CHAPTER 11

Structured Data

TOPICS

11.1 Abstract Data Types

CONCEPT: Abstract data types (ADTs) are data types created by the programmer. ADTs have their own range (or domain) of data and their own sets of operations that may be performed on them.

The term *abstract data type*, or ADT, is very important in computer science and is especially significant in object-oriented programming. This chapter introduces you to the structure, which is one of C++'s mechanisms for creating abstract data types.

Abstraction

An *abstraction* is a general model of something. It is a definition that includes only the general characteristics of an object. For example, the term "dog" is an abstraction. It defines a general type of animal. The term captures the essence of what all dogs are without specifying the detailed characteristics of any particular type of dog. According to *Webster's New Collegiate Dictionary*, a dog is a highly variable carnivorous domesticated mammal (*Canis familiaris*) probably descended from the common wolf.

In real life, however, there is no such thing as a mere "dog." There are specific types of dogs, each with its own set of characteristics. There are poodles, cocker spaniels, Great Danes,

rottweilers, and many other breeds. There are small dogs and large dogs. There are gentle dogs and ferocious dogs. They come in all shapes, sizes, and dispositions. A real-life dog is not abstract. It is concrete.

Data Types

C++ has several *primitive data types*, or data types that are defined as a basic part of the language, as shown in Table 11-1.

Table 11-1

`bool`	`int`	`unsigned long int`
`char`	`long int`	`float`
`unsigned char`	`unsigned short int`	`double`
`short int`	`unsigned int`	`long double`

A data type defines what values a variable may hold. Each data type listed in Table 11-1 has its own range of values, such as –32,768 to +32,767 for `shorts`, and so forth. Data types also define what values a variable may not hold. For example, integer variables may not be used to hold fractional numbers.

In addition to defining a range or domain of values that a variable may hold, data types also define the operations that may be performed on a value. All of the data types listed in Table 11-1 allow the following mathematical and relational operators to be used with them:

```
+   -   *   /   >   <   >=   <=   ==   !=
```

Only the integer data types, however, allow operations with the modulus operator (%). So, a data type defines what values an object may hold and the operations that may be performed on the object.

The primitive data types are abstract in the sense that a data type and an object of that data type are not the same thing. For example, consider the following variable definition:

```
int x = 1, y = 2, z = 3;
```

In the statement above the integer variables `x`, `y`, and `z` are defined. They are three separate instances of the data type `int`. Each variable has its own characteristics (`x` is set to 1, `y` is set to 2, and `z` is set to 3). In this example, the data type `int` is the abstraction, and the variables `x`, `y`, and `z` are concrete occurrences.

Abstract Data Types

An abstract data type (ADT) is a data type created by the programmer and is composed of one or more primitive data types. The programmer decides what values are acceptable for the data type, as well as what operations may be performed on the data type. In many cases, the programmer designs his or her own specialized operations.

For example, suppose a program is created to simulate a 12-hour clock. The program could contain three ADTs: `Hours`, `Minutes`, and `Seconds`. The range of values for the `Hours` data type would be the integers 1 through 12. The range of values for the `Minutes` and `Seconds` data types would be 0 through 59. If an `Hours` object is set to 12 and then incremented, it will then take on the value 1. Likewise if a `Minutes` object or a `Seconds` object is set to 59 and then incremented, it will take on the value 0.

Abstract data types often combine several values. In the clock program, the `Hours`, `Minutes`, and `Seconds` objects could be combined to form a single `Clock` object. In this chapter you will learn how to combine variables of primitive data types to form your own data structures, or ADTs.

11.2 Focus on Software Engineering: Combining Data into Structures

CONCEPT: **C++ allows you to group several variables together into a single item known as a structure.**

So far you've written programs that keep data in individual variables. If you need to group items together, C++ allows you to create arrays. The limitation of arrays, however, is that all the elements must be of the same data type. Sometimes a relationship exists between items of different types. For example, a payroll system might keep the variables shown in Table 11-2. These variables hold data for a single employee.

Table 11-2

Variable Definition	Data Held
`int empNumber;`	Employee number
`string name;`	Employee's name
`double hours;`	Hours worked
`double payRate;`	Hourly pay rate
`double grossPay;`	Gross pay

VideoNote **Creating a Structure**

All of the variables listed in Table 11-2 are related because they can hold data about the same employee. Their definition statements, though, do not make it clear that they belong together. To create a relationship between variables, C++ gives you the ability to package them together into a *structure*.

Before a structure can be used, it must be declared. Here is the general format of a structure declaration:

```
struct tag
{
   variable declaration;
   // ... more declarations
   //     may follow...
};
```

The *tag* is the name of the structure. As you will see later, it's used like a data type name. The variable declarations that appear inside the braces declare *members* of the structure. Here is an example of a structure declaration that holds the payroll data listed in Table 11-2:

```
struct PayRoll
{
   int empNumber;     // Employee number
   string name;       // Employee's name
   double hours;      // Hours worked
   double payRate;    // Hourly pay rate
   double grossPay;   // Gross pay
};
```

This declaration declares a structure named `PayRoll`. The structure has five members: `empNumber`, `name`, `hours`, `payRate`, and `grossPay`.

WARNING! Notice that a semicolon is required after the closing brace of the structure declaration.

NOTE: In this text we begin the names of structure tags with an uppercase letter. Later you will see the same convention used with unions. This visually differentiates these names from the names of variables.

NOTE: The structure declaration shown contains three `double` members, each declared on a separate line. The three could also have been declared on the same line, as

```
struct PayRoll
{
   int empNumber;
   string name;
   double hours, payRate, grossPay;
};
```

Many programmers prefer to place each member declaration on a separate line, however, for increased readability.

It's important to note that the structure declaration in our example does not define a variable. It simply tells the compiler what a `PayRoll` structure is made of. In essence, it creates a new data type named `PayRoll`. You can define variables of this type with simple definition statements, just as you would with any other data type. For example, the following statement defines a variable named `deptHead`:

```
PayRoll deptHead;
```

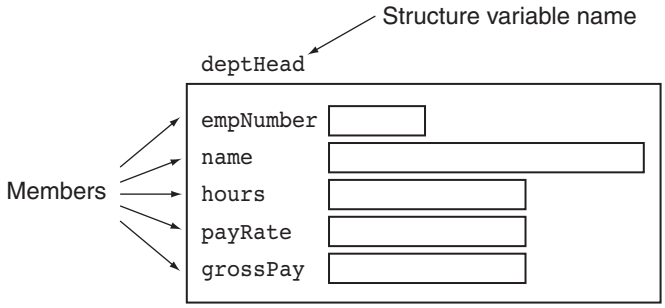
The data type of `deptHead` is the `PayRoll` structure. The structure tag, `PayRoll`, is listed before the variable name just as the word `int` or `double` would be listed to define variables of those types.

Remember that structure variables are actually made up of other variables known as members. Because `deptHead` is a `PayRoll` structure it contains the following members:

`empNumber`, an int
`name`, a `string` object
`hours`, a `double`
`payRate`, a `double`
`grossPay`, a `double`

Figure 11-1 illustrates this.

