value of sum is %d\n",sum);
   printf("value of money is %f\n",money);
   printf("value of letter is %c\n",letter);
   printf("value of pressure is %e\n",pressure);
}
```

which produces the following output:

```
value of sum is 33
value of money is 44.119999
value of letter is E
value of pressure is 2.010000e-10
```

Arithmetic Operators

- The primary arithmetic operators and their corresponding symbols in C are:

Negation	**-**
Multiplication	*****
Division	**/**

Modulus	**%**
Addition	**+**
Subtraction	**-**

- When the **/** operator is used to perform **integer division** the resulting integer is obtained by discarding (or truncating) the fractional part of the actual floating point value. For example:

  `1/2` → `0`

  `3/2` → `1`

- The **modulus operator** **%** only works with integer operands. The expression **a%b** is read as "a modulus b" and evaluates to the remainder obtained after dividing **a** by **b**. For example

  `7 % 2` → `1`

  `12 % 3` → `0`

Increment/Decrement Operators

- In C, specialized operators have been defined for the incrementing and decrementing of integer variables. The increment and decrement operators are **`++`** and **`--`** respectively. These operators allow a form of shorthand in C:

`++i;`	is equivalent to	`i=i+1;`
`--i;`	is equivalent to	`i=i-1;`

- The above example shows the **prefix form** of the increment/decrement operators. They can also be used in **postfix form**, as follows

`i++;`	is equivalent to	`i=i+1;`
`i--;`	is equivalent to	`i=i-1;`

Prefix versus Postfix

- The difference between prefix and postfix forms is apparent when the operators are used as part of a larger expression.
  - If `++k` is used in an expression, `k` is incremented ***before*** the expression is evaluated.
  - If `k++` is used in an expression, `k` is incremented ***after*** the expression is evaluated.
- The above distinction is also true of the decrement operator `--`
- Assume that the integer variables `m` and `n` have been initialized to zero. Then in the following statement

  `a=++m + ++n;`   `m` → `1,` `n` → `1,` then `a` → `2`

  whereas in this form of the statement

  `a=m++ + n++;`   `a` → `0` then `m` → `1,` `n` → `1`

Advanced Assignment Operators

- A further example of C shorthand are operators which combine an arithmetic operation and a assignment together in one form. For example, the following statement

  `k=k+5;` can be written as `k += 5;`

- The general syntax is

  ```
  variable = variable op expression;
  ```

  can alternatively be written as

  ```
  variable op= expression;
  ```

  common forms are:

  ```
  +=     -=     *=     /=     %=
  ```

- Examples:

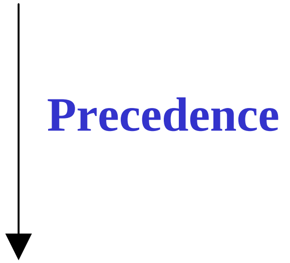
  ```
  j=j*(3+x);    j *= 3+x;
  a=a/(s-5);    a /= s-5;
  ```

Precedence & Associativity of Operators

- The precedence of operators determines the order in which operations are performed in an expression. Operators with higher precedence are used first. If two operators in an expression have the same precedence, associativity determines the direction in which the expression will be evaluated.

- C has a built-in **operator hierarchy** to determine the precedence of operators. Operators higher up in the following diagram have higher precedence. The associativity is also shown.

`- ++ --`	R	L
`* / %`	L	R
`+ -`	L	R
`=`	R	L



Precedence & Associativity of Operators: Examples

- This is how the following expression is evaluated

```
1 + 2 * 3 - 4
1 + 6 - 4
7 - 4
3
```

- The programmer can **use parentheses to override the hierarchy** and force a desired order of evaluation. **Expressions enclosed in parentheses are evaluated first**. For example:

```
(1 + 2) * (3 - 4)
3 * -1
-3
```

The `int` Data Type

- A typical `int` variable is in the range ±**`32,767`**. This value differs from computer to computer and is thus **machine-dependent**. It is possible in C to specify that an integer variable be stored using more memory bytes thereby increasing its effective range and allowing very large integers to be represented. This is accomplished by declaring the integer variable to have type `long int`.

```
long int national_debt;
```

  `long int` variables typically have a range of ±**`2,147,483,648`**.

- There are also `short int` variables which may or may not have a smaller range than normal **`int`** variables. All that C guarantees is that a `short int` will not take up more bytes than **`int`**.
- There are `unsigned` versions of all three types of integers. Negative integers cannot be assigned to `unsigned` integers, only a range of positive values. For example

```
unsigned int salary;
```

  typically has a range of **`0`** to **`65,535`**.

The `float` and `double` Data Types

- As with integers the different floating point types available in C correspond to different ranges of values that can be represented. More importantly, though, the number of bytes used to represent a real value determines the precision to which the real value is represented. The more bytes used the higher the number of decimal places of accuracy in the stored value. The actual ranges and accuracy are machine-dependent.

- The three C floating point types are:

```
float
double
long double
```

- In general, the accuracy of the stored real values increases as you move down the list.

The char Data Type

- Variables of type char take up exactly one byte in memory and are used to store printable and non-printable characters. The ASCII code is used to associate each character with an integer (see next page). For example the ASCII code associates the character ‘m’ with the integer 109. Internally, **C treats character variables as integers**.

ASCII Character Set

Ctrl	Decimal	Code
^@	0	NUL
^A	1	SOH
^B	2	STX
^C	3	ETX
^D	4	EOT
^E	5	ENQ
^F	6	ACK
^G	7	BEL
^H	8	BS
^I	9	HT
^J	10	LF
^K	11	VT
^L	12	FF
^M	13	CR
^N	14	SOH
^O	15	ST
^P	16	SLE
^Q	17	CS1
^R	18	DC2
^S	19	DC3
^T	20	DC4
^U	21	NAK
^V	22	SYN
^W	23	ETB
^X	24	CAN
^Y	25	EM
^Z	26	SIB
^[	27	ESC
^\	28	FS
^]	29	GS
^^	30	RS
^_	31	US

Decimal	Char
32	sp
33	!
34	"
35	#
36	$
37	%
38	&
39	
40	(
41	)
42	*
43	+
44	,
45	-
46	.
47	/
48	0
49	1
50	2
51	3
52	4
53	5
54	6
55	7
56	8
57	9
58	:
59	;
60	<
61	=
62	>
63	?

Decimal	Char
32	sp
33	!
34	"
35	#
36	$
37	%
38	&
39	
40	(
41	)
42	*
43	+
44	,
45	-
46	.
47	/
48	0
49	1
50	2
51	3
52	4
53	5
54	6
55	7
56	8
57	9
58	:
59	;
60	<
61	=
62	>
63	?

Decimal	Char
64	@
65	A
66	B
67	C
68	D
69	E
70	F
71	G
72	H
73	I
74	J
75	K
76	L
77	M
78	N
79	O
80	P
81	Q
82	R
83	S
84	T
85	U
86	V
87	W
88	X
89	Y
90	Z
91	[
92	\
93	]
94	^
95	_

Decimal	Char
96	`
97	a
98	b
99	c
100	d
101	e
102	f
103	g
104	h
105	I
106	j
107	k
108	l
109	m
110	n
111	o
112	p
113	q
114	r
115	s
116	t
117	u
118	v
119	w
120	x
121	y
122	z
123	{
124	|
125	}
126	~
127	DEL

Automatic Type Conversion

- How does C evaluate and type expressions that contain a **mixture of different data types**? For example, if `x` is a double and `i` an integer, what is the type of the expression

```
x+i
```

- In this case, `i` will be converted to type double and the expression will evaluate to a double. NOTE: the value of `i` stored in **memory is unchanged**. A temporary copy of `i` is converted to a double and used in the expression evaluation.
- This automatic conversion takes place in two steps. First, all floats are converted to doubles and all characters and shorts are converted to ints. In the second step “lower” types are promoted to “higher” types. The expression itself will have the type of its highest operand. The **type hierarchy** is as follows

```
long double
double
unsigned long
long
unsigned
int
```

“Higher” types

“Lower” types

Automatic Type Conversion: The Assignment Operator

- Automatic conversion even takes place if the operator is the assignment operator. This creates a method of type conversion. For example, if **`x`** is double and **`i`** an integer, then

```
x=i;
```

`i` is promoted to a double and resulting value given to **`x`**

- On the other hand say we have the following expression:

```
i=x;
```

a conversion occurs, but result is **machine-dependent**

Type Casting

- Programmers can override automatic type conversion and explicitly cast variables to be of a certain type when used in an expression. For example,

  ```
  (double) i
  ```

  will force `i` to be of type double. The general syntax is

  ```
  (type) expression
  ```

- Some examples,

  ```
  x = (float) 77;
  (double) k * 57
  ```

Input and Output

- Basic Output
- printf Function
- Format Specifiers Table
- Special Characters for Cursor Control
- Basic Output Examples
- Basic Input
- Basic Input Example

Basic Output

- Now, let us look more closely at the `printf()` function. In a previous program, we saw this example

```
print("value of sum is %d\n",sum);
```

which produced this output:

```
value of sum is 33
```

- The first argument of the `printf` function is called the **control string**. When the `printf` is executed, it starts printing the text in the control string until it encounters a `%` character. The `%` sign is a special character in C and marks the beginning of a **format specifier**. A format specifier controls how the value of a variable will be displayed on the screen. When a format specifier is found, `printf` looks up the next argument (in this case `sum`), displays its value and continues on. The `d` character that follows the `%` indicates that a (d)ecimal integer will be displayed. At the end of the control statement, `printf` reads the special character `\n` which indicates print the new line character.

printf Function

- General syntax of the `printf` function

```
printf(control string,argument list);
```

where the ***`control string`*** consists of 1) literal text to be displayed, 2) format specifiers, and 3)special characters. The arguments can be variables, constants, expressions, or function calls -- anything that produces a value which can be displayed. **Number of arguments must match the number of format identifiers**. Unpredictable results if argument type does not "match" the identifier.

Format Specifiers Table

- The following table show what format specifiers should be used with what data types:

Specifier	*Type*
`%c`	character
`%d`	decimal integer
`%o`	octal integer (leading 0)
`%x`	hexadecimal integer (leading 0x)
`%u`	unsigned decimal integer
`%ld`	long int
`%f`	floating point
`%lf`	double or long double
`%e`	exponential floating point
`%s`	character string

Special Characters for Cursor Control

- Some widely-used special characters for cursor control are:

\n	newline
\t	tab
\r	carriage return
\f	form feed
\v	vertical tab
\b	backspace
\”	Double quote (\ acts as an “escape” mark)
\nnn	octal character value

Basic Output Examples

```
printf(“ABC”);                           ABC  (cursor after the C)
printf(“%d\n”,5);                         5  (cursor at start of next line)
printf(“%c %c %  c”,’A’,’B’,’C’);         A B C
printf(“From sea ”);                      From sea to shining C
printf(“to shining “);
printf (“C”);
printf(“From sea \n”);                    From sea
printf(“to shining \n“);                  to shining
printf (“C”);                             C
leg1=200.3; leg2=357.4;
printf(“It was %f miles”                  It was 557.700012 miles
,leg1+leg2);
num1=10; num2=33;
printf(“%d\t%d\n”,num1,num2);             10     33
big=11e+23;
printf(“%e \n”,big);                      1.100000e+24
printf(“%c \n”,’?’);                      ?
printf(“%d \n”,’?’);                      63
printf(“\007 That was a beep\n”);         try it yourself
```

Basic Input

- There is a function in C which allows the program to accept input from the keyboard. The following program illustrates the use of this function.

```
#include <stdio.h>
main()   {
   int pin;
   printf("Please type in your PIN\n");
   scanf("%d",&pin);
   printf("Your access code is %d\n",pin);}
```

- What happens in this program? An integer called `pin` is defined. A prompt to enter in a number is then printed with the first **`printf`** statement. The **`scanf`** routine, which accepts the response, has a **control string** and an **address list**. In the control string, the format specifier **`%d`** shows what data type is expected. The **`&pin`** argument specifies the memory location of the variable the input will be placed in. After the **`scanf`** routine completes, the variable `pin` will be initialized with the input integer. This is confirmed with the second `printf` statement. The **& character** has a very special meaning in C. It **is the address operator**. (Much more with **&** when we get to pointers…)

Basic Input Example

```
#include <stdio.h>
main()   {
   int pin;
   printf("Please type in your PIN\n");
   scanf("%d",&pin);
   printf("Your access code is %d\n",pin);}
```

- A session using the above code would look like this

```
Please type your PIN
4589
Your access code is 4589
```

- The format identifier used for a specific C data type is the same as for the `printf` statement, with one exception. If you are inputting values for a `double` variable, use the `%lf` format identifier.
- White space is skipped over in the input stream (including carriage return) except for character input. **A blank is valid character input**.

Basic Input Example (Two Variables)

- The following code inputs two float values using one scanf statement:

```
#include <stdio.h>
main()   {
   float x,y;
   printf("Please type the coordinates\n");
   scanf("%f%f",&x,&y);
   printf(“The position is (%f,%f)\n",x,y);
}
```

- A session using the above code would look like this:

```
Please type the coordinates
5.46 13.8
The position is (5.460000,13.800000)
```

Program Looping

- Introduction to Program Looping
- Relational Operators
- Relational Operators Table
- for Loop
- for Loop Example
- for Loop Diagram
- General Comments about for Loop
- while Loop
- while Loop Example
- do while Loop
- do while Loop Example
- Input error Checking

Introduction to Program Looping

- Program looping is often desirable in coding in *any* language. Looping gives the programmer the ability to repeat a block of statements a number of times. In C, there are commands that allow iteration of this type. Specifically, there are two classes of program loops -- unconditional and conditional. An **unconditional loop** is repeated a set number of times. In a **conditional loop** the iterations are halted when a certain condition is true. Thus the actual number of iterations performed can vary each time the loop is executed.

Relational Operators

- Our first use of relational operators will be to set up the condition required to control a conditional loop. Relational operators allow the **comparison of two expressions**. Such as

  ```
  a < 4
  ```

  which reads **a** “less than” **4**. If **a** is less than **4**, this expression will evaluate to TRUE. If not it will evaluate to FALSE.

- Exactly what does it mean to say an expression is TRUE or FALSE? C uses the following definition

  - **FALSE means evaluates to ZERO**
  - **TRUE means evaluates to <u>any</u> NON-ZERO integer (even negative integers)**

Relational Operators Table

- The following table shows the various C relational operators

Operator	*Meaning*	*Example*
`==`	Equal to	`count == 10`
`!=`	Not equal to	`flag != DONE`
`<`	Less than	`a < b`
`<=`	Less than or equal to	`i <= LIMIT`
`>`	Greater than	`pointer > end_of_list`
`>=`	Greater than or equal to	`lap >= start`

- The relational operators have a precedence **below** the arithmetic operators.

for Loop

- The for loop is C’s implementation of an unconditional loop. The basic syntax of the for statement is,