Figure 11-1

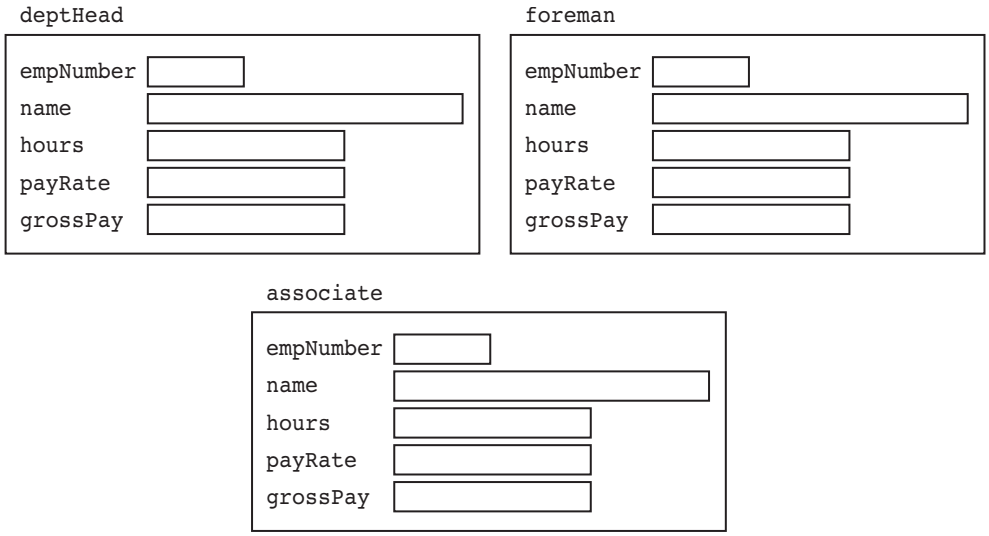


Just as it's possible to define multiple `int` or `double` variables, it's possible to define multiple structure variables in a program. The following statement defines three `PayRoll` variables: `deptHead`, `foreman`, and `associate`:

```
PayRoll deptHead, foreman, associate;
```

Figure 11-2 illustrates the existence of these three variables.

Figure 11-2



Each of the variables defined in this example is a separate *instance* of the `PayRoll` structure and contains its own members. An instance of a structure is a variable that exists in memory. It contains within it all the members described in the structure declaration.

Although the structure variables in the example are separate, each contains members with the same name. (In the next section you'll see how to access these members.) Here are some other examples of structure declarations and variable definitions:

```
struct Time
{
     int hour;
     int minutes;
     int seconds;
};

// Definition of the
// structure variable now.
Time now;
```

```
struct Date
{
    int day;
    int month;
    int year;
};

// Definition of the structure
// variable today.
Date today;
```

In review, there are typically two steps to implementing structures in a program:

- Create the structure declaration. This establishes the tag (or name) of the structure and a list of items that are members.
- Define variables (or instances) of the structure and use them in the program to hold data.

11.3 Accessing Structure Members

CONCEPT: The *dot operator* (.) allows you to access structure members in a program.

C++ provides the dot operator (a period) to access the individual members of a structure. Using our example of `deptHead` as a `PayRoll` structure variable, the following statement demonstrates how to access the `empNumber` member:

```
deptHead.empNumber = 475;
```

In this statement, the number 475 is assigned to the `empNumber` member of `deptHead`. The dot operator connects the name of the member variable with the name of the structure variable it belongs to. The following statements assign values to the `empNumber` members of the `deptHead`, `foreman`, and `associate` structure variables:

```
deptHead.empNumber = 475;
foreman.empNumber = 897;
associate.empNumber = 729;
```

With the dot operator you can use member variables just like regular variables. For example these statements display the contents of `deptHead`'s members:

```
cout << deptHead.empNumber << endl;
cout << deptHead.name << endl;
cout << deptHead.hours << endl;
cout << deptHead.payRate << endl;
cout << deptHead.grossPay << endl;
```

Program 11-1 is a complete program that uses the `PayRoll` structure.

Program 11-1

```
// This program demonstrates the use of structures.
#include <iostream>
#include <string>
#include <iomanip>
using namespace std;

struct PayRoll
{
   int empNumber;    // Employee number
   string name;      // Employee's name
   double hours;     // Hours worked
   double payRate;   // Hourly payRate
   double grossPay;  // Gross pay
};

int main()
{
    PayRoll employee; // employee is a PayRoll structure.

    // Get the employee's number.
    cout << "Enter the employee's number: ";
    cin >> employee.empNumber;

    // Get the employee's name.
    cout << "Enter the employee's name: ";
    cin.ignore();   // To skip the remaining '\n' character
    getline(cin, employee.name);

    // Get the hours worked by the employee.
    cout << "How many hours did the employee work? ";
    cin >> employee.hours;

    // Get the employee's hourly pay rate.
    cout << "What is the employee's hourly payRate? ";
    cin >> employee.payRate;

    // Calculate the employee's gross pay.
    employee.grossPay = employee.hours * employee.payRate;

    // Display the employee data.
    cout << "Here is the employee's payroll data:\n";
    cout << "Name: " << employee.name << endl;
    cout << "Number: " << employee.empNumber << endl;
    cout << "Hours worked: " << employee.hours << endl;
    cout << "Hourly payRate: " << employee.payRate << endl;
    cout << fixed << showpoint << setprecision(2);
    cout << "Gross Pay: $" << employee.grossPay << endl;
   return 0;
}
```

(program output continues)

Program 11-1 *(continued)*

Program Output with Example Input Shown in Bold

```
Enter the employee's number: 489 [Enter]
Enter the employee's name: Jill Smith [Enter]
How many hours did the employee work? 40 [Enter]
What is the employee's hourly pay rate? 20 [Enter]
Here is the employee's payroll data:
Name: Jill Smith
Number: 489
Hours worked: 40
Hourly pay rate: 20
Gross pay: $800.00
```

NOTE: Program 11-1 has the following call, in line 26, to `cin`'s ignore member function:

```
cin.ignore();
```

Recall that the `ignore` function causes `cin` to ignore the next character in the input buffer. This is necessary for the `getline` function to work properly in the program.

NOTE: The contents of a structure variable cannot be displayed by passing the entire variable to `cout`. For example, assuming `employee` is a `PayRoll` structure variable, the following statement will not work:

```
cout << employee << endl;  // Will not work!
```

Instead, each member must be separately passed to cout.

As you can see from Program 11-1, structure members that are of a primitive data type can be used with `cin`, `cout`, mathematical statements, and any operation that can be performed with regular variables. The only difference is that the structure variable name and the dot operator must precede the name of a member. Program 11-2 shows the member of a structure variable being passed to the `pow` function.

Program 11-2

```
1  // This program stores data about a circle in a structure.
2  #include <iostream>
3  #include <cmath> // For the pow function
4  #include <iomanip>
5  using namespace std;
6
7  // Constant for pi.
8  const double PI = 3.14159;
```

```
 9
10  // Structure declaration
11  struct Circle
12  {
13      double radius;     // A circle's radius
14      double diameter;   // A circle's diameter
15      double area;       // A circle's area
16  };
17
18  int main()
19  {
20      Circle c;     // Define a structure variable
21
22      // Get the circle's diameter.
23      cout << "Enter the diameter of a circle: ";
24      cin >> c.diameter;
25
26      // Calculate the circle's radius.
27      c.radius = c.diameter / 2;
28
29      // Calculate the circle's area.
30      c.area = PI * pow(c.radius, 2.0);
31
32      // Display the circle data.
33      cout << fixed << showpoint << setprecision(2);
34      cout << "The radius and area of the circle are:\n";
35      cout << "Radius: " << c.radius << endl;
36      cout << "Area: " << c.area << endl;
37      return 0;
38  }
```

Program Output with Example Input Shown in Bold

```
Enter the diameter of a circle: 10 [Enter]
The radius and area of the circle are:
Radius: 5
Area: 78.54
```

Comparing Structure Variables

You cannot perform comparison operations directly on structure variables. For example, assume that `circle1` and `circle2` are `Circle` structure variables. The following statement will cause an error.

```
if (circle1 == circle2)  // Error!
```

In order to compare two structures, you must compare the individual members, as shown in the following code.

```
if (circle1.radius == circle2.radius &&
    circle1.diameter == circle2.diameter &&
    circle1.area == circle2.area)
```

11.4 Initializing a Structure

CONCEPT: The members of a structure variable may be initialized with starting values when the structure variable is defined.

A structure variable may be initialized when it is defined, in a fashion similar to the initialization of an array. Assume the following structure declaration exists in a program:

```
struct CityInfo
{
   string cityName;
   string state;
   long population;
   int distance;
};
```

A variable may then be defined with an initialization list, as shown in the following:

```
CityInfo location = {"Asheville", "NC", 50000, 28};
```

This statement defines the variable `location`. The first value in the initialization list is assigned to the first declared member, the second value in the initialization list is assigned to the second member, and so on. The `location` variable is initialized in the following manner:

The string "Asheville" is assigned to `location.cityName`
The string "NC" is assigned to `location.state`
50000 is assigned to `location.population`
28 is assigned to `location.distance`

You do not have to provide initializers for all the members of a structure variable. For example, the following statement only initializes the `cityName` member of `location`:

```
CityInfo location = {"Tampa"};
```

The `state`, `population`, and `distance` members are left uninitialized. The following statement only initializes the `cityName` and `state` members, while leaving `population` and `distance` uninitialized:

```
CityInfo location = {"Atlanta", "GA"};
```

If you leave a structure member uninitialized, you must leave all the members that follow it uninitialized as well. C++ does not provide a way to skip members in a structure. For example, the following statement, which attempts to skip the initialization of the `population` member, is *not* legal:

```
CityInfo location = {"Knoxville", "TN", , 90};  // Illegal!
```

Program 11-3 demonstrates the use of partially initialized structure variables.

Program 11-3

```
1  // This program demonstrates partially initialized
2  // structure variables.
3  #include <iostream>
```

```
#include <string>
#include <iomanip>
using namespace std;

struct EmployeePay
{
    string name;         // Employee name
    int empNum;          // Employee number
    double payRate;      // Hourly pay rate
    double hours;        // Hours worked
    double grossPay;     // Gross pay
};

int main()
{
    EmployeePay employee1 = {"Betty Ross", 141, 18.75};
    EmployeePay employee2 = {"Jill Sandburg", 142, 17.50};

    cout << fixed << showpoint << setprecision(2);

    // Calculate pay for employee1
    cout << "Name: " << employee1.name << endl;
    cout << "Employee Number: " << employee1.empNum << endl;
    cout << "Enter the hours worked by this employee: ";
    cin >> employee1.hours;
    employee1.grossPay = employee1.hours * employee1.payRate;
    cout << "Gross Pay: " << employee1.grossPay << endl << endl;

    // Calculate pay for employee2
    cout << "Name: " << employee2.name << endl;
    cout << "Employee Number: " << employee2.empNum << endl;
    cout << "Enter the hours worked by this employee: ";
    cin >> employee2.hours;
    employee2.grossPay = employee2.hours * employee2.payRate;
    cout << "Gross Pay: " << employee2.grossPay << endl;
    return 0;
}
```

Program Output with Example Input Shown in Bold

```
Name: Betty Ross
Employee Number: 141
Enter the hours worked by this employee: 40 [Enter]
Gross Pay: 750.00

Name: Jill Sandburg
Employee Number: 142
Enter the hours worked by this employee: 20 [Enter]
Gross Pay: 350.00
```

It's important to note that you cannot initialize a structure member in the declaration of the structure. For instance, the following declaration is illegal:

```
// Illegal structure declaration
struct CityInfo
```

```
{
   string cityName = "Asheville";   // Error!
   string state = "NC";             // Error!
   long population = 50000;         // Error!
   int distance = 28;               // Error!
};
```

Remember that a structure declaration doesn't actually create the member variables. It only declares what the structure "looks like." The member variables are created in memory when a structure variable is defined. Because no variables are created by the structure declaration, there's nothing that can be initialized there.

Checkpoint

11.1 Write a structure declaration to hold the following data about a savings account:

Account Number (`string` object)
Account Balance (`double`)
Interest Rate (`double`)
Average Monthly Balance (`double`)

11.2 Write a definition statement for a variable of the structure you declared in Question 11.1. Initialize the members with the following data:

Account Number: ACZ42137-B12-7
Account Balance: $4512.59
Interest Rate: 4%
Average Monthly Balance: $4217.07

11.3 The following program skeleton, when complete, asks the user to enter these data about his or her favorite movie:

Name of movie
Name of the movie's director
Name of the movie's producer
The year the movie was released

Complete the program by declaring the structure that holds this data, defining a structure variable, and writing the individual statements necessary.

```
#include <iostream>
using namespace std;

// Write the structure declaration here to hold the movie data.

int main()
{
   // define the structure variable here.

   cout << "Enter the following data about your\n";
   cout << "favorite movie.\n";
   cout << "name: ";
   // Write a statement here that lets the user enter the
   // name of a favorite movie. Store the name in the
   // structure variable.
   cout << "Director: ";
   // Write a statement here that lets the user enter the
   // name of the movie's director. Store the name in the
   // structure variable.
```

```
        cout << "Producer: ";
        // Write a statement here that lets the user enter the
        // name of the movie's producer. Store the name in the
        // structure variable.
        cout << "Year of release: ";
        // Write a statement here that lets the user enter the
        // year the movie was released. Store the year in the
        // structure variable.
        cout << "Here is data on your favorite movie:\n";
        // Write statements here that display the data.
        // just entered into the structure variable.
        return 0;
    }
```

11.5 Arrays of Structures

CONCEPT: Arrays of structures can simplify some programming tasks.

In Chapter 7 you saw that data can be stored in two or more arrays, with a relationship established between the arrays through their subscripts. Because structures can hold several items of varying data types, a single array of structures can be used in place of several arrays of regular variables.

An array of structures is defined like any other array. Assume the following structure declaration exists in a program:

```
struct BookInfo
{
   string title;
   string author;
   string publisher;
   double price;
};
```

The following statement defines an array, `bookList`, that has 20 elements. Each element is a `BookInfo` structure.

```
BookInfo bookList[20];
```

Each element of the array may be accessed through a subscript. For example, `bookList[0]` is the first structure in the array, `bookList[1]` is the second, and so forth. To access a member of any element, simply place the dot operator and member name after the subscript. For example, the following expression refers to the `title` member of `bookList[5]`:

```
bookList[5].title
```

The following loop steps through the array, displaying the data stored in each element:

```
for (int index = 0; index < 20; index++)
{
   cout << bookList[index].title << endl;
   cout << bookList[index].author << endl;
   cout << bookList[index].publisher << endl;
   cout << bookList[index].price << endl << endl;
}
```

Program 11-4 calculates and displays payroll data for three employees. It uses a single array of structures.

Program 11-4

```
// This program uses an array of structures.
#include <iostream>
#include <iomanip>
using namespace std;

struct PayInfo
{
    int hours;       // Hours worked
    double payRate;  // Hourly pay rate
};

int main()
{
    const int NUM_WORKERS = 3;    // Number of workers
    PayInfo workers[NUM_WORKERS]; // Array of structures
    int index;                    // Loop counter

    // Get employee pay data.
    cout << "Enter the hours worked by " << NUM_WORKERS
         << " employees and their hourly rates.\n";

    for (index = 0; index < NUM_WORKERS; index++)
    {
        // Get the hours worked by an employee.
        cout << "Hours worked by employee #" << (index + 1);
        cout << ": ";
        cin >> workers[index].hours;

        // Get the employee's hourly pay rate.
        cout << "Hourly pay rate for employee #";
        cout << (index + 1) << ": ";
        cin >> workers[index].payRate;
        cout << endl;
    }

    // Display each employee's gross pay.
    cout << "Here is the gross pay for each employee:\n";
    cout << fixed << showpoint << setprecision(2);
    for (index = 0; index < NUM_WORKERS; index++)
    {
        double gross;
        gross = workers[index].hours * workers[index].payRate;
        cout << "Employee #" << (index + 1);
        cout << ": $" << gross << endl;
    }
    return 0;
}
```

Program Output with Example Input Shown in Bold

```
Enter the hours worked by 3 employees and their hourly rates.
Hours worked by employee #1: 10 [Enter]
Hourly pay rate for employee #1: 9.75 [Enter]

Hours worked by employee #2: 20 [Enter]
Hourly pay rate for employee #2: 10.00 [Enter]

Hours worked by employee #3: 40 [Enter]
Hourly pay rate for employee #3: 20.00 [Enter]

Here is the gross pay for each employee:
Employee #1: $97.50
Employee #2: $200.00
Employee #3: $800.00
```

Initializing a Structure Array

To initialize a structure array, simply provide an initialization list for one or more of the elements. For example, the array in Program 11-4 could have been initialized as follows:

```
PayInfo workers[NUM_WORKERS] = {
                                  {10, 9.75 },
                                  {15, 8.62 },
                                  {20, 10.50},
                                  {40, 18.75},
                                  {40, 15.65}
                               };
```

As in all single-dimensional arrays, you can initialize all or part of the elements in an array of structures, as long as you do not skip elements.