```
for (initialization expression; test expr; increment expr)
              program statement;
```

- Here is an example

```
sum=10;
for (i=0; i<6; ++i)
        sum = sum+i;
```

- The operation of the loop is as follows

1) The initialization expression is evaluated.

2) The test expression is evaluated. If it is TRUE, the body of the loop is executed. If it is FALSE, exit the for loop.

3) Assume test expression is TRUE. Execute the program statements making up the body of the loop.

4) Evaluate the increment expression and return to step 2.

5) When test expression is FALSE, exit loop and move on to next line of code.

for Loop Example

- Sample Loop (same as on previous page):

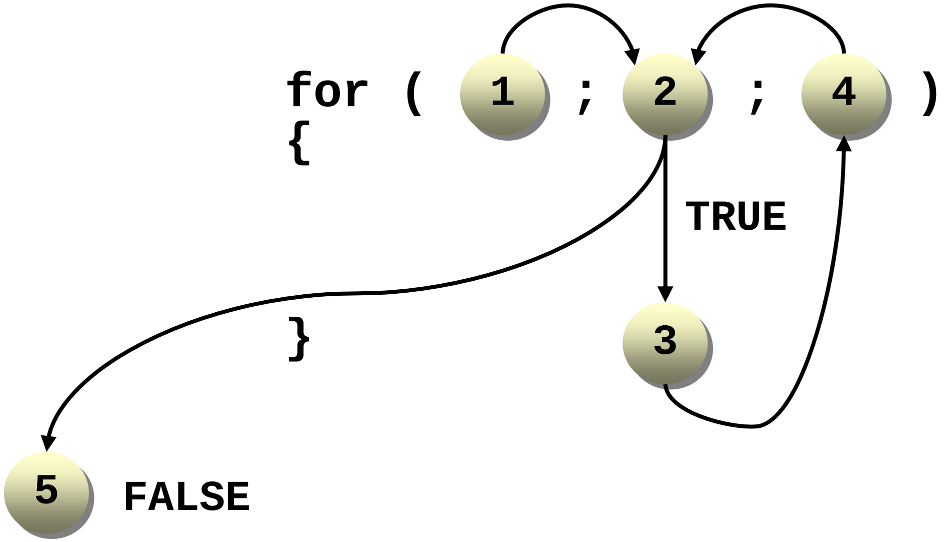
```
sum = 10;
for (i=0; i<6; ++i)
   sum=sum+i;
```

- We can trace the execution of the sample loop in this table

Iteration	*i*	*i<6*	*sum*
1st	0	TRUE	10
2nd	1	TRUE	11
3rd	2	TRUE	13
4th	3	TRUE	16
5th	4	TRUE	20
6th	5	TRUE	25
7th	6	FALSE	25

for Loop Diagram

- The following diagram illustrates the operation of a for loop



for Loop: General Comments

- Some common observations regarding the use of the for statement:
  - **Control expressions are separated by ; (semicolon) not , (comma)**
  - **If there are multiple C statements that make up the loop body, enclose them in brackets (USE INDENTATION FOR READABILITY)**

```
 for (x=100; x!=65; x-=5)   {
    z=sqrt(x);
    printf("The square root of %d is %f\n",x,z);
}
```

A block of code containing more than one statement is referred to as a compound statement

  - **Control expressions can be any valid expression. They don't necessarily have to perform initialization, testing, and incrementation.**
  - **Any of the control expressions can be omitted (but always need the two semicolons for syntax sake).**

```
 product=1;
for (i=1;i<=6;)
 product*=i++;
```

for Loop: General Comments

- Since testing is performed at the beginning of the loop, the body may never get executed

```
x=10;
for (y=10;y!=x;++y)
  printf ("%d",y);
```

- Can string together multiple expressions in the for statement by separating them by commas

```
for (x=1,y=5;x+y<100;++x)
  z=x%y;
```

`while` Loop

- The **`while`** loop provides a mechanism for repeating C statements while a condition is true. Its format is

```
while(control expression){
   program statement 1;
   program statement 2;
              …
}
```

- The **`while`** statement works as follows:

1) Control expression is evaluated (“entry condition”)
2) If it is FALSE, skip over the loop.
3) If it is TRUE, loop body is executed.
4) Go back to step 1

`while` Loop Example

- Using a while loop:

```
i=1; factorial=1;
while (i<=13) {
   factorial *= i;
   i=i+1;
}
```

- **Programmer is responsible for initialization and incrementation**. At some point in the body of the loop, the control expression must be altered in order to allow the loop to finish. Otherwise: **infinite loop**.

- Will this loop end?

```
j=15;
while (j--)
   …;
```

`do while` Loop

- The **`do while`** statement is a variant of the while statement in which the conditional test is performed at the "bottom" of the loop. This guarantees that the loop is executed at least once.

- The syntax of the **`do while`** statement is

```
do
   program statement;
while (control expression);
```

NOTE: Unlike previous loops, `do while` has a semicolon at the end of the control expression

- The operation of the **`do while`** loop is as follows

  1) The body of the loop is executed.

  2) The control expression is evaluated ("exit condition").

  3) If it is TRUE, go back to step 1. If it is FALSE, exit loop.

do while Loop Example

- Here is a sample program that reverses an integer with a **do while** loop:

```
main() {
   int value, r_digit;
   printf("Enter the number to be reversed\n");
   scanf("%d", &value);
   do {
      r_digit = value % 10;
      printf("%d", r_digit);
      value = value / 10;
   } while (value != 0);
   printf("\n");
}
```

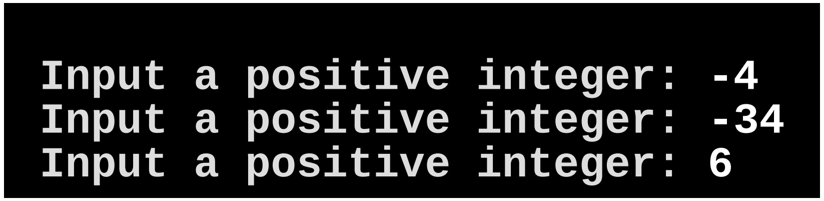
```
Enter the number to be reversed
362855
558263
```

`do while` Loop Example: Error Checking

- A common use of the **`do while`** statement is input error checking. A simple example is shown here

```
do {
   printf("Input a positive integer: ");
   scanf("%d",&n);
} while (n<=0);
```

- The user will remain in this loop continually being prompted for and entering integers until a positive one is entered. A sample session using this loop looks like this



```
Input a positive integer: -4
Input a positive integer: -34
Input a positive integer: 6
```

Decision Making Statements

- Introduction to Decision Making Statements
- `if` Statement
- `if` Statement Examples
- `if-else` Statement
- `if-else` Ladder
- `switch` Statement
- `switch` Statement Example
- `switch` Statement Operation
- `switch` Statement Example: Characters
- `switch` Statement Example: Menus
- Conditional Operator
- Conditional Operator Examples
- Logical Operators
- Logical Operators Precedence

Introduction to Decision Making Statements

- These commands are used to have a program execute different statements depending on certain conditions. In a sense, they make a program “smarter” by allowing different choices to be made by the program. In C, there are three decision making commands.

`if`	execute a statement or not
`if-else`	choose to execute one of two statements
`switch`	choose to execute one of a number of statements

`if` Statement

- The **`if`** statement allows branching (decision making) depending upon a condition. **Program code is executed or skipped**. The basic syntax is

```
if (control expression)
   program statement;
```

- If the control expression is TRUE, the body of the **`if`** is executed. If it is FALSE, the body of the **`if`** is skipped.

- There is **no “then”** keyword in C!

- Because of the way in which floating point types are stored, it makes it less reliable to compare such types for equality. **Avoid trying to compare real variables for equality**, especially if the values are nearly identical.

if Statement Examples

- Theses code fragments illustrate some uses of the **if** statement
  - **Avoid division by zero**

```
if (x != 0)
   y = y/x;
```

  - **Customize output**

```
if (grade >= 90)
   printf("\nCongratulations!");
printf("\nYour grade is "%d",grade);
```

  - **Nested ifs**

```
if (letter >= 'A')
   if (letter <= 'Z')
      printf("The letter is a capital \n");
```

`if-else` Statement

- **Used to decide between two courses of action**. The syntax of the **`if-else`** statement is

```
if (expression)
   statement1;
else
   statement2;
```

- If the expression is TRUE, ***`statement1`*** is executed; ***`statement2`*** is skipped.
- If the expression is FALSE, ***`statement2`*** is executed; ***`statement1`*** is skipped.
- Some examples

```
if (x < y)
  min=x;
else
   min=y;
```

```
if (letter == 'e') {
   ++e_count;
   printf(“Found an e\n”);
}
else
   ++other_count;
```

if-else Ladder

- What if we wanted to extend the task shown in the previous example and not just counts how many e’s there are in a piece of text, but also make counts of the other vowels? This is possible by nesting **if-else** statements together to make what is called an **if-else ladder**. For example, consider the following code

```
if (letter == 'a')
   ++a_count;
else if (letter == 'e')
   ++e_count;
else if (letter == 'i')
   ++i_count;
else if (letter == 'o')
   ++o_count;
else if (letter == 'u')
   ++u_count;
else
   ++const_count;
```

- As soon as a TRUE control expression is found, the statement associated with it is executed and the rest of the ladder is bypassed. If no control expressions are found to be TRUE, the final **else** statement acts as a default.

switch Statement

- The **switch** statement is a alternate way of writing a program which employs an **if-else** ladder. It is C’s built-in **multiple branch decision statement**. The syntax for the **switch** statement is as follows:

```
switch (integer expression) {
   case constant1:
      statement1;
      break;
   case constant2:
      statement2;
      break;
   ...
   default:
      statement;
}
```

- The keyword **break** should be included at the end of each case statement. In general, whenever a **break** statement is encountered in C, it interrupts the normal flow of control. In the **switch** statement, it causes an exit from the switch. The **default** clause is optional. The right brace at the end marks the end of **switch** statement.

`switch` Statement Example

- Here is a simple example of a **`switch`** statement:

```
switch(n) {
   case 12:
      printf("value is 12\n");
      break;
   case 25:
      printf("value is 25\n");
      break;
   case 03:
      printf("value is 03\n");
      break;
   default:
      printf("number is not part of the Xmas date\n");
}
```

`switch` Statement Operation

- The **`switch`** statement works as follows

1) **Integer control expression is evaluated.**
2) **A match is looked for between this expression value and the `case` *`constants`*. If a match is found, execute the statements for that `case`. If a match is not found, execute the `default` statement (if present).**
3) **Terminate `switch` when a `break` statement is encountered or by "falling out the end".**

- Some things to be aware of when using a switch statement:

  - **`case` constants must be unique (How to decide otherwise?)**
  - **`case` constants must be simple constants (symbolic OK)**
  - **`switch` statement only tests for equality**
  - **The *`control expression`* can be of type character since characters are internally treated as integers**

switch Statement Example: Characters

```
switch(ch) {
   case 'a':
      ++a_count;
      break;
   case 'b':
      ++b_count;
      break;
   case 'c':
   case 'C':   /* multiple values, same statements */
      ++c_count;
 }
```

switch Statement Example: Menus

- A common application of the **switch** statement is to control menu-driven software:

```
switch(choice) {
   case 'S':
      check_spelling(); /* User-written function */
      break;
   case 'C':
      correct_errors(); /* ditto */
      break;
   case 'D':
      display_errors(); /* ditto */
      break;
   default:
      printf("Not a valid option\n");
}
```

Conditional Operator

- This *operator* is a shorthand notation for an `if-else` **statement that performs assignments**. The conditional expression operator takes THREE operands. The two symbols used to denote this operator are the `?` and the `:`. The first operand is placed before the `?`, the second operand between the `?` and the `:`, and the third after the `:`. The general syntax is thus

```
condition ? expression1 : expression2
```

- If the result of ***`condition`*** is TRUE (non-zero), ***`expression1`*** is evaluated and the result of the evaluation becomes the value of the entire expression. If the condition is FALSE (zero), then ***`expression2`*** is evaluated and its result is the return value for the entire expression.

- Consider the examples on the next page …

Conditional Operator Examples

```
s = (x<0) ? -1 : x*x;
```

- If `x` is less than zero, then `s=-1`. If `x` is greater than or equal to zero, then `s=x*x`.

- The following code sets the logical status of the variable `even`

```
if (number%2==0)
   even=1;
else
   even=0;
```

- Identical, shorthand code to perform the same task is

```
even=(number%2==0) ? 1 : 0;
```

Logical Operators

- Logical *operators* are used to create more sophisticated conditional expressions which can then be used in any of the C looping or decision making statements that have been discussed. When expressions are combined with a logical operator, either TRUE (i.e., 1) or FALSE (i.e., 0) is returned.

Operator	Symbol	Usage	Operation
LOGICAL AND	**`&&`**	**`exp1 && exp2`**	Requires both **`exp1`** and **`exp2`** to be TRUE to return TRUE. Otherwise, the logical expression is FALSE.
LOGICAL OR	**`||`**	**`exp1 || exp2`**	Will be TRUE if either (or both) **`exp1`** or **`exp2`** is TRUE. Otherwise, it is FALSE.
LOGICAL NOT	**`!`**	**`!exp`**	Negates (changes from TRUE to FALSE and visa versa) the expression.

In C, “short-circuting” is often performed. If the value of **`exp1`** determines the value of the entire logical expression, **`exp2`** is not evaluated. DANGEROUS to assume “short-circuting”.

Logical Operators Precedence

- The negation operator, **!**, has the highest precedence and is always performed first in a mixed expression. The remaining logical operators have a precedence below relational operators.

- Some typical examples using logical operators:

```
if (year<1900 && year>1799)
   printf("Year in question is in the 19th century\n");

if (ch=='a' || ch=='e' || ch='i' || ch='o' || ch='u')
   ++vowel_count;

done=0;
while(!done) {
   …
}
```

Array Variables

- Introduction to Array Variables
- Array Variables Example
- Array Elements
- Declaring Arrays
- Initializing Arrays during Declaration
- Using Arrays
- Multi-dimensional Arrays
- Multi-dimensional Array Illustration
- Initializing Multi-dimensional Arrays
- Using Multi-dimensional Arrays

Introduction to Array Variables

- Arrays are a data structure which **hold multiple values of the same data type**. Arrays are an example of a **structured variable** in which 1) there are a number of pieces of data contained in the variable name, and 2) there is an ordered method for extracting individual data items from the whole.

- Consider the case where a programmer needs to keep track of the ID numbers of people within an organization. Her first approach might be to create a specific variable for each user. This might look like

```
int id1 = 101;    int id2 = 232;      int id3 = 231;
```

- It becomes increasingly more difficult to keep track of the IDs as the number of personnel increases. Arrays offer a solution to this problem.

Array Variables Example

- An array is a multi-element box, a bit like a filing cabinet, and uses an indexing system to find each variable stored within it. **In C, indexing starts at zero**. Arrays, like other variables in C, must be declared before they can be used.

- The replacement of the previous example using an array looks like this:

```
int id[3];    /* declaration of array id */
id[0] = 101;
id[1] = 232;
id[2] = 231;
```

- In the first line, we declared an array called **`id`**, which has space for three integer variables. Each piece of data in an array is called an **element**. Thus, array **`id`** has three elements. After the first line, each element of **`id`** is initialized with an ID number.

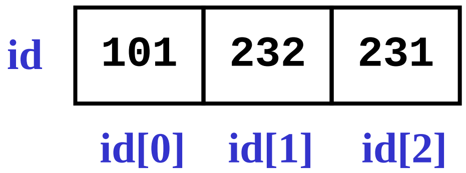
Array Elements

- The syntax for an element of an array called `a` is

  `a[i]`

  where `i` is called the index of the array element. **The array element `id[1]` is just like any normal integer variable and can be treated as such**.

- In memory, one can picture the array id like this:



id	101	232	231
	id[0]	id[1]	id[2]

Declaring Arrays

- Arrays may consist of any of the valid data types. Arrays are declared along with all other variables in the declaration section of the program and the following syntax is used

```
type   array_name[n];
```

- where *n* is the **number of elements** in the array. Some examples are

```
int    final[160];
float  distance[66];
```

- During declaration **consecutive memory locations** are reserved for the array and all its elements. After the declaration, you cannot assume that the elements have been initialized to zero. Random junk is at each element’s memory location.

Initializing Arrays during Declaration

- If the declaration of an array is preceded by the word static, then the array can be initialized at declaration. The initial values are enclosed in braces. e.g.,

```
static int   value[9] = {1,2,3,4,5,6,7,8,9};
static float height[5]={6.0,7.3,2.2,3.6,19.8};
```

- Some rules to remember when initializing at declaration

1 **If the list of initial elements is shorter than the number of array elements, the remaining elements are initialized to zero.**

2 **If a static array is not explicitly initialized at declaration, its elements are automatically initialized to zero.**

3 **If a static array is declared without a size specification, its size equals the length of the initialization list. In the following declaration, a has size 5.**

```
static int   a[]={-6,12,18,2,323};
```

Using Arrays

- Recall that indexing is the method of accessing individual array elements. Thus `grade[89]` refers to the `90`th element of the `grade`s array. A common programming error is **out-of-bounds array indexing**. Consider the following code:

```
static float  grade[3];
grade[0] = grade[2] + grade[5];
```

  The result of this mistake is unpredictable and machine and compiler dependent. You have no way of knowing what value will be returned from the memory location `grade[5].` Often run-time errors result, or code crash.

- **Array variables and for loops often work hand-in-hand** since the for loop offers a convenient way to successively access array elements and perform some operation with them. Basically, the for loop counter can do double-duty and act as an index for the array, as in the following summation example:

```
int total=0,i;
int num[4]={93,94,67,78};
for (i=0; i<4; ++i)
   total += num[i];
```

Multi-Dimensional Arrays

- Multi-dimensional arrays have two or more index values which are used to specify a particular element in the array. For this 2D array element,

```
image[i][j]
```

  the first index value `i` specifies a row index, while `j` specifies a column index.

- Declaring multi-dimensional arrays is similar to the 1D case:

```
int a[10];          /* declare 1D array */
float b[3][5];      /* declare 2D array */
double c[6][4][2];  /* declare 3D array */
```

- Note that it is quite easy to allocate a large chunk of **consecutive memory** with multi-dimensional arrays. Array `c` contains `6x4x2=48 double`s.

Multi-Dimensional Array Illustration

- A useful way to picture a 2D array is as a grid or matrix. Picture array **b** as

	0th column	1st column	2nd column	3rd column	4th column
0th row	`b[0][0]`	`b[0][1]`	`b[0][2]`	`b[0][3]`	`b[0][4]`
1st row	`b[1][0]`	`b[1][1]`	`b[1][2]`	`b[1][3]`	`b[1][4]`
2nd row	`b[2][0]`	`b[2][1]`	`b[2][2]`	`b[2][3]`	`b[2][4]`

- In C, **2D arrays are stored in memory by row**. Which means that first the 0th row is put into its memory locations, the 1st row then takes up the next memory locations, the 2nd row takes up the next memory locations, and so on.

Initializing Multi-Dimensional Arrays

- This procedure is entirely analogous to that used to initialize 1D arrays at their declaration. For example, this declaration

  ```
  static int age[2][3]={4,8,12,19,6,-1};
  ```

  will fill up the array age as it is stored in memory. That is, the array is initialized row by row. Thus, the above statement is equivalent to:

  ```
  age[0][0]=4;  age[0][1]=8;  age[0][2]=12;
  age[1][0]=19; age[1][1]=6;  age[1][2]=-1;
  ```

- As before, if there are fewer initialization values than array elements, the remainder are initialized to zero.
- To make your program more readable, you can explicitly put the values to be assigned to the same row in inner curly brackets:

  ```
  static int age[2][3]={{4,8,12},{19,6,-1}};
  ```

- In addition, if the number of rows is omitted from the actual declaration, it is set equal to the number of inner brace pairs:

  ```
  static int age[][3]= ]={{4,8,12},{19,6,-1}};
  ```

Using Multi-Dimensional Arrays

- Again, as with 1D arrays, `for` loops and multi-dimensional arrays often work hand-in-hand. In this case, though, **loop nests** are what is most often used. Some examples

Summation of array elements

```
double temp[256][3000],sum=0;
int i,j;
for (i=0; i<256; ++i)
   for (j=0; j<3000; ++j)
      sum += temp[i][j];
```

Trace of Matrix

```
int voxel[512][512][512];
int i,j,k,trace=0;
for (i=0; i<512; ++i)
   for (j=0; j<512; ++j)
      for (k=0; k<512; ++k)
         if (i==j && j==k)
            trace += voxel[i][j][k];
```

Strings

- Arrays of Characters
- Initializing Strings
- Copying Strings
- String I/O Functions
- String Library Functions
- Using String Functions
- Character I/O Functions
- Character Library Functions
- Character Functions Example

Arrays of Characters

- Strings are **1D arrays of characters**. Strings must be terminated by the null character `'\0'` which is (naturally) called the **end-of-string character**. Don't forget to remember to count the end-of-string character when you calculate the size of a string.
- As with all C variables, strings must be declared before they are used. Unlike 1D arrays of other data types, the **number of elements set** for a string at declaration is only an **upper limit**. The actual strings used in the program can have fewer elements. Consider the following code:

  ```
  static char name[18] = "Ivanova";
  ```

  The string called `name` actually has only `8` elements. They are

  ```
  'I' 'v' 'a' 'n' 'o' 'v' 'a' '\0'
  ```

- Notice another interesting feature of this code. String constants **marked with double quotes** automatically include the end-of-string character. The **curly braces are not required** for string initialization at declaration, but can be used if desired (**but don't forget the end-of-string character**).

Initializing Strings

- Initializing a string can be done in three ways: 1) at declaration, 2) by reading in a value for the string, and 3) by using the **`strcpy`** function. **Direct initialization using the assignment operator is invalid**. The following code would produce an error:

```
char name[34];
name = "Erickson";     /* ILLEGAL */
```

- To read in a value for a string use the **`%s`** format identifier:

```
scanf("%s",name);
```

- Note that the address operator **`&`** is not needed for inputting a string variable (explained later). The end-of-string character will automatically be appended during the input process.

Copying Strings

- The **`strcpy` function** is one of a set of built-in string handling functions available for the C programmer to use. To use these functions be sure to include the **`string.h`** header file at the beginning of your program. The syntax of **`strcpy`** is

  `strcpy(`*`string1`*`,`*`string2`*`);`

- When this function executes, ***`string2`*** is copied into ***`string1`*** at the beginning of ***`string1`***. The previous contents of ***`string1`*** are overwritten.

- In the following code, **`strcpy`** is used for string initialization:

```
#include <string.h>
#include <stdio.h>
main ()   {
   char job[50];
   strcpy(job,"Professor");
   printf("You are a %s \n",job);
}
```

```
You are a Professor
```

String I/O Functions

- A limitation of using `scanf` to read in strings is that **the input string cannot contain spaces** (or blanks).

- These are special functions designed specifically for string I/O. They do not have the above restriction: **input strings may have spaces**.

  ```
  gets(string_name);
  puts(string_name);
  ```

- The `gets` function reads in a string from the keyboard. When the user hits a carriage return the string is inputted. The carriage return is not part of the string and the end-of-string character is automatically appended.

- The function `puts` displays a string on the monitor. It does not print the end-of-string character, but does output a carriage return at the end of the string.

String I/O Sample Program

- Here is a program fragment illustrating the use of **`gets`** and **`puts`**

```
    char phrase[100];
    printf("Please enter a sentence\n");
    gets(phrase);
    puts(phrase);
```

- A session using this code would produce this on the screen

```
Please enter a sentence
The best lack all conviction, while the worst are passionate.
The best lack all conviction, while the worst are passionate.
```

More String Functions

- Declared in the `string.h` file are several more string-related functions that are free for you to use. Here is a brief table of some of the more popular ones

Function	Operation
`strcat`	Appends to a string
`strchr`	Finds first occurrence of a given character
`strcmp`	Compares two strings
`strcmpi`	Compares two, strings, non-case sensitive
`strcpy`	Copies one string to another
`strlen`	Finds length of a string
`strncat`	Appends ***n*** characters of string
`strncmp`	Compares ***n*** characters of two strings
`strncpy`	Copies ***n*** characters of one string to another
`strnset`	Sets ***n*** characters of string to a given character
`strrchr`	Finds last occurrence of given character in string
`strspn`	Finds first substring from given character set in string

More String Functions Continued

- Most of the functions on the previous page are self-explanatory. **The UNIX man pages provide a full description of their operation**. Take for example, **`strcmp`** which has this syntax

```
strcmp(string1,string2);
```

- It returns an integer that is less than zero, equal to zero, or greater than zero depending on whether ***`string1`*** is less than, equal to, or greater than ***`string2`***.

- String comparison is done character-pair by character-pair using the ASCII numerical code

Examples of String Functions

- Here are some examples of string functions in action:

```
static char s1[]="big sky country";
static char s2[]="blue moon";
static char s3[]="then falls Caesar";
```

Function	***Result***
`strlen(s1)`	`15 /* e-o-s not counted */`
`strlen(s2)`	`9`
`strcmp(s1,s2)`	*negative number*
`strcmp(s3,s2)`	*positive number*
`strcat(s2,” tonight”)`	`blue moon tonight`

Character I/O Functions

- Analogous to the **`gets`** and **`puts`** functions there are the **`getchar`** and **`putchar`** functions specially designed for character I/O. The following program illustrates their use:

```
#include <stdio.h>
main() {
   int n; char lett;
   putchar('?');
   n=45;
   putchar(n-2);
   lett=getchar();
   putchar(lett);
   putchar('\n');
}
```

- A sample session using this code would look like:

```
?+f↵
f
```

More Character Functions

- As with strings, there is a library of functions designed to work with character variables. The file **`ctype.h`** declares additional routines for manipulating characters. Here is a partial list

Function	***Operation***
`isalnum`	**Tests for alphanumeric character**
`isalpha`	**Tests for alphabetic character**
`isascii`	**Tests for ASCII character**
`iscntrl`	**Tests for control character**
`isdigit`	**Tests for 0 to 9**
`isgraph`	**Tests for printable character**
`islower`	**Tests for lowercase character**
`isprint`	**Tests for printable character**
`ispunct`	**Tests for punctuation character**
`isspace`	**Tests for space character**
`isupper`	**Tests for uppercase character**
`isxdigit`	**Tests for hexadecimal**
`toascii`	**Converts character to ASCII code**
`tolower`	**Converts character to lowercase**
`toupper`	**Converts character to upper**

Character Functions Example

- In the following program, character functions are used to convert a string to all uppercase characters:

```
#include <stdio.h>
#include <ctype.h>
main() {
   char name[80];
   int loop;
   printf ("Please type in your name\n");
   gets(name);
   for (loop=0; name[loop] !=0; loop++)
      name[loop] = toupper(name[loop]);
   printf ("You are %s\n",name);
}
```

- A sample session using this program looks like this:

```
Please type in your name
Dexter Xavier
You are DEXTER XAVIER
```

Math Library Functions

- “Calculator-class” Functions
- Using Math Library Functions

“Calculator-class” Library Functions

- You may have started to guess that there should be a header file called **`math.h`** which contains declarations of useful “calculator-class” mathematical functions. Well there is! Some functions found in **`math.h`** are

  ```
  acos asin atan
  cos sin tan
  cosh sinh tanh
  exp log log10
  pow sqrt
  ceil floor
  erf
  gamma
  j0 j1 jn
  y0 y1 yn
  ```

Using Math Library Functions

- The following code fragment uses the Pythagorean theorem $\boldsymbol{c^2 = a^2 + b^2}$ to calculate the length of the hypotenuse given the other two sides of a right triangle:

```
double c, a, b
c=sqrt(pow(a,2)+pow(b,2));
```

- In some cases, to use the math functions declared in the **`math.h`** include file, the user must explicitly load the math library during compilation. On most systems the compilation would look like this:

```
cc myprog.c -lm
```

User-defined Functions

- Introduction to User-defined Functions
- Reasons for Modular Programming
- Three Steps Required
- Function Definition
- User-defined Function Example 1
- User-defined Function Example 2
- return Statement
- return Statement Example
- Using Functions
- Considerations when Using Functions
- Pass-by-Value
- Introduction to Function Prototypes
- Function Prototypes
- Recursion
- Storage Classes
- auto Storage Class
- extern Storage Class
- extern Storage Class Example
- static and register Storage Class

Introduction to User-defined Functions

- A function in C is a **small "sub-program"** that performs a particular task, and thus supports the concept of **modular programming design** techniques. In modular programming the various tasks that your entire program must accomplish are assigned to individual functions and the main program basically calls these functions in a certain order.

- We have already been exposed to functions. The main body of a C program, identified by the keyword **`main`**, and enclosed by left and right braces is a function. It is called by the operating system when the program is run, and when terminated, returns to the operating system. We have also seen examples of **library functions** which can be used for I/O, mathematical tasks, and character/string handling.

- But can the programmer define and use their own functions? **Absolutely YES!**

Reasons for Modular Programming

- There are many good reasons to program in a modular style:
  - **Don't have to repeat the same block of code many times in your code. Make that code block a function and reference it when needed.**
  - **Function portability: useful functions can be used in a number of programs.**
  - **Supports the top-down technique for devising a program algorithm. Make an outline and hierarchy of the steps needed to solve your problem and create a function for each step.**
  - **Easy to debug. Get one function working correctly then move on to the others.**
  - **Easy to modify and expand. Just add more functions to extend program capability**
  - **For a large programming project, a specific programmer will code only a small fraction of the program.**
  - **Makes program self-documenting and readable.**

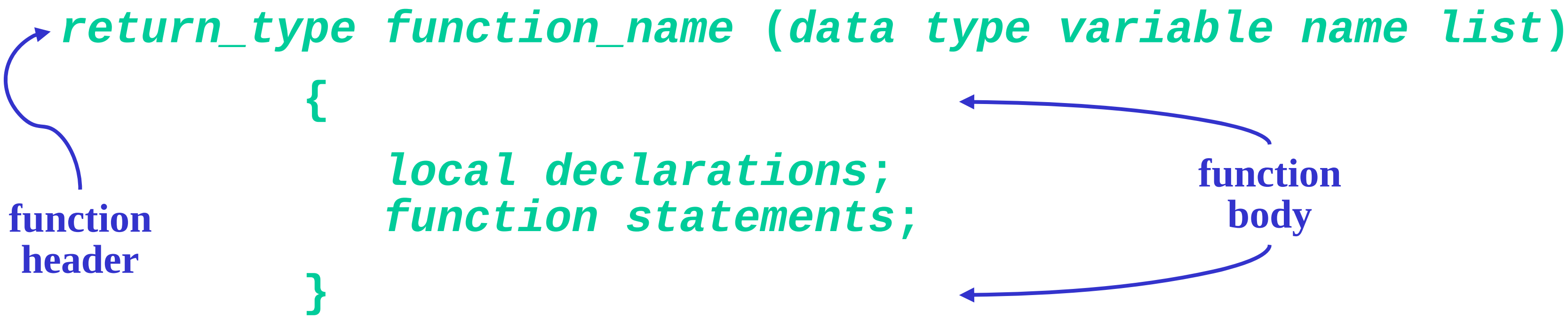
Three Steps Required

- In order to use their own functions, the programmer must do three things (not necessarily in this order):
  - **Define** the function
  - **Declare** the function
  - **Use** the function in the main code.

- In the following pages, we examine each of these steps in detail.

Function Definition

- The function definition is the C code that implements what the function does. Function definitions have the following syntax



```
return_type function_name (data type variable name list)
         {
            local declarations;
            function statements;
         }
```

function header

function body

where the ***`return_type`*** in the function header tells the type of the value returned by the function (default is **`int`**)

where the ***`data type variable name list`*** tells what arguments the function needs when it is called (and what their types are)

where ***`local declarations`*** in the function body are local constants and variables the function needs for its calculations.

Function Definition Example 1

- Here is an example of a function that calculates n!

```
int factorial (int n) {
      int i,product=1;
      for (i=2; i<=n; ++i)
         product *= i;
      return product;
}
```

Function Definition Example 2

- Some functions will not actually return a value or need any arguments. For these functions the keyword **`void`** is used. Here is an example:

```
void write_header(void) {
     printf("Navier-Stokes Equations Solver ");
     printf("v3.45\n");
     printf("Last Modified: ");
     printf("12/04/95 - viscous coefficient added\n");
}
```

- The **1st `void`** keyword indicates that **no value will be returned**.

- The **2nd `void`** keyword indicates that **no arguments** are needed for the function.

- This makes sense because all this function does is print out a header statement.

return Statement

- A function returns a value to the calling program with the use of the **keyword `return`**, followed by a data variable or constant value. The return statement can even contain an expression. Some examples

```
return 3;
return n;
return ++a;
return (a*b);
```

- When a **`return`** is encountered the following events occur:

  1) execution of the function is terminated and control is passed back to the calling program, and
  2) the function reference evaluates to the value of the ***`return expression`***.

- If there is no **`return`** statement control is passed back when the closing brace of the function is encountered ("falling off the end").

return Statement Examples

- The data type of the ***return expression*** **must match** that of the declared ***return_type*** for the function.

```
float add_numbers (float n1, float n2) {
   return n1 + n2; /*legal*/
   return 6;       /*illegal, not the same data type*/
   return 6.0;     /*legal but stupid */
 }
```

- It is possible for a function to have **multiple `return` statements**. For example:

```
double absolute(double x) {
   if (x>=0.0)
      return x;
   else
      return -x;
}
```

Using Functions

- This is the easiest part! To invoke a function, **just type its name** in your program and be sure to supply actual arguments (if necessary). A statement using our factorial function would look like

```
number=factorial(9);
```

- To invoke our write_header function, use this statement

```
write_header();
```

- When your program encounters a function reference, control passes to the function. When the function is completed, control passes back to the main program. In addition, if a value was returned, the function reference evaluates to that return value. In the above example, upon return from the `factorial` function the statement

```
factorial(9) → 362880
```

and that integer is assigned to the variable `number`.

Considerations when using Functions

- Some points to keep in mind when referencing functions (your own or a library's):

  - **The number of actual arguments in the function reference must match the number of dummy arguments in the function definition.**

  - **The type of the actual arguments in the function reference must match the type of the dummy arguments in the function definition. (Unless automatic type conversion occurs).**

  - **The actual arguments in the function reference are matched up in-order with the dummy arguments in the function definition.**

  - **The actual arguments are passed by-value to the function. The dummy arguments in the function are initialized with the present values of the actual arguments.**

  - ***Any changes made to a dummy argument inside the function will NOT affect the corresponding actual argument in the main program.***

Pass-by-Value

- The independence of actual and dummy arguments is demonstrated in the following program.

```
#include <stdio.h>
int compute_sum(int n) {
   int sum=0;
   for(;n>0;--n)
      sum+=n;
   printf("Local n in function is %d\n",n);
   return sum; }
main() {
   int lim=8,sum;
   printf ("Main lim (before call) is %d\n",lim);
   sum=compute_sum(lim);
   printf ("Main lim (after call) is %d\n",lim);
   printf ("\nThe sum of integers from 1 to %d is %d\n",lim,sum);
}
```

```
Main lim (before call) is 8
Local n in function is 0
Main lim (after call) is 8

The sum of integers from 1 to 8 is 36
```

Introduction to Function Prototypes

- Function prototypes are **used to declare a function** so that it can be used in a program before the function is actually defined. Consider the program on the previous page. In some sense, it reads “backwards”. All the secondary functions are defined first, and then we see the main program that shows the major steps in the program. This example program can be rewritten using a function prototype as follows:

```
#include <stdio.h>
int compute_sum(int n); /* Function Prototype */
main() {
   int lim=8,sum;
   printf ("Main lim (before call) is %d\n",lim);
   sum=compute_sum(lim);
   printf ("Main lim (after call) is %d\n",lim);
   printf ("\nThe sum of integers from 1 to %d is %d\n",lim,sum);
}
int compute_sum(int n) {
   int sum=0;
   for(;n>0;--n)
      sum+=n;
   printf("Local n in function is %d\n",n);
   return sum;
}
```

Function Prototypes

- With the function prototype, the program reads in a "natural" order. You know that a function called **`compute_sum`** will be defined later on, and you see its immediate use in the main program. Perhaps you don’t care about the details of how the sum is computed and you won’t need to read the actual function definition.

- As this example shows, a function prototype is simply the **function header** from the function definition **with a semi-colon attached to the end**. The prototype tells the compiler the number and type of the arguments to the function and the type of the return value. Function prototypes should be placed **before the start of the main program**. The function definitions can then follow the main program (or, actually be in separate files). In fact, if you look at one of the include files -- say **`string.h`** -- you will see the prototypes for all the string functions available!

- In addition to making code more readable, the use of function prototypes offers **improved type checking** between actual and dummy arguments. In some cases, the type of actual arguments will automatically be coerced to match the type of the dummy arguments. Prototypes also allow the compiler to check that the return value is used correctly.

Recursion

- Recursion is the process in which a function repeatedly calls itself to perform calculations. Typical applications are in mathematics, sorting trees and lists. Recursive algorithms are not mandatory; an iterative approach can always be found which runs significantly faster.

- The following function elegantly calculates factorials recursively:

```
int factorial(int n) {
   int result;

   if (n<=1)
      result=1;
   else
      result = n * factorial(n-1);

   return result;
}
```

Storage Classes

- Every variable in C actually has two attributes: its data type and its storage class. The storage class refers to the **manner in which memory is allocated** for the variable. The storage class also determines the **scope of the variable**, that is, what parts of a program the variable's name has meaning. In C, the four possible Storage classes are
  - auto
  - extern
  - static
  - register

auto Storage Class

- This is the **default classification** for all variables declared within a function body [including **`main()`**] .
- Automatic variables are truly **local**.
- They exist and their names have meaning only while the function is being executed.
- They are unknown to other functions.
- When the function is exited, the values of automatic variables are not retained.
- They are normally implemented on a stack.
- They are recreated each time the function is called.

extern Storage Class

- In contrast, extern variables are **global**.
- If a variable is declared at the beginning of a program outside all functions [including **`main()`**] it is classified as an external by default.
- **External variables can be accessed and changed by any function in the program**.
- Their storage is in permanent memory, and thus never disappear or need to be recreated.

What is the advantage of using global variables?

It is a method of transmitting information between functions in a program without using arguments.

extern Storage Class Example

- The following program illustrates the global nature of extern variables:

```
#include <stdio.h>
int a=4,b=5,c=6;   /* default extern */
int sum(void); int prod(void);
main() {
   printf ("The sum is %d\n",sum());
   printf ("The product is %d\n",prod());
}
int sum(void) {
  return (a+b+c); }
int prod(void) {
  return (a*b*c); }
```

```
The sum is 15
The product is 120
```

- There are two disadvantages of global variables versus arguments. **First**, the function is much less portable to other programs. **Second**, is the concept of **local dominance**. If a local variable has the **same name** as a global variable, only the local variable is changed while in the function. Once the function is exited, the global variable has the same value as when the function started.

static and register Storage Class

static Storage Class

- A static variable is a local variable that **retains its latest value** when a function is recalled. Its scope is still local in that it will only be recognized in its own function. Basically, static variables are created and initialized once during the first reference to the function. With clever programming, one can use static variables to enable a function to do different things depending on how many times it has been called. (Consider a function that counts the number of times it has been called).

register Storage Class

- It is often true that the time bottleneck in computer calculations is the time it takes to fetch a variable from memory and store its value in a register where the CPU can perform some calculation with it. So for performance reasons, it is sometimes advantageous to store variables directly in registers. This strategy is most often used with loop counter variables, as shown below.

```
register int i;
for (i=0; i<n; ++i)
   ...
```

Formatted Input and Output

- Formatted Output
- char and int Formatted Output Example
- f Format Identifier
- e Format Identifier
- Real Formatted Output Example
- s Format Identifier
- Strings Formatted Output Example
- Formatted Input
- Formatted Input Examples

Formatted Output

- Can you control the appearance of your output on the screen? Or do you have to accept the default formatting provided by the C compiler? It turns out you can format your output in a number of ways.
- You can control how many columns will be used to output the contents of a particular variable by specifying the **field width**. The desired field width is inserted in the format specifier after the `%` and before the letter code indicating the data type. Thus, the format specifier `%5d` is interpreted as use 5 columns to display the integer. Further examples:

`%3c`	display the character in 3 columns
`%13x`	display the hexadecimal integer in 13 columns

- Within the field, the argument value is **right-adjusted** and **padded with blanks**. If left adjustment is preferred use the syntax `%-3c`. If you wish to pad with zeros use the syntax `%04d`.

Nice Feature:

If the value to be printed out takes up more columns than the specified field width, the field is **automatically expanded**.

char and int Formatted Output Example

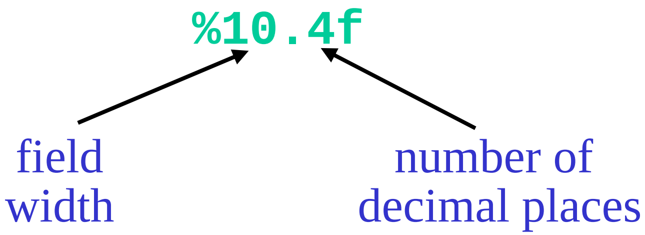
- This program and it output demonstrate various-sized field widths and their variants.