11.6 Focus on Software Engineering: Nested Structures

CONCEPT: **It's possible for a structure variable to be a member of another structure variable.**

Sometimes it's helpful to nest structures inside other structures. For example, consider the following structure declarations:

```
struct Costs
{
   double wholesale;
   double retail;
};

struct Item
{
   string partNum;
   string description;
   Costs pricing;
};
```

The `Costs` structure has two members: `wholesale` and `retail`, both `doubles`. Notice that the third member of the `Item` structure, `pricing`, is a `Costs` structure. Assume the variable `widget` is defined as follows:

```
Item widget;
```

The following statements show examples of accessing members of the `pricing` variable, which is inside `widget`:

```
widget.pricing.wholesale = 100.0;
widget.pricing.retail = 150.0;
```

Program 11-5 gives a more elaborate illustration of nested structures.

Program 11-5

```
1  // This program uses nested structures.
2  #include <iostream>
3  #include <string>
4  using namespace std;
5
6  // The Date structure holds data about a date.
7  struct Date
8  {
9       int month;
10      int day;
11      int year;
12 };
13
14 // The Place structure holds a physical address.
15 struct Place
16 {
17      string address;
18      string city;
19      string state;
20      string zip;
21 };
22
23 // The EmployeeInfo structure holds an employee's data.
24 struct EmployeeInfo
25 {
26      string name;
27      int employeeNumber;
28      Date birthDate;              // Nested structure
29      Place residence;             // Nested structure
30 };
31
32 int main()
33 {
34      // Define a structure variable to hold info about the manager.
35      EmployeeInfo manager;
36
```

```
37      // Get the manager's name and employee number
38      cout << "Enter the manager's name: ";
39      getline(cin, manager.name);
40      cout << "Enter the manager's employee number: ";
41      cin >> manager.employeeNumber;
42
43      // Get the manager's birth date
44      cout << "Now enter the manager's date of birth.\n";
45      cout << "Month (up to 2 digits): ";
46      cin >> manager.birthDate.month;
47      cout << "Day (up to 2 digits): ";
48      cin >> manager.birthDate.day;
49      cout << "Year: ";
50      cin >> manager.birthDate.year;
51      cin.ignore();  // Skip the remaining newline character
52
53      // Get the manager's residence information
54      cout << "Enter the manager's street address: ";
55      getline(cin, manager.residence.address);
56      cout << "City: ";
57      getline(cin, manager.residence.city);
58      cout << "State: ";
59      getline(cin, manager.residence.state);
60      cout << "ZIP Code: ";
61      getline(cin, manager.residence.zip);
62
63      // Display the information just entered
64      cout << "\nHere is the manager's information:\n";
65      cout << manager.name << endl;
66      cout << "Employee number " << manager.employeeNumber << endl;
67      cout << "Date of birth: ";
68      cout << manager.birthDate.month << "-";
69      cout << manager.birthDate.day << "-";
70      cout << manager.birthDate.year << endl;
71      cout << "Place of residence:\n";
72      cout << manager.residence.address << endl;
73      cout << manager.residence.city << ", ";
74      cout << manager.residence.state << " ";
75      cout << manager.residence.zip << endl;
76      return 0;
77  }
```

Program Output with Example Input Shown in Bold

```
Enter the manager's name: John Smith [Enter]
Enter the manager's employee number: 789 [Enter]
Now enter the manager's date of birth.
Month (up to 2 digits): 10 [Enter]
Day (up to 2 digits): 14 [Enter]
Year: 1970 [Enter]
Enter the manager's street address: 190 Disk Drive [Enter]
City: Redmond [Enter]
```

(program output continues)

Program 11-5 *(continued)*

```
State: WA [Enter]
ZIP Code: 98052 [Enter]
Here is the manager's information:
John Smith
Employee number 789
Date of birth: 10-14-1970
Place of residence:
190 Disk Drive
Redmond, WA 98052
```

Checkpoint

For Questions 11.4–11.7 below, assume the `Product` structure is declared as follows:

```
struct Product
{
     string description;   // Product description
     int partNum;          // Part number
     double cost;          // Product cost
};
```

11.4 Write a definition for an array of 100 `Product` structures. Do not initialize the array.

11.5 Write a loop that will step through the entire array you defined in Question 11.4, setting all the product descriptions to an empty string, all part numbers to zero, and all costs to zero.

11.6 Write the statements that will store the following data in the first element of the array you defined in Question 11.4:

Description: Claw hammer
Part Number: 547
Part Cost: $8.29

11.7 Write a loop that will display the contents of the entire array you created in Question 11.4.

11.8 Write a structure declaration named `Measurement`, with the following members:

`miles`, an integer
`meters`, a `long` integer

11.9 Write a structure declaration named `Destination`, with the following members:

`city`, a `string` object
`distance`, a `Measurement` structure (declared in Question 11.8)

Also define a variable of this structure type.

11.10 Write statements that store the following data in the variable you defined in Question 11.9:

City: Tupelo
Miles: 375
Meters: 603,375

11.7 Structures as Function Arguments

CONCEPT: **Structure variables may be passed as arguments to functions.**

VideoNote
Passing a Structure to a Function

Like other variables, the individual members of a structure variable may be used as function arguments. For example, assume the following structure declaration exists in a program:

```
struct Rectangle
{
   double length;
   double width;
   double area;
};
```

Let's say the following function definition exists in the same program:

```
double multiply(double x, double y)
{
   return x * y;
}
```

Assuming that `box` is a variable of the `Rectangle` structure type, the following function call will pass `box.length` into `x` and `box.width` into `y`. The return value will be stored in `box.area`.

```
box.area = multiply(box.length, box.width);
```

Sometimes it's more convenient to pass an entire structure variable into a function instead of individual members. For example, the following function definition uses a `Rectangle` structure variable as its parameter:

```
void showRect(Rectangle r)
{
   cout << r.length << endl;
   cout << r.width << endl;
   cout << r.area << endl;
}
```

The following function call passes the `box` variable into `r`:

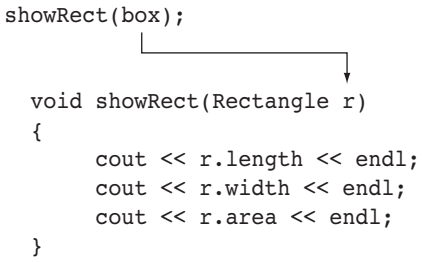
```
showRect(box);
```

Inside the function `showRect`, `r`'s members contain a copy of `box`'s members. This is illustrated in Figure 11-3.

Once the function is called, `r.length` contains a copy of `box.length`, `r.width` contains a copy of `box.width`, and `r.area` contains a copy of `box.area`.

Structures, like all variables, are normally passed by value into a function. If a function is to access the members of the original argument, a reference variable may be used as the parameter. Program 11-6 uses two functions that accept structures as arguments. Arguments are passed to the `getItem` function by reference and to the `showItem` function by value.