```
#include <stdio.h>
main() {
   char lett='w';
   int i=1,j=29;
   printf ("%c\n",lett);
   printf ("%4c\n",lett);
   printf ("%-3c\n",lett);
   printf ("%d\n",i);
   printf ("%d\n",j);
   printf ("%10d\n",j);
   printf ("%010d\n",j);
   printf ("%-010d\n",j);
   printf ("%2o\n",j);
   printf ("%2x\n",j);
}
```

```
w
   w
w
1
29
        29
0000000029
29
35
1d
```

f Format Identifier

- For floating-point values, in addition to specifying the field width, the **number of decimal places** can also be set. A sample format specifier would look like this



`%10.4f`

field width

number of decimal places

- Note that a period separates the two numbers in the format specifier. Don’t forget to count the column needed for the decimal point when calculating the field width. We can use the above format identifier as follows:

```
printf("%10.4f",4.0/3.0); ⟶ ----1.3333
```

where **-** indicates the blank character.

e Format Identifier

- When using the e format identifier, the second number after the decimal point determines **how many significant figures** (SF) will be displayed. For example

```
printf("%10.4e",4.0/3.0); → _1.333e+10
```

number of significant figures

- Note that only 4 significant figures are shown. Remember that now the field size must include the actual numerical digits as well as columns for '`.`','`e`', and '`+00`' in the exponent.
- It is possible to print out as many SFs as you desire. But it only makes sense to print out as many SFs as match the precision of the data type. The following table shows a rough guideline:

Data Type	*# Mantissa bits*	*Precision (#SF)*
float	16	~7
double	32	~16
long double	64	~21

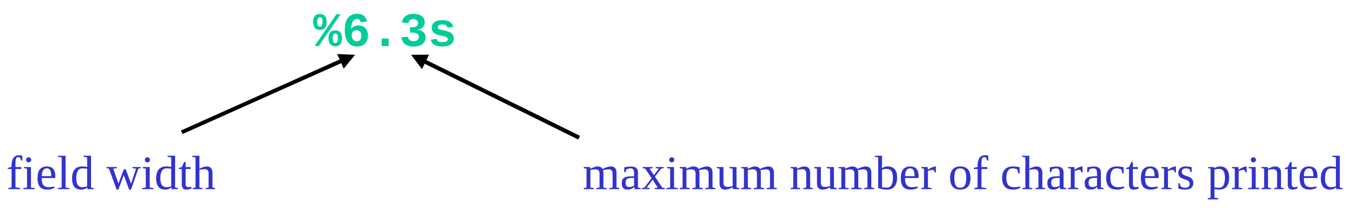
Real Formatted Output Example

```
#include <stdio.h>
main() {
   float x=333.123456;
   double y=333.1234567890123456;

   printf ("%f\n",x);
   printf ("%.1f\n",x);
   printf ("%20.3f\n",x);
   printf ("%-20.3f\n",x);
   printf ("%020.3f\n",x);
   printf ("%f\n",y);
   printf ("%.9f\n",y);
   printf ("%.20f\n",y);
   printf ("%20.4e\n",y);
}
```

```
333.123444
333.1
             333.123
333.123
0000000000000333.123
333.123457
333.123456789
333.12345678901232304270
           3.331e+02
```

s Format Identifier

- For strings, the **field length** specifier works as before and will **automatically expand** if the string size is bigger than the specification. A more sophisticated string format specifier looks like this



%6.3s

field width

maximum number of characters printed

where the value after the decimal point specifies the **maximum number of characters** printed.

- For example;

```
printf(“%3.4s\n","Sheridan"); ⟶ Sher
```

Strings Formatted Output Example

```
#include <stdio.h>
main() {
   static char s[]="an evil presence";

   printf ("%s\n",s);
   printf ("%7s\n",s);
   printf ("%20s\n",s);
   printf ("%-20s\n",s);
   printf ("%.5s\n",s);
   printf ("%.12s\n",s);
   printf ("%15.12s\n",s);
   printf ("%-15.12s\n",s);
   printf ("%3.12s\n",s);
}
```

```
an evil presence
an evil presence
    an evil presence
an evil presence
an ev
an evil pres
   an evil pres
an evil pres
an evil pres
```

Formatted Input

- Modifications can be made to the control string of the `scanf` function which enables more sophisticated input. The formatting features that can be inserted into the control string are

  – **Ordinary characters (not just format identifiers) can appear in the `scanf` control string. They must exactly match corresponding characters in the input. These “normal” characters will not be read in as input.**

  – **An asterisk can be put after the % symbol in an input format specifier to suppress the input.**

  – **As with formatted output, a field width can be specified for inputting values. The field width specifies the number of columns used to gather the input.**

Formatted Input Examples

```
#include <stdio.h>
main() {
   int m,n,o;
   scanf("%d : %d : %d",&m,&n,&o);
   printf("%d \n %d \n %d\n",m,n,o);
}
```

```
10 : 15 : 17
10
15
17
```

```
 #include <stdio.h>
 main() {
    int i; char lett; char word[15];
    scanf("%d , %*s %c %5s",&i,&lett,word);
    printf("%d \n %s \n %s\n",i,lett,word);
}
```

```
45 , ignore_this C read_this
45
C
read_
```

Pointers

- Pointer Uses
- Memory Addressing
- The Address Operator
- Pointer Variables
- Pointer Arithmetic
- Indirection Operator
- “Call-by-Reference” Arguments
- Tripling Function
- Swap Function
- Pointers and Arrays
- Pointers and Arrays Figure
- Pointers and Arrays Examples
- Arrays as Function Arguments
- Arrays as Function Arguments Example
- Pointers and Character Strings
- Alternate Definition of a String

Pointer Uses

- Pointers are an **intimate part of C** and separate it from more traditional programming languages. Pointers **make C more powerful** allowing a wide variety of tasks to be accomplished. Pointers enable programmers to

  - **effectively represent sophisticated data structures [later chapter]**
  - **change values of actual arguments passed to functions (“call-by-reference”)**
  - **work with memory which has been dynamically allocated [later chapter]**
  - **more concisely and efficiently deal with arrays**
  - **represent strings in a different manner**

- On the other hand, pointers are usually difficult for new C programmers to comprehend and use. If you remember the following simple statement, working with pointers should be less painful…

POINTERS CONTAIN MEMORY ADDRESSES, NOT DATA VALUES!

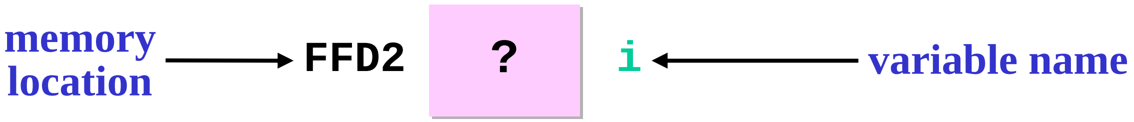
Memory Addressing

POINTERS CONTAIN MEMORY ADDRESSES, NOT DATA VALUES!

- When you declare a simple variable, say

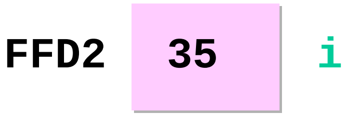
```
int i;
```

a memory location with a certain address is set aside for any values that will be placed in i. We thus have the following picture:



memory location → FFD2 ? i ← variable name

- After the statement `i=35;` the location corresponding to `i` will be filled



FFD2 35 i

The Address Operator

- You can find out the **memory address of a variable** by simply using the address operator **&**. Here is an example of its use:

  &v

- The above expression should be read as “address of **v**”, and it returns the memory address of the variable **v**.

- Consider the artificial example shown on the previous page, **&i** would be the memory address FFD2

- As will be shown, when using pointers the programmer never needs to know **“actual” value** of any memory address. Only that a pointer variable contains a memory address.

Pointer Variables

- A pointer is a C variable that contains memory addresses. Like all other C variables, pointers must be declared before they are used. The syntax for **pointer declaration** is as follows:

```
int *p;
double* offset;  /* Both forms legal */
```

- Note that the prefix * defines the variable to be a pointer. In the above example, p is the type **“pointer to integer”** and offset is the type **“pointer to double”.**
- Once a pointer has been declared, it can be assigned an address. This is commonly done with the address operator. For example,

```
int *p;
int count;
p=&count;
```

- After this assignment, we say that p is “**pointing to**” the variable count. The pointer p contains the memory address of the variable count.

Pointer Arithmetic

- A limited amount of pointer arithmetic is possible. The "unit" for the arithmetic is the size of the variable being pointed to in bytes. Thus, incrementing a pointer-to-an-int variable automatically adds to the pointer address the number of bytes used to hold an int (on that machine).
  - Programmer can use addition, subtraction and multiplication with a pointer and an integer as operands
  - Pointers can be incremented and decremented.
  - In addition, different pointers can be assigned to each other

- Some examples,

```
int *p, *q;
p=p+2;  /* p increased by 2 int memory sizes */
q=p;
```

Indirection Operator

- The indirection operator, ***** , can be considered as the complement to the address operator. It **returns the contents of the address stored in a pointer variable**. It is used as follows:

***p**

- The above expression is read as “contents of **p**”. What is returned is the value stored at the memory address **p**.
- Consider the sample code:

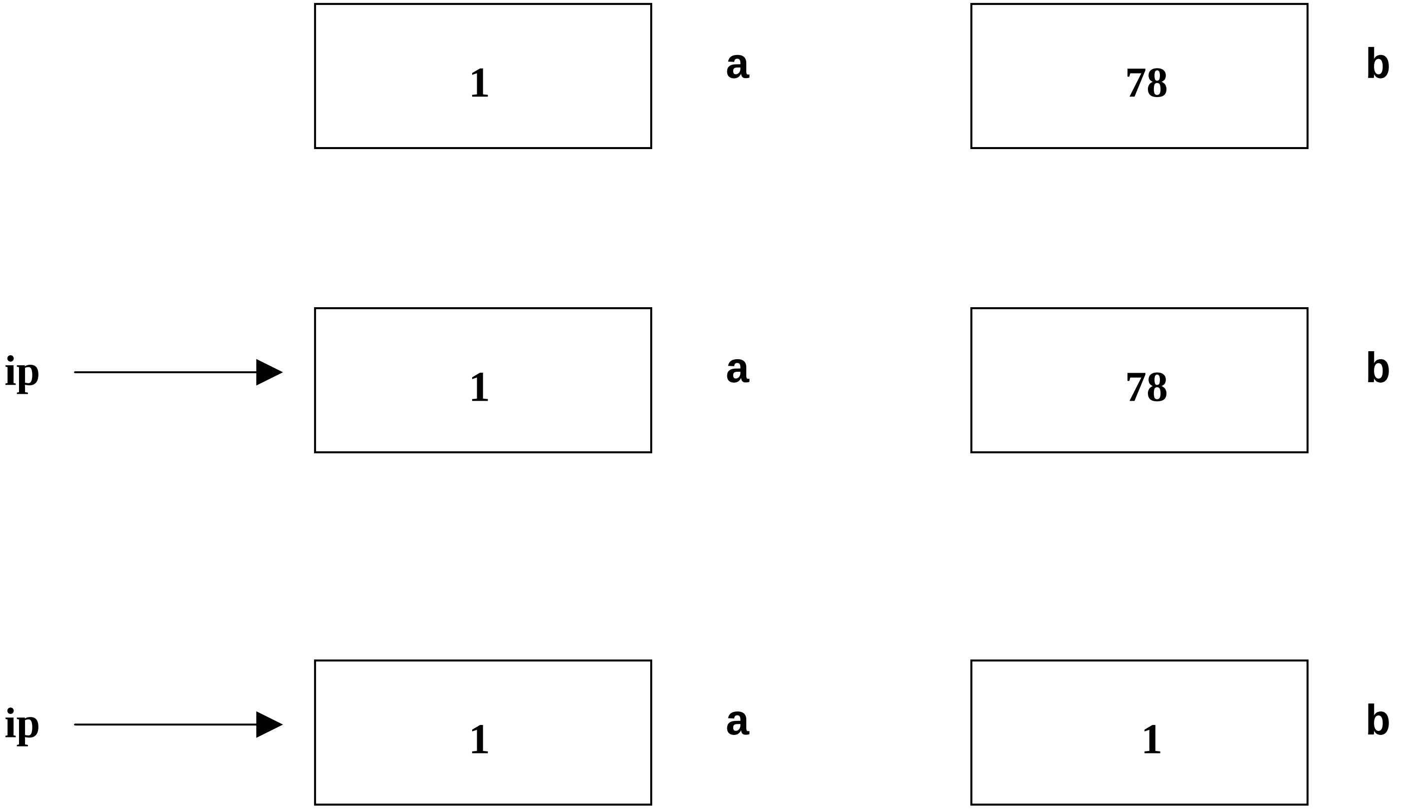
```
#include <stdio.h>
main() {
   int a=1,b=78,*ip;
   ip=&a;
   b=*ip;     /* equivalent to b=a */
   printf("The value of b is %d\n",b); }
```

```
The value of b is 1
```

- Note that **b** is assigned the value of **a** but it is done **indirectly**; by using a pointer to **a**.

Memory Point-of-View

- The following diagrams illustrate what occurred **in memory** while our sample program (previous slide) was run:



“Call-by-Reference” Arguments

- We learned earlier that if a variable in the main program is used as an actual argument in a function reference, its value won’t be changed no matter what is done to the corresponding dummy argument in the function.

- **What if we would like the function to change the main variable’s contents?**

  – To do this we use pointers as dummy arguments in functions and indirect operations in the function body. (The actual arguments must then be addresses)

  – Since the **actual argument variable and the corresponding dummy pointer refer to the same memory location**, changing the contents of the dummy pointer will- by necessity- change the contents of the actual argument variable.

Tripling Function

- An example of “call-by-reference” is a **tripling function** designed to triple the value of a variable in the main program. Here is the program and function:

```
#include <stdio.h>

void triple_value(float *fp);

main() {
   float x=43.15;
   triple_value(&x);
   printf(“x is now %0.4f\n",x);
}

void triple_value(float *fp) {
      *fp = *fp * 3.0;
}
```

```
x is now 129.4500
```

Swap Function

- The classic example of “call-by-reference” is a **swap function** designed to exchange the values of two variables in the main program. Here is a typical swapping program:

```
#include <stdio.h>
void swap(int *p,int *q);

main() {
   int i=3,j=9876;
   swap(&i,&j);
   printf("After swap, i=%d j=%d\n",i,j);
}

void swap(int *p,int *q) {
      int temp;
      temp=*p;
      *p=*q;
      *q=temp;
   }
```

```
After swap, i=9876 j=3
```

Pointers and Arrays

- Although this may seem strange at first, in C an **array name contains an address**. In fact, it is the **base address** of all the consecutive memory locations that make up the entire array.

- We have actually seen this fact before: when using scanf to input a character array called name the statement looked like

- `scanf("%s",name);` **NOT** `scanf("%s",&name);`

- Given this fact, we can use **pointer arithmetic to access array elements.** Adding one to the array name can move a pointer to the next array element, add another one and the pointer moves to the element after that, and so on … In this manner the entire array can be indirectly accessed with a pointer variable.

Pointers and Arrays Figure

- Given the following array declaration

```
int a[467];
```

- The following two statements **do the exact same thing**:

```
a[5]=56;
*(a+5)=56;
```

- Here is a possible layout in memory:

a	133268	a[0]
a+1	133272	a[1]
a+2	133276	a[2]
a+3	133280	a[3]
a+4	133284	a[4]
a+5	133288	a[5]

Pointers and Arrays Examples

- The next examples show how to sum up all the elements of a 1D array using different approaches:
  - Normal way (element notation)

```
    int a[100],i,*p,sum=0;

    for(i=0; i<100; ++i)
       sum +=a[i];
```

  - Alternate way (use addresses)

```
    int a[100],i,*p,sum=0;

    for(i=0; i<100; ++i)
       sum += *(a+i);
```

  - Yet another way (use a pointer)

```
    int a[100],i,*p,sum=0;

    for(p=a; p<&a[100]; ++p)
       sum += *p;
```

Arrays as Function Arguments

- When you are writing functions that work on arrays, it is efficient to **use pointers as dummy arguments**. Once the function has the base address of the array, it can use pointer arithmetic to indirectly work with all the array elements. The alternative is to use global array variables or -- more horribly -- pass all the array elements into the function.

- Consider the following function designed to take the sum of elements in a 1D array of doubles:

```
double sum(double *dp, int n) {
      int i; double res=0.0;
      for(i=0; i<n; ++i)
         res += *(dp+i);
      return res;
   }
```

- Note that all the sum function needed was a **starting address in the array and the number of elements** to be summed together (**n**). A compact argument list.

Arrays as Function Arguments Example

- Considering the previous example

```
double sum(double *dp, int n) {
      int i; double res=0.0;
      for(i=0; i<n; ++i)
         res += *(dp+i);
      return res;
   }
```

- In the main program, the **sum** function could be used in any of these ways:

```
double position[150],length;

length=sum(position,150); /* sum entire array */
length=sum(position,75);  /* sum first half */
length=sum(&position[10],10);/* sum from element
                             10 to element 19 */
```

Pointers and Character Strings

- As strange as this sounds, a string constant -- such as “Happy Thanksgiving” -- is treated by the compiler as an address (Just like we saw with an array name). The value of the string constant address is the **base address** of the character array. In other words, the address of the first character in the string.

- Thus, we can **use pointers to work with character strings**, in a similar manner that we used pointers to work with “normal” arrays. This is demonstrated in the following code:

```
#include <stdio.h>

main() {
   char *cp;
   cp="Civil War";  /* Now this is legal */
   printf("%c\n",*cp);
   printf("%c\n",*(cp+6));
}
```

```
C
W
```

Alternate Definition of a String

- Another example illustrates easy string input using pointers:

```
#include <stdio.h>

main() {
   char *name;
   printf("Who are you?\n");
   scanf("%s",name);
   printf("Hi %s welcome to the party, pal\n",name);
}
```

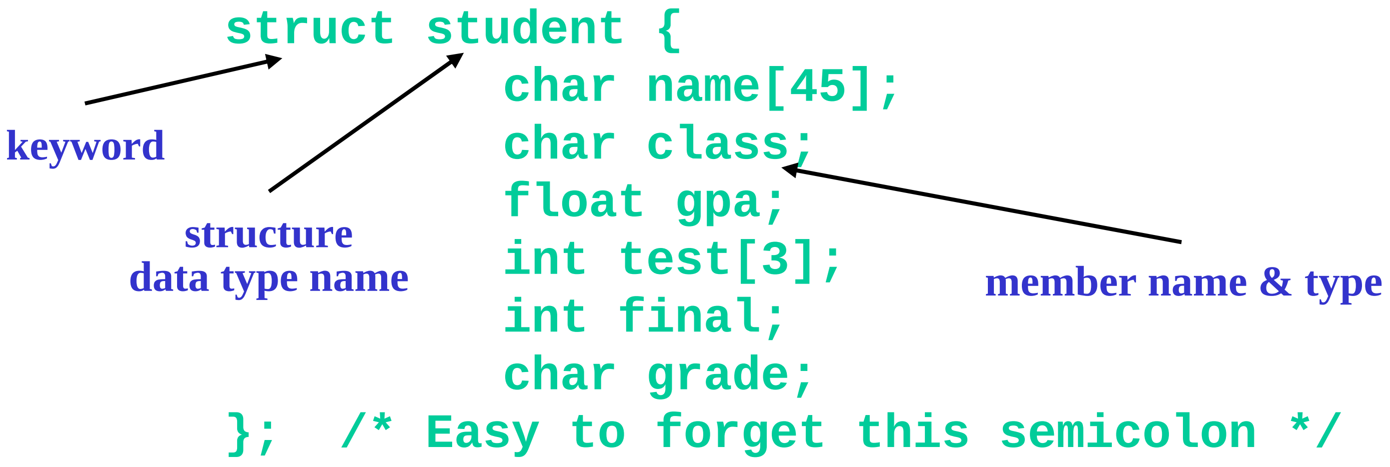
```
Who are you?
Seymour
Hi Seymour welcome to the party, pal
```

Structures

- Introduction to Structures
- Structure Variable Declaration
- Structure Members
- Initializing Structure Members
- Array of Structures
- Structures within Structures
- Initializing Structures within Structures
- Pointers to Structures
- Structure Pointer Operator

Introduction to Structures

- A structure is a variable in which **different types of data** can be stored together in **one variable name**. Consider the data a teacher might need for a student: Name, Class, GPA, test scores, final score, and final course grade. A structure data type called `student` can hold all this information:



```
struct student {
         char name[45];
         char class;
         float gpa;
         int test[3];
         int final;
         char grade;
};  /* Easy to forget this semicolon */
```

keyword

structure data type name

member name & type

- The above is a **declaration of a new data type** called `student`. It is not a variable declaration, but a type declaration.

Structure Variable Declaration

- To actually declare a structure variable, the standard syntax is used:

```
struct student  Lisa, Bart, Homer;
```

- You can declare a structure type and variables simultaneously. Consider the following structure representing playing cards.

```
struct playing_card {
   int number;
   char *suit;
} card1,card2,card3;
```

- Notice that in both the structure type declaration and the structure variable declaration the **keyword struct must precede the meaningful name** you chose for the structure type.

Structure Members

- The different variable types stored in a structure are called its **members**. To access a given member the **dot notation** is use. The "dot" is officially called the member access operator. Say we wanted to initialize the structure `card1` to the two of hearts. It would be done this way:

```
card1.number = 2;
card1.suit = "Hearts";
```

- Once you know how to name of a member, it can be treated the same as any other variable of that type. For example the following code:

```
card2.number = card1.number + 5;
```

  would make `card2` the seven of some suit.

- Structure variables can also be assigned to each other, just like with other variable types:

```
card3 = card1;
```

  would fill in the `card3` `number` member with 2 and the `suit` member with "Hearts". In other words, each member of `card3` gets assigned the value of the corresponding member of `card1`.

Initializing Structure Members

- Structure members can be **initialized at declaration**. This is similar to the initialization of arrays; the initial values are simply listed inside a pair of braces, with each value separated by a comma. The structure declaration is preceded by the keyword **`static`**

```
static struct student Lisa =
{"Simpson",'S',3.95,100,87,92,96,'A'};
```

- The same member names can appear in different structures. This will be no confusion to the compiler because when the member name is used it is prefixed by the name of the structure variable. For example:

```
struct fruit {
   char *name;
   int calories; } snack;
struct vegetable {
   char *name;
   int calories; } dinner_course;
snack.name="banana";
dinner_course.name="broccoli";
```

Array of Structures

- What data type are allowed to be structure members? **Anything goes**: basic types, arrays, strings, pointers, even other structures. You can even make an **array of structures**.
- Consider the program on the next few pages which uses an array of structures to make a deck of cards and deal out a poker hand.

```
#include <stdio.h>

struct playing_card {
      int number;
      char *suit;
};
struct playing_card deck[52];

void make_deck(void);
void show_card(int n);
main() {
   make_deck();
   show_card(5);
   show_card(37);
   show_card(26);
   show_card(51);
   show_card(19);
}
```

Array of Structures

```
void make_deck(void) {
    int k;
    for(k=0; k<52; ++k) {
      if (k>=0 && k<13) {
         deck[k].suit="Hearts";
         deck[k].number=k%13+2; }
      if (k>=13 && k<26) {
         deck[k].suit="Diamonds";
         deck[k].number=k%13+2; }
      if (k>=26 && k<39) {
         deck[k].suit="Spades";
         deck[k].number=k%13+2; }
      if (k>=39 && k<52) {
         deck[k].suit="Clubs";
         deck[k].number=k%13+2; }
    }
  }
```

Array of Structures

```
void show_card(int n) {
    switch(deck[n].number) {
      case 11:
        printf("%c of %s\n",'J',deck[n].suit);
        break;
      case 12:
        printf("%c of %s\n",'Q',deck[n].suit);
        break;
      case 13:
        printf("%c of %s\n",'K',deck[n].suit);
        break;
      case 14:
        printf("%c of %s\n",'A',deck[n].suit);
        break;
      default:
        printf("%c of %s\n",deck[n].number,deck[n].suit);
    }
  }
```

```
7 of Hearts
K of Spades
2 of Spades
A of Clubs
8 of Diamonds
```

Structures within Structures

- As mentioned earlier, structures can have as members other structures. Say you wanted to make a structure that contained both date and time information. One way to accomplish this would be to combine two separate structures; one for the date and one for the time. For example,

```
struct date {
      int month;
      int day;
      int year;
  };
struct time {
      int hour;
      int min;
      int sec;
  };
struct date_time {
      struct date today;
      struct time now;
  };
```

- This declares a structure whose elements consist of two other previously declared structures.

Initializing Structures within Structures

- Initialization could be done as follows,

```
static struct date_time veteran = {{11,11,1918},{11,11,11}};
```

which sets the `today` element of the structure `veteran` to the eleventh of November, 1918. The `now` element of the structure is initialized to eleven hours, eleven minutes, eleven seconds. Each item within the structure can be referenced if desired. The "dot notation" will be used twice. For example,

```
++veteran.now.sec;
if (veteran.today.month == 12)
   printf("Wrong month! \n");
```

Pointers to Structures

- One can have pointer variable that contain the address of a structure variable, just like with the basic data types. Structure pointers are declared and used in the same manner as “simple” pointers:

```
struct playing_card *card_pointer,down_card;
card_pointer=&down_card;
(*card_pointer).number=8;
(*card_pointer).suit="Clubs";
```

- The above code has **indirectly initialized** the structure `down_card` to the Eight of Clubs through the use of the pointer `card_pointer`.

- The type of the variable `card_pointer` is “pointer to a playing_card structure”.

Pointers to Structures: ->

- In C, there is a special operator `->` which is used as a shorthand when working with pointers to structures. It is officially called the **structure pointer operator**. Its syntax is as follows:

  `*(struct_ptr).member` **is the same as** `struct_ptr->member`

- Thus, the last two lines of the previous example could also have been written as:

```
card_pointer->number=8;
card_pointer->suit="Clubs";
```

Question: What is the value of `*(card_pointer->suit+2)`?

```
Answer: *( *(card_pointer).suit + 2)
        *( “Clubs” + 2) = ‘u’
```

- As with arrays, **use structure pointers as dummy arguments for functions** working with structures. This is efficient, since only an address is passed and can also enable the “call-by-reference” technique.

Unions

- Introduction to Unions
- Unions and Memory
- Unions Example

Introduction to Unions

- Unions are C variables whose syntax look similar to structures, but act in a completely different manner. A union is **a variable that can take on different data types** in different situations. The union syntax is:

```
union tag_name {
      type1 member1;
      type2 member2;
      …
   };
```

- For example, the following code declares a union data type called `intfloat` and a union variable called `proteus`:

```
union intfloat {
      float f;
      int i;
   };

union intfloat proteus;
```

Unions and Memory

- Once a union variable has been declared, the amount of memory reserved is just enough to be able to represent the **largest member**. (Unlike a structure where memory is reserved for **all** members).

- In the previous example, 4 bytes are set aside for the variable **`proteus`** since a **`float`** will take up 4 bytes and an **`int`** only 2 (on some machines).

- Data actually stored in a union's memory can be the data associated with **any** of its members. But **only one** member of a union can contain valid data at a given point in the program.

- It is the **user's responsibility** to keep track of which type of data has most recently been stored in the union variable.

Unions Example

- The following code illustrates the chameleon-like nature of the union variable **`proteus`** defined on the previous page.

```
#include <stdio.h>
main() {
  union intfloat {
        float f;
        int i;
     } proteus;
  proteus.i=4444   /* Statement 1 */
  printf(“i:%12d f:%16.10e\n”,proteus.i,proteus.f);
  proteus.f=4444.0;   /* Statement 2 */
  printf(“i:%12d f:%16.10e\n”,proteus.i,proteus.f);
}
```

```
i:        4444 f:6.2273703755e-42
i:  1166792216 f:4.440000000e+03
```

- After **Statement 1**, data stored in **`proteus`** is an integer the the float member is full of junk.
- After **Statement 2**, the data stored in **`proteus`** is a float, and the integer value is meaningless.

File Input and Output

- Introduction to File Input and Output
- Declaring FILE Variables
- Opening a Disk File for I/O
- Reading and Writing to Disk Files
- Closing a Disk File
- Additional File I/O Functions
- COMPLETE File I/O Program

Introduction to File Input and Output

- So far, all the output (formatted or not) in this course has been written out to what is called **standard output** (which is traditionally the monitor). Similarly all input has come from **standard input** (commonly assigned to the keyboard). A C programmer can also read data directly from files and write directly to files. To work with a file, the following steps must be taken:

1 Declare a **variable to be of type pointer-to-`FILE`**.

2 Connect the internal **`FILE`** variable with an actual data file on your hard disk. This association of a **`FILE`** variable with a file name is done with the **`fopen()`** function.

3 Perform I/O with the actual files using **`fprint()`** and **`fscanf()`** functions. (All you have learned still works).

4 Break the connection between the internal **`FILE`** variable and actual disk file. This disassociation is done with the **`fclose()`** function.

Declaring FILE variables

- Declarations of the file functions highlighted on the previous page must be included into your program. This is done in the standard manner by having

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

at the beginning of your program.

- The first step is using files in C programs is to declare a file variable. This variable must be of type `FILE` (which is a predefined type in C) and it is a pointer variable. For example, the following statement

```
FILE *in_file;
```

declares the variable `in_file` to be a “pointer to type `FILE`”.

Opening a Disk File for I/O

- Before using a **`FILE`** variable, it must be associated with a specific file name. The **`fopen()`** function performs this association and takes two arguments:
  - 1) the pathname of the disk file
  - 2) the access mode which indicates how the file is to be used.
- The following statement