Figure 11-3



Program 11-6

```
1  // This program has functions that accept structure variables
2  // as arguments.
3  #include <iostream>
4  #include <string>
5  #include <iomanip>
6  using namespace std;
7
8  struct InventoryItem
9  {
10     int partNum;                 // Part number
11     string description;          // Item description
12     int onHand;                  // Units on hand
13     double price;                // Unit price
14 };
15
16 // Function Prototypes
17 void getItem(InventoryItem&);    // Argument passed by reference
18 void showItem(InventoryItem);    // Argument passed by value
19
20 int main()
21 {
22     InventoryItem part;
23
24     getItem(part);
25     showItem(part);
26     return 0;
27 }
28
29 //************************************************************
30 // Definition of function getItem. This function uses       *
31 // a structure reference variable as its parameter. It asks *
32 // the user for information to store in the structure.      *
33 //************************************************************
34
```

```
35  void getItem(InventoryItem &p)  // Uses a reference parameter
36  {
37       // Get the part number.
38       cout << "Enter the part number: ";
39       cin >> p.partNum;
40
41       // Get the part description.
42       cout << "Enter the part description: ";
43       cin.ignore();  // Ignore the remaining newline character
44       getline(cin, p.description);
45
46       // Get the quantity on hand.
47       cout << "Enter the quantity on hand: ";
48       cin >> p.onHand;
49
50       // Get the unit price.
51       cout << "Enter the unit price: ";
52       cin >> p.price;
53  }
54
55  //*********************************************************
56  // Definition of function showItem. This function accepts  *
57  // an argument of the InventoryItem structure type. The    *
58  // contents of the structure is displayed.                 *
59  //*********************************************************
60
61  void showItem(InventoryItem p)
62  {
63       cout << fixed << showpoint << setprecision(2);
64       cout << "Part Number: " << p.partNum << endl;
65       cout << "Description: " << p.description << endl;
66       cout << "Units On Hand: " << p.onHand << endl;
67       cout << "Price: $" << p.price << endl;
68  }
```

Program Output with Example Input Shown in Bold

```
Enter the part number: 800 [Enter]
Enter the part description: Screwdriver [Enter]
Enter the quantity on hand: 135 [Enter]
Enter the unit price: 1.25 [Enter]
Part Number: 800
Description: Screwdriver
Units on Hand: 135
Price: $1.25
```

Notice that the `InventoryItem` structure declaration in Program 11-6 appears before both the prototypes and the definitions of the `getItem` and `showItem` functions. This is because both functions use an `InventoryItem` structure variable as their parameter. The compiler must know what `InventoryItem` is before it encounters any definitions for variables of that type. Otherwise, an error will occur.

Constant Reference Parameters

Sometimes structures can be quite large. Passing large structures by value can decrease a program's performance because a copy of the structure has to be created. When a structure is passed by reference, however, it isn't copied. A reference that points to the original argument is passed instead. So, it's often preferable to pass large objects such as structures by reference.

Of course, the disadvantage of passing an object by reference is that the function has access to the original argument. It can potentially alter the argument's value. This can be prevented, however, by passing the argument as a constant reference. The `showItem` function from Program 11-6 is shown here, modified to use a constant reference parameter.

```
void showItem(const InventoryItem &p)
{
   cout << fixed << showpoint << setprecision(2);
   cout << "Part Number: " << p.partNum << endl;
   cout << "Description: " << p.description << endl;
   cout << "Units on Hand: " << p.onHand << endl;
   cout << "Price: $" << p.price << endl;
}
```

This version of the function is more efficient than the original version because the amount of time and memory consumed in the function call is reduced. Because the parameter is defined as a constant, the function cannot accidentally corrupt the value of the argument.

The prototype for this version of the function follows.

```
void showItem(const InventoryItem&);
```

11.8 Returning a Structure from a Function

CONCEPT: **A function may return a structure.**

Just as functions can be written to return an `int`, `long`, `double`, or other data type, they can also be designed to return a structure. Recall the following structure declaration from Program 11-2:

```
struct Circle
{
   double radius;
   double diameter;
   double area;
};
```

A function, such as the following, could be written to return a variable of the `Circle` data type:

```
Circle getCircleData()
{
   Circle temp;           // Temporary Circle structure

   temp.radius = 10.0;    // Store the radius
   temp.diameter = 20.0;  // Store the diameter
```

```
    temp.area = 314.159;    // Store the area
    return temp;            // Return the temporary structure
}
```

Notice that the `getCircleData` function has a return data type of `Circle`. That means the function returns an entire `Circle` structure when it terminates. The return value can be assigned to any variable that is a `Circle` structure. The following statement, for example, assigns the function's return value to the `Circle` structure variable named `myCircle`:

```
myCircle = getCircleData();
```

After this statement executes, `myCircle.radius` will be set to 10.0, `myCircle.diameter` will be set to 20.0, and `myCircle.area` will be set to 314.159.

When a function returns a structure, it is always necessary for the function to have a local structure variable to hold the member values that are to be returned. In the `getCircleData` function, the values for `diameter`, `radius`, and `area` are stored in the local variable `temp`. The `temp` variable is then returned from the function.

Program 11-7 is a modification of Program 11-2. The function `getInfo` gets the circle's diameter from the user and calculates the circle's radius. The diameter and radius are stored in a local structure variable, `round`, which is returned from the function.

Program 11-7

```
1  // This program uses a function to return a structure. This
2  // is a modification of Program 11-2.
3  #include <iostream>
4  #include <iomanip>
5  #include <cmath>  // For the pow function
6  using namespace std;
7
8  // Constant for pi.
9  const double PI = 3.14159;
10
11 // Structure declaration
12 struct Circle
13 {
14     double radius;      // A circle's radius
15     double diameter;    // A circle's diameter
16     double area;        // A circle's area
17 };
18
19 // Function prototype
20 Circle getInfo();
21
22 int main()
23 {
24     Circle c;         // Define a structure variable
25
26     // Get data about the circle.
27     c = getInfo();
```

(program continues)

Program 11-7 *(continued)*

```
28
29      // Calculate the circle's area.
30      c.area = PI * pow(c.radius, 2.0);
31
32      // Display the circle data.
33      cout << "The radius and area of the circle are:\n";
34      cout << fixed << setprecision(2);
35      cout << "Radius: " << c.radius << endl;
36      cout << "Area: " << c.area << endl;
37      return 0;
38  }
39
40  //*************************************************************
41  // Definition of function getInfo. This function uses a local   *
42  // variable, tempCircle, which is a circle structure. The user   *
43  // enters the diameter of the circle, which is stored in         *
44  // tempCircle.diameter. The function then calculates the radius *
45  // which is stored in tempCircle.radius. tempCircle is then      *
46  // returned from the function.                                   *
47  //*************************************************************
48
49  Circle getInfo()
50  {
51      Circle tempCircle;  // Temporary structure variable
52
53      // Store circle data in the temporary variable.
54      cout << "Enter the diameter of a circle: ";
55      cin >> tempCircle.diameter;
56      tempCircle.radius = tempCircle.diameter / 2.0;
57
58      // Return the temporary variable.
59      return tempCircle;
60  }
```

Program Output with Example Input Shown in Bold

```
Enter the diameter of a circle: 10 [Enter]
The radius and area of the circle are:
Radius: 5.00
Area: 78.54
```

NOTE: In Chapter 6 you learned that C++ only allows you to return a single value from a function. Structures, however, provide a way around this limitation. Even though a structure may have several members, it is technically a single value. By packaging multiple values inside a structure, you can return as many variables as you need from a function.

11.9 Pointers to Structures

CONCEPT: **You may take the address of a structure variable and create variables that are pointers to structures.**

Defining a variable that is a pointer to a structure is as simple as defining any other pointer variable: The data type is followed by an asterisk and the name of the pointer variable. Here is an example:

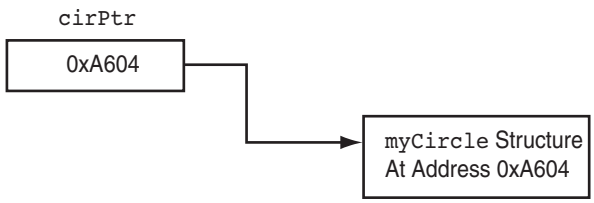
```
Circle *cirPtr = nullptr;
```

This statement defines `cirPtr` as a pointer to a `Circle` structure. Look at the following code:

```
Circle myCircle = { 10.0, 20.0, 314.159 };
Circle *cirPtr = nullptr;
cirPtr = &myCircle;
```

The first two lines define `myCircle`, a structure variable, and `cirPtr`, a pointer. The third line assigns the address of `myCircle` to `cirPtr`. After this line executes, `cirPtr` will point to the `myCircle` structure. This is illustrated in Figure 11-4.

Figure 11-4



Indirectly accessing the members of a structure through a pointer can be clumsy, however, if the indirection operator is used. One might think the following statement would access the `radius` member of the structure pointed to by `cirPtr`, but it doesn't:

```
*cirPtr.radius = 10;
```

The dot operator has higher precedence than the indirection operator, so the indirection operator tries to dereference `cirPtr.radius`, not `cirPtr`. To dereference the `cirPtr` pointer, a set of parentheses must be used.

```
(*cirPtr).radius = 10;
```

Because of the awkwardness of this notation, C++ has a special operator for dereferencing structure pointers. It's called the *structure pointer operator*, and it consists of a hyphen (-) followed by the greater-than symbol (>). The previous statement, rewritten with the structure pointer operator, looks like this:

```
cirPtr->radius = 10;
```

The structure pointer operator takes the place of the dot operator in statements using pointers to structures. The operator automatically dereferences the structure pointer on its left. There is no need to enclose the pointer name in parentheses.

NOTE: The structure pointer operator is supposed to look like an arrow, thus visually indicating that a "pointer" is being used.

Program 11-8 shows that a pointer to a structure may be used as a function parameter, allowing the function to access the members of the original structure argument.

Program 11-8

```
// This program demonstrates a function that uses a
// pointer to a structure variable as a parameter.
#include <iostream>
#include <string>
#include <iomanip>
using namespace std;

struct Student
{
     string name;          // Student's name
     int idNum;            // Student ID number
     int creditHours;      // Credit hours enrolled
     double gpa;           // Current GPA
};

void getData(Student *);  // Function prototype

int main()
{
     Student freshman;

     // Get the student data.
     cout << "Enter the following student data:\n";
     getData(&freshman);     // Pass the address of freshman.
     cout << "\nHere is the student data you entered:\n";

     // Now display the data stored in freshman
     cout << setprecision(3);
     cout << "Name: " << freshman.name << endl;
     cout << "ID Number: " << freshman.idNum << endl;
     cout << "Credit Hours: " << freshman.creditHours << endl;
     cout << "GPA: " << freshman.gpa << endl;
     return 0;
}

```

```
36  //*****************************************************
37  // Definition of function getData. Uses a pointer to a *
38  // Student structure variable. The user enters student *
39  // information, which is stored in the variable.       *
40  //*****************************************************
41
42  void getData(Student *s)
43  {
44       // Get the student name.
45       cout << "Student name: ";
46       getline(cin, s->name);
47
48       // Get the student ID number.
49       cout << "Student ID Number: ";
50       cin >> s->idNum;
51
52       // Get the credit hours enrolled.
53       cout << "Credit Hours Enrolled: ";
54       cin >> s->creditHours;
55
56       // Get the GPA.
57       cout << "Current GPA: ";
58       cin >> s->gpa;
59  }
```

Program Output with Example Input Shown in Bold

```
Enter the following student data:
Student Name: Frank Smith [Enter]
Student ID Number: 4876 [Enter]
Credit Hours Enrolled: 12 [Enter]
Current GPA: 3.45 [Enter]

Here is the student data you entered:
Name: Frank Smith
ID Number: 4876
Credit Hours: 12
GPA: 3.45
```

Dynamically Allocating a Structure

You can also use a structure pointer and the `new` operator to dynamically allocate a structure. For example, the following code defines a `Circle` pointer named `cirPtr` and dynamically allocates a `Circle` structure. Values are then stored in the dynamically allocated structure's members.

```
Circle *cirPtr = nullptr; // Define a Circle pointer
cirPtr = new Circle;      // Dynamically allocate a Circle structure
cirPtr->radius = 10;      // Store a value in the radius member
cirPtr->diameter = 20;    // Store a value in the diameter member
cirPtr->area = 314.159;   // Store a value in the area member
```

You can also dynamically allocate an array of structures. The following code shows an array of five `Circle` structures being allocated.

```
Circle *circles = nullptr;
circles = new Circle[5];
for (int count = 0; count < 5; count++)
{
   cout << "Enter the radius for circle "
        << (count + 1) << ": ";
   cin >> circles[count].radius;
}
```

11.10 Focus on Software Engineering: When to Use ., When to Use –>, and When to Use *

Sometimes structures contain pointers as members. For example, the following structure declaration has an `int` pointer member:

```
struct GradeInfo
{
   string name;                  // Student names
   int *testScores;              // Dynamically allocated array
   float average;                // Test average
};
```

It is important to remember that the structure pointer operator (`->`) is used to dereference a pointer to a structure, not a pointer that is a member of a structure. If a program dereferences the `testScores` pointer in this structure, the indirection operator must be used. For example, assume that the following variable has been defined:

```
GradeInfo student1;
```

The following statement will display the value pointed to by the `testScores` member:

```
cout << *student1.testScores;
```

It is still possible to define a pointer to a structure that contains a pointer member. For instance, the following statement defines `stPtr` as a pointer to a `GradeInfo` structure:

```
GradeInfo *stPtr = nullptr;
```

Assuming that `stPtr` points to a valid `GradeInfo` variable, the following statement will display the value pointed to by its `testScores` member:

```
cout << *stPtr->testScores;
```

In this statement, the `*` operator dereferences `stPtr->testScores`, while the `->` operator dereferences `stPtr`. It might help to remember that the following expression:

```
stPtr->testScores
```

is equivalent to

```
(*stPtr).testScores
```

So, the expression

```
*stPtr->testScores
```

is the same as

```
*(*stPtr).testScores
```

The awkwardness of this last expression shows the necessity of the -> operator. Table 11-3 lists some expressions using the *, ->, and . operators and describes what each references.

Table 11-3

Expression	Description
`s->m`	`s` is a structure pointer and `m` is a member. This expression accesses the `m` member of the structure pointed to by `s`.
`*a.p`	`a` is a structure variable and `p`, a pointer, is a member. This expression dereferences the value pointed to by `p`.
`(*s).m`	`s` is a structure pointer and `m` is a member. The `*` operator dereferences `s`, causing the expression to access the `m` member of the structure pointed to by `s`. This expression is the same as `s->m` .
`*s->p`	`s` is a structure pointer and `p`, a pointer, is a member of the structure pointed to by `s`. This expression accesses the value pointed to by `p`. (The `->` operator dereferences `s` and the `*` operator dereferences `p`.)
`*(*s).p`	`s` is a structure pointer and `p`, a pointer, is a member of the structure pointed to by `s`. This expression accesses the value pointed to by `p`. `(*s)` dereferences `s` and the outermost `*` operator dereferences `p`. The expression `*s->p` is equivalent.

Checkpoint

Assume the following structure declaration exists for Questions 11.11–11.15:

```
struct Rectangle
{
   int length;
   int width;
};
```

11.11 Write a function that accepts a `Rectangle` structure as its argument and displays the structure's contents on the screen.