```
in_file = fopen("myfile.dat","r");
```

connects the local variable **`in_file`** to the disk file **`myfile.dat`** for **read** access. Thus, **`myfile.dat`** will **only** be read from. Two other access modes are also useful:

“**`w`**”	indicating write-mode
“**`a`**”	indicating append_mode

Reading and Writing to Disk Files

- The functions `fprintf` and `fscanf` are provided by C to perform the analogous operations of the `printf` and `scanf` functions but on a file.

- These functions take an additional (first) argument which is the FILE pointer that identifies the file to which data is to be written to or read from. Thus the statement,

```
fscanf(in_file,"%f%d",&x,&m);
```

- will input -- from the file `myfile.dat` -- real and integer values into the variables `x` and `m` respectively.

Closing a Disk File

- The **`fclose`** function in a sense does the opposite of what the **`fopen`** does: it tells the system that we no longer need access to the file. This allows the operating system to cleanup any resources or buffers associated with the file.

- The syntax for file closing is simply

```
fclose(in_file);
```

Additional File I/O Functions

- Many of the specialized I/O functions for characters and strings that we have described in this course have analogs which can be used for file I/O. Here is a list of these functions

Function	*Result*
`fgets`	file string input
`fputs`	file string output
`getc(file_ptr)`	file character input
`putc(file_ptr)`	file character output

- Another useful function for file I/O is **`feof()`** which tests for the end-of-file condition. **`feof`** takes one argument -- the FILE pointer -- and returns a nonzero integer value (TRUE) if an attempt has been made to read past the end of a file. It returns zero (FALSE) otherwise. A sample use:

```
while( !feof(in_file) ) {
         …
   printf (“Still have lines of data\n");
}
```

Sample File I/O Program

- The program on the next few pages illustrates the use of file I/O functions. It is an inventory program that reads from the following file

```
lima beans
1.20
10
5
thunder tea
2.76
5
10
Greaters ice-cream
3.47
5
5
boneless chicken
4.58
12
10
```

which contains stock information for a store. The program will output those items which need to be reordered because their number-on-hand is below a certain limit

Sample File I/O Program: main

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

 struct goods {
       char name[20];
       float price;
       int quantity;
       int reorder;
    };

 FILE *stock_list;

 void processfile(void);
 void getrecord(struct goods *recptr);
 void printrecord(struct goods record);

 main() {
   char filename[40];
   printf("Example Goods Re-Order File Program\n");
   printf("Enter database file \n");
   scanf("%s",filename);
   stock_list = fopen(filename, "r");
   processfile();
}
```

Sample File I/O Program: processfile

```
void processfile(void) {
      struct goods record;
      while (!feof(stock_list)) {
         getrecord(&record);
         if (record.quantity <= record.reorder)
            printrecord(record);
      }
   }
```

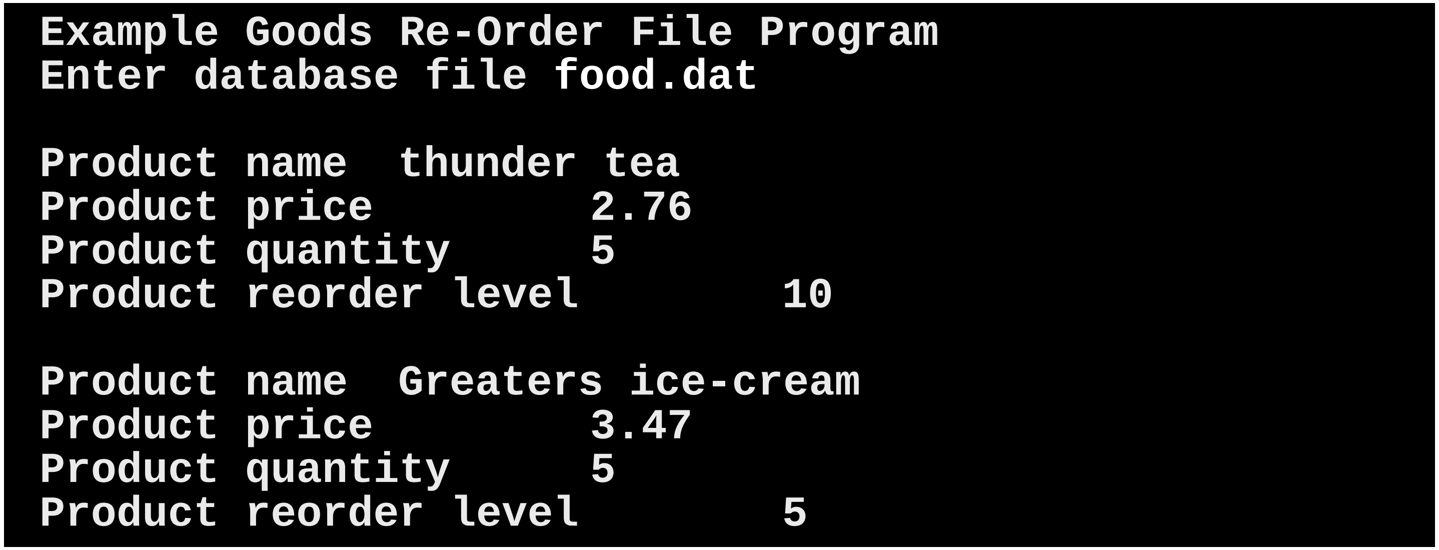
Sample File I/O Program: getrecord

```
void getrecord(struct goods *recptr) {
      int loop=0,number,toolow;
      char buffer[40],ch;
      float cost;

      ch=fgetc(stock_list);  /* Input string character
      while (ch!='\n') {        by character */
         buffer[loop++]=ch;
         ch=fgetc(stock_list);
      }
      buffer[loop]=0;
      strcpy(recptr->name,buffer);

      fscanf(stock_list,"%f",&cost);
      recptr->price = cost;
      fscanf(stock_list,"%d",&number);
      recptr->quantity = number;
      fscanf(stock_list,"%d",&toolow);
      recptr->reorder = toolow;
   }
```

Sample File I/O Program: printrecord

```
void printrecord (struct goods record) {
      printf("\nProduct name \t%s\n",record.name);
      printf("Product price \t%f\n",record.price);
      printf("Product quantity \t%d\n",record.quantity);
      printf("Product reorder level \t%d\n",record.reorder);
   }
```

Sample File I/O Program: sample session



```
Example Goods Re-Order File Program
Enter database file food.dat

Product name  thunder tea
Product price        2.76
Product quantity     5
Product reorder level        10

Product name  Greaters ice-cream
Product price        3.47
Product quantity     5
Product reorder level        5
```

Dynamic Memory Allocation

- Introduction to Dynamic Memory Allocation
- Dynamic Memory Allocation: calloc
- Dynamic Memory Allocation: free

Introduction to Dynamic Memory Allocation

- A common programming problem is knowing how large to make arrays when they are declared. Consider a grading program used by a professor which keeps track of student information (using structures). We want his program to be general-purpose so we need to make arrays large enough to handle the biggest possible class size:

```
struct student course[600];
```

- But when a certain upper-level class has only seven students, this approach can be inelegant and **extremely wasteful of memory** especially if the `student` structure is quite large itself.

- Thus, it is desirable to **create correct-sized array variables at runtime**. The C programming language allows users to dynamically allocate and deallocate memory when required. The functions that accomplish this are `calloc()` which allocates memory to a variable, `sizeof()`, which determines how much memory a specified variable occupies, and `free()`, which deallocates the memory assigned to a variable.

Dynamic Memory Allocation: sizeof

- The `sizeof()` auxillary function **returns the memory size** (in bytes) of a requested variable type. This call should be used in conjunction with the `calloc()` function call, so that the correct amount of memory on that machine is allocated. Consider the following code fragment:

```
struct time {
      int hour;
      int min;
      int sec;
   };
int x;
x=sizeof(struct time);
```

- `x` now contains how many bytes are taken up by a `time` structure (which turns out to be 12 on many machines). `sizeof` can also be used to determine the memory size of basic data type variables as well. For example, it is valid to write `sizeof(double)`.

Dynamic Memory Allocation: calloc

- The `calloc` function is used to **allocate storage to a variable** while the program is running. The function takes two arguments that specify the number of elements to be reserved, and the size of each element in bytes (obtained from `sizeof`). The function returns a pointer to the beginning of the allocated storage area in memory. The storage area is also initialized to zeros.

```
struct time *appt;
appt = (struct time *) calloc(100,sizeof(struct time));
```

- The (prefix code) `(struct time *)` is a type cast operator which converts the pointer returned from `calloc` to a pointer to a structure of type time. The above function call will allocate just enough memory for one hundred `time` structures, and `appt` will point to the first in the array. Now the array of `time` structures can be used, just like a statically declared array:

```
appt[5].hour=10;
appt[5].min=30;
appt[5].sec=0;
```

Dynamic Memory Allocation: free

- When the **variables are no longer required**, the space which was allocated to them by **`calloc`** should be returned to the system. This is done by,

```
free(appt);
```

Command-Line Arguments

- Introduction to Command-Line Arguments
- Command-Line Arguments Example
- Command-Line Arguments: Interactive Session
- String-to-Number Conversion

Introduction to Command-Line Arguments

- In every program seen so far, the **`main`** function has had no dummy arguments between its parentheses. The **`main` function is allowed to have dummy arguments** and they match up with command-line arguments used when the program is run.

- The two dummy arguments to the **`main`** function are called **`argc`** and **`argv`**.
  - **`argc`** contains the number of command-line arguments passed to the main program (The program name is also counted.)
  - **`argv[]`** is an array of pointers-to-**`char,`** each element of which points to a passed command-line argument. (Consider this an array of strings.)

Command-Line Arguments Example

- A simple example follows, which checks to see if only a single argument is supplied on the command line when the program is invoked

```
#include <stdio.h>
main(int argc, char *argv[]) {
   if (argc == 2)
      printf("The argument supplied is %s\n", argv[1]);
   else if (argc > 2)
      printf("Too many arguments supplied.\n");
   else
      printf("One argument expected.\n");
   }
```

- Note that `*argv[0]` is the program name itself, which means that `*argv[1]` is a string containing the first “actual” argument supplied, and `*argv[n]` is the last argument string. If no arguments are supplied, `argc` will be one. Thus for `n` arguments, `argc` will be equal to `n+1`.

Command-Line Arguments: Sample Session

- A sample session using the previous example follows:

```
#include <stdio.h>
main(int argc, char *argv[]) {
   if (argc == 2)
      printf("The argument supplied is %s\n", argv[1]);
   else if (argc > 2)
      printf("Too many arguments supplied.\n");
   else
      printf("One argument expected.\n");
}
```

```
$ a.out
One argument expected.
$ a.out help
The argument supplied is help
$ a.out help verbose
Too many arguments supplied.
```

String-to-Number Conversion

- Let’s say one the command line arguments is the string “200”. In your program, you (probably) want to use this command line argument as the integer 200.
- To perform the conversion, a useful function is **`sscanf`**, a member of the **`scanf`** family of functions. **`sscanf`** allows **reading input from a string**.
- The syntax for **`sscanf`** is

```
sscanf(input string, control string, address list);
```

- Consider this sample program (convert.c) and a demonstration of using it:

```
#include <stdio.h>
void main(int argc, char *argv[]) {
   int limit;
   printf(“First command line arg is %s\n”,argv[1];
   sscanf(argv[1],”%d”,&limit);
   limit += 100;
   printf(“Integer limit is now %d\n”,limit);
}
```

```
$ cc –o convert convert.c
$ convert 200
First command line arg is 200
Integer limit is now 300
```

Software Engineering

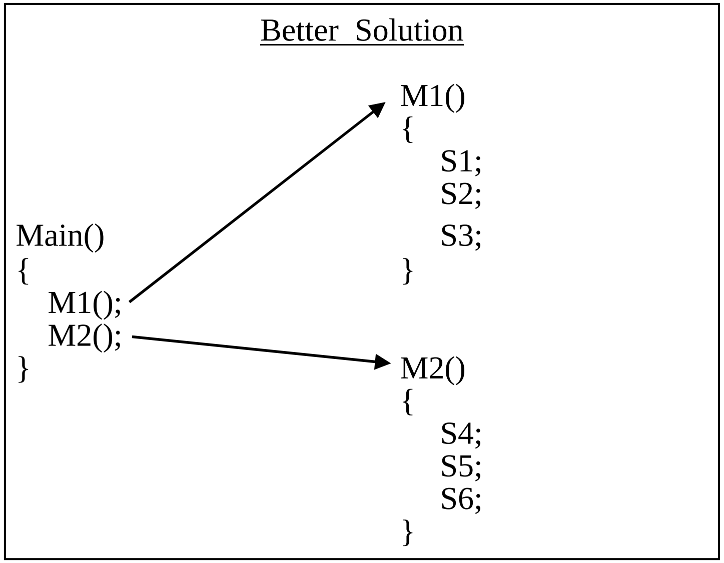
- Structured Programming
- Inheriting Weaknesses
- Top-down With C
- Example: Dithering Pallets
- Makefiles
- Platform independent packages

Structured Programming

- Popular during the 1970s and into the 80s
- To solve a large problem, break the problem into several pieces
- Work on each piece separately
- Treat each piece as a new problem which can itself be broken down into smaller problems
- Eventually, pieces can be solved directly, without further decomposition
- This approach is called top-down programming, code-centric

Linear Solution

```
Main()
{
   S1;
   S2;
   S3;
   S4;
   S5;
   S6;
}
```



Better Solution

```
Main()
{
   M1();
   M2();
}
```

```
M1()
{
    S1;
    S2;
    S3;
}
```

```
M2()
{
    S4;
    S5;
    S6;
}
```

Inheriting Weaknesses

- It deals almost entirely with the **instructions**
  - **Data structures** for a program was as least as important as the design of subroutines and control structures
  - Doesn’t give adequate consideration to the data that the program manipulates
- Difficult to reuse work done for other projects
  - Tends to produce a design that is unique to a particular problem
  - The ability to use a large chunk of code from another program is unlikely
  - Reusable code is very desirable

Top-down with C

- Up to now, main() and subroutines() included in one file
- Decompose this problem into smaller functions
- Combine similar routines in one file
- Examine the compile line which includes multiple source files

Example: Dithering Pallets

- Convert an image to line-printer art
- Display the image in the shell window using the ascii character set
- Images are assumed to be PNM format
- The ascii, PNM image files have the following format, line by line
  - Format key word, here "P2", 'P' meaning PNM, and '2' meaning greyscale
  - Comment line
  - Two integers, describing the width and height of the image.
  - One integer, the maximum value of the color range
  - Each line that follows is the color value of each of the *width x height* pixels
- Analysis of the routines needed
  - Main(): coordinates the execution of the application
  - GetMem(): allocate memory for the image
  - ReadImage(): read image from file
  - WriteImage(): write image to window, STDOUT
  - FillDither (): creates the dither color pallet
  - CnvrtImage(): convert the color information to a character