11.12 Write a function that uses a `Rectangle` structure reference variable as its parameter and stores the user's input in the structure's members.

11.13 Write a function that returns a `Rectangle` structure. The function should store the user's input in the members of the structure before returning it.

11.14 Write the definition of a pointer to a `Rectangle` structure.

11.15 Assume `rptr` is a pointer to a `Rectangle` structure. Which of the expressions, A, B, or C, is equivalent to the following expression:

```
rptr->width
```

A) `*rptr.width`
B) `(*rptr).width`
C) `rptr.(*width)`

11.11 Unions

CONCEPT: A *union* is like a structure, except all the members occupy the same memory area.

A union, in almost all regards, is just like a structure. The difference is that all the members of a union use the same memory area, so only one member can be used at a time. A union might be used in an application where the program needs to work with two or more values (of different data types), but only needs to use one of the values at a time. Unions conserve memory by storing all their members in the same memory location.

Unions are declared just like structures, except the key word `union` is used instead of `struct`. Here is an example:

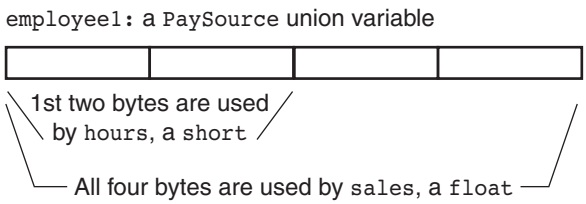
```
union PaySource
{
   short hours;
   float sales;
};
```

A union variable of the data type shown above can then be defined as

```
PaySource employee1;
```

The `PaySource` union variable defined here has two members: `hours` (a `short`), and `sales` (a `float`). The entire variable will only take up as much memory as the largest member (in this case, a `float`). The way this variable is stored on a typical PC is illustrated in Figure 11-5.

Figure 11-5



As shown in Figure 11-5, the union uses four bytes on a typical PC. It can store a `short` or a `float`, depending on which member is used. When a value is stored in the `sales` member, all four bytes are needed to hold the data. When a value is stored in the `hours` member, however, only the first two bytes are used. Obviously, both members can't hold values at the same time. This union is demonstrated in Program 11-9.

Program 11-9

```
// This program demonstrates a union.
#include <iostream>
#include <iomanip>
using namespace std;

union PaySource
{
    int hours;         // Hours worked
    float sales;       // Amount of sales
};

int main()
{
    PaySource employee1;     // Define a union variable
    char payType;            // To hold the pay type
    float payRate;           // Hourly pay rate
    float grossPay;          // Gross pay

    cout << fixed << showpoint << setprecision(2);
    cout << "This program calculates either hourly wages or\n";
    cout << "sales commission.\n";

    // Get the pay type, hourly or commission.
    cout << "Enter H for hourly wages or C for commission: ";
    cin >> payType;

    // Determine the gross pay, depending on the pay type.
    if (payType == 'H' || payType == 'h')
    {
        // This is an hourly paid employee. Get the
        // pay rate and hours worked.
        cout << "What is the hourly pay rate? ";
        cin >> payRate;
        cout << "How many hours were worked? ";
        cin >> employee1.hours;

        // Calculate and display the gross pay.
        grossPay = employee1.hours * payRate;
        cout << "Gross pay: $" << grossPay << endl;
    }
    else if (payType == 'C' || payType == 'c')
    {
        // This is a commission-paid employee. Get the
        // amount of sales.
        cout << "What are the total sales for this employee? ";
        cin >> employee1.sales;

        // Calculate and display the gross pay.
        grossPay = employee1.sales * 0.10;
        cout << "Gross pay: $" << grossPay << endl;
    }
```

(program continues)

Program 11-9 *(continued)*

```
52       else
53       {
54            // The user made an invalid selection.
55            cout << payType << " is not a valid selection.\n";
56       }
57       return 0;
58  }
```

Program Output with Example Input Shown in Bold

```
This program calculates either hourly wages or
sales commission.
Enter H for hourly wages or C for commission: C [Enter]
What are the total sales for this employee? 5000 [Enter]
Gross pay: $500.00
```

Program Output with Different Example Input Shown in Bold

```
This program calculates either hourly wages or
sales commission.
Enter H for hourly wages or C for commission: H [Enter]
What is the hourly pay rate? 20 [Enter]
How many hours were worked? 40 [Enter]
Gross pay: $800.00
```

Everything else you already know about structures applies to unions. For example, arrays of unions may be defined. A union may be passed as an argument to a function or returned from a function. Pointers to unions may be defined, and the members of the union referenced by the pointer can be accessed with the -> operator.

Anonymous Unions

The members of an anonymous union have names, but the union itself has no name. Here is the general format of an anonymous union declaration:

```
union
{
     member declaration;
     ...
};
```

An anonymous union declaration actually creates the member variables in memory, so there is no need to separately define a union variable. Anonymous unions are simple to use because the members may be accessed without the dot operator. Program 11-10, which is a modification of Program 11-9, demonstrates the use of an anonymous union.

Program 11-10

```
1  // This program demonstrates an anonymous union.
2  #include <iostream>
3  #include <iomanip>
4  using namespace std;
```

```
 5
 6  int main()
 7  {
 8      union                       // Anonymous union
 9      {
10          int hours;
11          float sales;
12      };
13
14      char payType;               // To hold the pay type
15      float payRate;              // Hourly pay rate
16      float grossPay;             // Gross pay
17
18      cout << fixed << showpoint << setprecision(2);
19      cout << "This program calculates either hourly wages or\n";
20      cout << "sales commission.\n";
21
22      // Get the pay type, hourly or commission.
23      cout << "Enter H for hourly wages or C for commission: ";
24      cin >> payType;
25
26      // Determine the gross pay, depending on the pay type.
27      if (payType == 'H' || payType == 'h')
28      {
29          // This is an hourly paid employee. Get the
30          // pay rate and hours worked.
31          cout << "What is the hourly pay rate? ";
32          cin >> payRate;
33          cout << "How many hours were worked? ";
34          cin >> hours; // Anonymous union member
35
36          // Calculate and display the gross pay.
37          grossPay = hours * payRate;
38          cout << "Gross pay: $" << grossPay << endl;
39      }
40      else if (payType == 'C' || payType == 'c')
41      {
42          // This is a commission-paid employee. Get the
43          // amount of sales.
44          cout << "What are the total sales for this employee? ";
45          cin >> sales; // Anonymous union member
46
47          // Calculate and display the gross pay.
48          grossPay = sales * 0.10;
49          cout << "Gross pay: $" << grossPay << endl;
50      }
51      else
52      {
53          // The user made an invalid selection.
54          cout << payType << " is not a valid selection.\n";
55      }
56      return 0;
57  }
```

(program output continues)

Program 11-10 *(continued)*

Program Output with Example Input Shown in Bold

```
This program calculates either hourly wages or
sales commission.
Enter H for hourly wages or C for commission: C [Enter]
What are the total sales for this employee? 12000 [Enter]
Gross pay: $1200.00
```

NOTE: Notice the anonymous union in Program 11-10 is declared inside function `main`. If an anonymous union is declared globally (outside all functions), it must be declared static. This means the word `static` must appear before the word `union`.

Checkpoint

11.16 Declare a union named `ThreeTypes` with the following members:

`letter:`	A character
`whole:`	An integer
`real:`	A `double`

11.17 Write the definition for an array of 50 of the `ThreeTypes` structures you declared in Question 11.16.

11.18 Write a loop that stores the floating point value 2.37 in all the elements of the array you defined in Question 11.17.

11.19 Write a loop that stores the character 'A' in all the elements of the array you defined in Question 11.17.

11.20 Write a loop that stores the integer 10 in all the elements of the array you defined in Question 11.17.

11.12 Enumerated Data Types

CONCEPT: An enumerated data type is a programmer-defined data type. It consists of values known as enumerators, which represent integer constants.