Example: Dithering Pallets

- Header file, dither.h
  - System include files
    - #include <stdio.h>
  - Declare functions
    - int ReadImage(char *, struct PixelData *, int, int, int);
    - Strong prototyping
  - Declares data types used by all procedures

```
struct PixelData {
  int greyval;
  char dithval;
};
```

  - Declare macros and static variables
    - #define   minval(x, y)   (x < y) ? x : y
- Functions grouped in four files
  - img_dither.c
    - main procedure
  - convert.c
    - void CnvrtImage(struct PixelData *d, char *pal, int n, int w, int h, int max)
    - Take the PixelData structure, palette, passed by reference
    - Take the width, height, and maxval, passed by value

Example: Dithering Pallets

- Functions grouped in four files (cont’d)
  - make_pal.c
    - void FillDither (char *mydither, int num)
    - Pass by reference the color palette
    - Pass by value the size of the palette
  - io_image.c
    - Note variables passed by reference and passed by value
    - struct PixelData * GetMem(char *fn, int *width, int *height, int *maxval)
    - int ReadImage(char *fn, struct PixelData *d, int width, int height, int maxval)
    - void WriteImage(char * fn, struct PixelData *d, int width, int height)

Example: Dithering Pallets

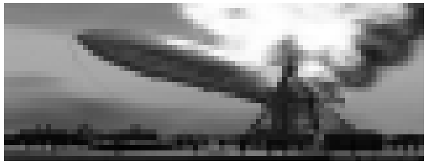
- Compile command
  - Previous exercises main() and subroutines in one file
  - Link to math library
    - -*lm*, shorthand for libm.so or libm.a
    - For many functions use man pages, *man sqrt*
    - Compiler looks in standard locations
      - /usr/lib
      - /usr/local/lib
    - Can direct to special purpose libraries
      - -L/myown/libraries/
      - Compiler looks in the directory path for linked library

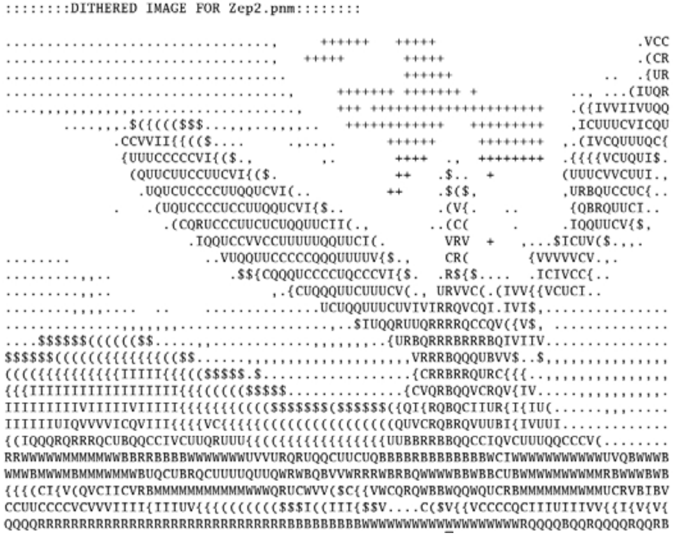
Example: Dithering Pallets

- Compile command (cont’d)
  - Default locations for header files
    - #include <**stdio.h**>
    - Standard locations /usr/include, /usr/local/include
    - Use *–I/special/include* to point to alternate directory
  - Default executable named “a.out”
  - Redirect executable name with ‘-o’ flag
- Optimize the exectable
  - Flags include –g, -O3, -O, etc.
  - Use **man gcc**
  - Size of executable file effected
- Compile image dithering program
  - gcc -g -o imgdither make_pal.c convert.c io_image.c img_dither.c
  - Order of the listing of the source files important
  - Files to the right dependent on procedures defined in files to the left
  - Compare size of executable file with different optimization flags

Example: Dithering Pallets

- Running the program
  - One argument required, name of the pnm image filename
  - Should reply a ‘Usage’ comment
  - Depending on the PATH environment variable setting
  - ./imgdither Zep2.pnm
  - Note the different aspect ratios





```
::::::::DITHERED IMAGE FOR Zep2.pnm::::::::

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```

Makefiles

- Compiling source code files can be tedious
- Makefiles are special format files
- Build and manage projects with the Unix *make* utility
- Allows you to specify which files are created from which others
- Then run appropriate commands to update the created files

Platform independent packages

- Cmake
  - Cross-platform, open-source make system
  - Used to control the software compilation process
    - uses simple platform and compiler independent configuration files
  - Generates native makefiles and workspaces
  - Can be used in the compiler environment of your choice
  - Used in projects like VTK and Paraview
- Imake
  - *imake* is a *Makefile*-generator
  - Easier to develop software portably for multiple systems
  - Makefiles are inherently non-portable
  - Instead of writing a *Makefile*, you write an *Imakefile*
  - machine-independent description of what targets you want to build
- Both are not too widely used

Platform independent packages

- Gnu autoconf
  - Extensible package of m4 macros
  - Produces shell scripts
    - automatically configure software source code packages.
    - Can adapt the packages to many kinds of UNIX-like systems without manual user intervention
  - Autoconf creates a configuration script for a package
    - A template file lists the operating system features that the package can use
    - In the form of m4 macro calls.
      - GNU m4 is an implementation of the traditional UNIX macro processor
      - It is mostly SVR4 compatible
  - Becoming more popular

Operator Precedence Table

	Description	*Represented by*
1	Parenthesis	() []
1	Structure Access	. ->
2	Unary	! ++ -- - * &
3	Multiply, Divide, Modulus	* / %
4	Add, Subtract	+ -
5	Shift Right, Left	>> <<
6	Greater, Less Than, etc.	> < => <=
7	Equal, Not Equal	== !=
8	Bitwise AND	&
9	Bitwise Exclusive OR	^
10	Bitwise OR	|
11	Logical AND	&&
12	Logical OR	||
13	Conditional Expression	? :
14	Assignment	= += -= etc
15	Comma	,

Problem Set

1) Write a program that sets the length and width of a rectangle to 13.5 and 5.375. Your program should then calculate and output the area and perimeter of the rectangle.

2) Write a program that works with two Cartesian points (3.4,12.3) and (5.6,15.0). Compute the slope of the straight line between these two points and their midpoint. Output your results. (If you need help with any math formulae, just ask your instructor).

3) Write a program that converts a temperature of 35° Celsius to degrees Fahrenheit. The conversion equation is:

$$T_F = (9.0/5.0)T_c + 32$$

4) Write a program that sets up variables to hold the distance of a job commute in miles, the car's fuel efficiency in mpg, and the price of gasoline. Set the distance to 5.5 miles, the mpg to 20.0 miles/gallon and the cost of gas to be $1.78 a gallon. Your program should then calculate and output the total cost of the commute.

5) Write a program that will calculate the final exam grade a student must achieve in order to get a certain percentage of the total course points. You may assume that the student has already taken three exams worth 100 points. The final exam is worth 200 points. Your program should read in the scores on the first three exams and the percentage the student is shooting for. Your program should then calculate and print out the final exam score needed to achieve that percentage.

6) Print a table of values for F where F = xy-1 and x has values 1, 2, … ,9 and y has values 0.5, 0.75, 1.0, … ,2.5.

7) The numbers 1, 2, 3, 5, 8, 13, 21, 34,… where each number after the second is equal to the sum of the two numbers before it, are are called Fibonacci numbers. Write a program that will print the first 50 Fibonacci numbers. (Some Fibonacci numbers can be quite large …)

8) Write a program that will calculate interest on an initial deposit. Your program should read in the beginning balance and an annual interest rate and print out how much money you would have each year for a run of twenty years.

9) Write a program that reads in three integers i, j, k. Determine if the integers are in ascending order (i <= j <= k) or descending order (i >= j >= k) or in neither order. Print an appropriate message.

10) Write a program to read in the coefficients A, B, C of a quadratic equation

$$Ax^2 + Bx + C = 0$$

and solve it. If the roots are positive or zero, print the values. If the roots are complex, compute the real and imaginary parts as two real numbers and print these with appropriate formatting.

11) Write a program that calculates the approximate square root of a number x by repeating the following formula:

$$\text{Next Guess} = 0.5\ (\text{Last Guess} + x\ /\ \text{Last Guess})$$

Use an initial guess of 1.0. You will know when your approximation is good enough by comparing the Next Guess with the Last Guess. If the difference between them is <0.000001, you stop your iteration: you have calculated the approximate square root.

12) Write a program that will determine the amount of change to return to a customer.Your program should read in the price of the object and the amount of money the customer gives. If the amount tendered equals the price, thank the customer for the exact change. If not, let the customer know if he needs to pay more or if he will get change back. In either case, your program should break down the difference into dollars, half-dollars, quarters, dimes, nickels, and pennies.

13) Write a program that will guess the number the user is thinking of between 1 and 10000. The program should print out a guess which is always the mid-point of the range of numbers remaining. Hence, the first prompt the computer will ask is if the number is equal to, above, or below 5000. The player should press E for equal, A for above, or B for below. The program should read in the response and repeat its prompt with the new guess. For example, if the number was above 5000, the computer would repeat the question with a guess of 7500. The process continues until the computer guesses the number. Once the number is guessed, the computer should ask if the user wants to play again and act appropriately.

14) Write a program which will input a 2D array of integers and summarize the frequency of occurrence of each of the ten digits. For example, the following array:

```
8 0 0
7 5 0
1 2 3
9 0 0
```

would produce the following results:

```
Digit   Occurrences          Digit   Occurrences
  0          5                  5         1
  1          1                  6         0
  2          1                  7         1
  3          0                  8         1
  4           0                 9         1
```

15) Write a program to compute the transpose on a double 2D matrix.

16) Write a program that will input a 3X3 array of integers and determine if it is a "magic square." Magic squares have a special property: the values in **each row**, in **each column**, and in **each diagonal** add up to the **same** number.

17) Write a program that normalizes the float values in a 3D array to values between 0.0 and 1.0.

18) Write a program that inputs a piece of text and analyzes its characters. Your program should:

- **Determine which character has the highest ASCII code**
- **Determine which character has the lowest ASCII code**
- **Determine which character(s) occurred most often in text and how many times they appeared**
- **Count the number of times certain special characters appeared:**
  - **Punctuation symbols**
  - **Upper-case letters**
  - **Lower-case letters**
  - **Vowels (either case)**
  - **Numerical digits**

19) Write a program in which an input string is checked to see if it is a palindrome (reads the same backwards as forwards, i.e., MADAM).

20) Write a program that will input a character string and output the same character string but without any blanks or punctuation symbols.

21) Write a program that will read in a value of x and compute the value of the Gaussian function at that value

$$(1/\sqrt{2\pi})\ e^{-x^2/2}$$

Check out your function in the main program.

22) Write a function *total* that will convert its three arguments representing hours, minutes, and seconds to all seconds. Write a prototype for *total* and use it in a main program.

23) Write a function *range* that receives an integer array with 50 elements and calculates the maximum and minimum values (which should be represented as global variables). Check out the function *range* with sample data in a main program.

24) Write a program in which the total, average, and standard deviation of a float array X with 100 data values are calculated. The total, average, and standard deviation should each be calculated in a separate function.

25) Write a program to print the following pattern on the screen:

```
  *
 ***
*****
 ***
  *
```

26) Write a program to read in the diameter of a circle. Compute the radius, circumference and area of the circle. Print the calculated values in the following format:

```
PROPERTIES OF A CIRCLE WITH DIAMETER XXXX.XXX
      (1) RADIUS = XXXX.XXX
      (2) CIRCUMFERENCE = XXXX.XXX
      (3) AREA = XXXX.XXX
```

27) Write a program that uses loops to produce the following formatted output:

```
2       4       6       8       10
3       6       9       12      15
4       8       12      16      20
5       10      15      20      25
```

28) Using pointers, write a function that will copy the first half of one string into another.

29) Extend the deck of cards program shown in the handouts so that it deals out eight poker hands and ranks them. (You will need to use a random-number function to randomly generate cards from the deck.)

30) Using structures, write a program that will keep track of the electoral votes by state won by a candidate in a presidential election. The structures should contain the state name, number of electoral votes, and what party won the state. The user should be able to find out the following from the program:

- How many total votes a certain party has
- How that total breaks down by state
- How many votes are still needed to win (270 needed to win)

Here are the number of electoral votes for each state: Alabama—9, Alaska—3, Arizona—8, Arkansas—6, California—54, Colorado—8, Connecticut—8, Delaware—3, District of Columbus—3, Florida—25, Georgia—13, Hawaii—4, Idaho—4, Illinois—22, Indiana-12, Iowa—7, Kansas—6, Kentucky—8, Louisiana—9, Maine—4, Maryland—10, Massachusetts—12, Michigan—18, Minnesota—10, Mississippi—7, Missouri—11, Montana—3, Nebraska—5, Nevada—4, New Hampshire—4, New Jersey—15, New Mexico—5, New York—33, North Carolina—14, North Dakota—3, Ohio—21, Oklahoma—8, Oregon—7, Pennsylvania—23, Rhode Island—4, South Carolina—8, South Dakota—3, Tennessee—11, Texas—32, Utah—5, Vermont—3, Virginia—13, Washington—11, West Virginia—5, Wisconsin—11, Wyoming—3

To simulate the election, have the user enter in a state name and what party won it, and check the tallies. Keep providing input until we have a President.

31) Assume that a data file called “points.dat” contains a set of coordinates. The first line of the file contains the number of data coordinates in the file and each of the remaining lines contain the x and y data values of one of the data points. Write a program that will read in the data points and make a new file called “polar.dat” that prints the coordinates in polar form instead of rectangular form. The following are the conversion equations:

$$\mathbf{r = (x^2 + y^2)^{1/2}}$$

$$\boldsymbol{\theta = \mathrm{atan}(y/x)}$$

32) Write an inventory program that uses the goods structure defined in the main handout. Prompt the user to enter the number of items to be stored in the warehouse and then dynamically allocate an array of goods structures that is exactly that size. Initialize the goods array with your own choices.

33) Write a program to accept a number of integer arguments on the command line and print out the max, min, sum, and average of the numbers passed.