Using the `enum` key word you can create your own data type and specify the values that belong to that type. Such a type is known as an *enumerated data type*. Here is an example of an enumerated data type declaration:

```
enum Day { MONDAY, TUESDAY, WEDNESDAY, THURSDAY, FRIDAY };
```

An enumerated type declaration begins with the key word `enum`, followed by the name of the type, followed by a list of identifiers inside braces, and is terminated with a semicolon. The example declaration creates an enumerated data type named `Day`. The identifiers `MONDAY`, `TUESDAY`, `WEDNESDAY`, `THURSDAY`, and `FRIDAY`, which are listed inside the braces,

are known as *enumerators*. They represent the values that belong to the `Day` data type. Here is the general format of an enumerated type declaration:

```
enum TypeName { One or more enumerators };
```

Note that the enumerators are not enclosed in quotation marks; therefore they are not strings. Enumerators must be legal C++ identifiers.

Once you have created an enumerated data type in your program, you can define variables of that type. For example, the following statement defines `workDay` as a variable of the `Day` type:

```
Day workDay;
```

Because `workDay` is a variable of the `Day` data type, we may assign any of the enumerators `MONDAY`, `TUESDAY`, `WEDNESDAY`, `THURSDAY`, or `FRIDAY` to it. For example, the following statement assigns the value `WEDNESDAY` to the `workDay` variable.

```
Day workDay = WEDNESDAY;
```

So just what are these enumerators `MONDAY`, `TUESDAY`, `WEDNESDAY`, `THURSDAY`, and `FRIDAY`? You can think of them as integer named constants. Internally, the compiler assigns integer values to the enumerators, beginning with 0. The enumerator `MONDAY` is stored in memory as the number 0, `TUESDAY` is stored in memory as the number 1, `WEDNESDAY` is stored in memory as the number 2, and so forth. To prove this, look at the following code.

```
cout << MONDAY << endl << TUESDAY << endl
     << WEDNESDAY << endl << THURSDAY << endl
     << FRIDAY << endl;
```

This statement will produce the following output:

```
0
1
2
3
4
```

NOTE: When making up names for enumerators, it is not required that they be written in all uppercase letters. For example, we could have written the enumerators of the `Days` type as `monday`, `tuesday`, etc. Because they represent constant values, however, many programmers prefer to write them in all uppercase letters. This is strictly a preference of style.

Assigning an Integer to an `enum` Variable

Even though the enumerators of an enumerated data type are stored in memory as integers, you cannot directly assign an integer value to an `enum` variable. For example, assuming that `workDay` is a variable of the `Day` data type previously described, the following assignment statement is illegal.

```
workDay = 3;   // Error!
```

Compiling this statement will produce an error message such as "Cannot convert `int` to `Day`." When assigning a value to an `enum` variable, you should use a valid enumerator. However, if circumstances require that you store an integer value in an `enum` variable, you can do so by casting the integer. Here is an example:

```
workDay = static_cast<Day>(3);
```

This statement will produce the same results as:

```
workDay = THURSDAY;
```

Assigning an Enumerator to an `int` Variable

Although you cannot directly assign an integer value to an `enum` variable, you can directly assign an enumerator to an integer variable. For example, the following code will work just fine.

```
enum Day { MONDAY, TUESDAY, WEDNESDAY, THURSDAY, FRIDAY };
int x;
x = THURSDAY;
cout << x << endl;
```

When this code runs it will display 3. You can also assign a variable of an enumerated type to an integer variable, as shown here:

```
Day workDay = FRIDAY;
int x = workDay;
cout << x << endl;
```

When this code runs it will display 4.

Comparing Enumerator Values

Enumerator values can be compared using the relational operators. For example, using the `Day` data type we have been discussing, the following expression is `true`.

```
FRIDAY > MONDAY
```

The expression is `true` because the enumerator `FRIDAY` is stored in memory as 4 and the enumerator `MONDAY` is stored as 0. The following code will display the message "Friday is greater than Monday."

```
if (FRIDAY > MONDAY)
   cout << "Friday is greater than Monday. \n";
```

You can also compare enumerator values with integer values. For example, the following code will display the message "Monday is equal to zero."

```
if (MONDAY == 0)
   cout << "Monday is equal to zero.\n";
```

Let's look at a complete program that uses much of what we have learned so far. Program 11-11 uses the `Day` data type that we have been discussing.

Program 11-11

```
1  // This program demonstrates an enumerated data type.
2  #include <iostream>
3  #include <iomanip>
4  using namespace std;
5
6  enum Day { MONDAY, TUESDAY, WEDNESDAY, THURSDAY, FRIDAY };
7
8  int main()
9  {
10     const int NUM_DAYS = 5;     // The number of days
11     double sales[NUM_DAYS];     // To hold sales for each day
12     double total = 0.0;         // Accumulator
13     int index;                  // Loop counter
14
15     // Get the sales for each day.
16     for (index = MONDAY; index <= FRIDAY; index++)
17     {
18         cout << "Enter the sales for day "
19              << index << ": ";
20         cin >> sales[index];
21     }
22
23     // Calculate the total sales.
24     for (index = MONDAY; index <= FRIDAY; index++)
25        total += sales[index];
26
27     // Display the total.
28     cout << "The total sales are $" << setprecision(2)
29          << fixed << total << endl;
30
31     return 0;
32 }
```

Program Output with Example Input Shown in Bold

```
Enter the sales for day 0: 1525.00 [Enter]
Enter the sales for day 1: 1896.50 [Enter]
Enter the sales for day 2: 1975.63 [Enter]
Enter the sales for day 3: 1678.33 [Enter]
Enter the sales for day 4: 1498.52 [Enter]
The total sales are $8573.98
```

Anonymous Enumerated Types

Notice that Program 11-11 does not define a variable of the `Day` data type. Instead it uses the `Day` data type's enumerators in the `for` loops. The counter variable `index` is initialized to `MONDAY` (which is 0), and the loop iterates as long as `index` is less than or equal to `FRIDAY` (which is 4). When you do not need to define variables of an enumerated type, you can actually make the type anonymous. An *anonymous enumerated type* is simply one that does not have a name. For example, in Program 11-11 we could have declared the enumerated type as:

```
enum { MONDAY, TUESDAY, WEDNESDAY, THURSDAY, FRIDAY };
```

This declaration still creates the enumerators. We just can't use the data type to define variables because the type does not have a name.

Using Math Operators to Change the Value of an enum Variable

Even though enumerators are really integers, and enum variables really hold integer values, you can run into problems when trying to perform math operations with them. For example, look at the following code.

```
Day day1, day2;    // Defines two Day variables.
day1 = TUESDAY;    // Assign TUESDAY to day1.
day2 = day1 + 1;   // ERROR! This will not work!
```

The third statement causes a problem because the expression day1 + 1 results in the integer value 2. The assignment operator then attempts to assign the integer value 2 to the enum variable day2. Because C++ cannot implicitly convert an int to a Day, an error occurs. You can fix this by using a cast to explicitly convert the result to Day, as shown here:

```
day2 = static_cast<Day>(day1 + 1);   // This works.
```

Using an enum Variable to Step Through an Array's Elements

Because enumerators are stored in memory as integers, you can use them as array subscripts. For example, look at the following code.

```
enum Day { MONDAY, TUESDAY, WEDNESDAY, THURSDAY, FRIDAY };
const int NUM_DAYS = 5;
double sales[NUM_DAYS];
sales[MONDAY] = 1525.0;     // Stores 1525.0 in sales[0].
sales[TUESDAY] = 1896.5;    // Stores 1896.5 in sales[1].
sales[WEDNESDAY] = 1975.63; // Stores 1975.63 in sales[2].
sales[THURSDAY] = 1678.33;  // Stores 1678.33 in sales[3].
sales[FRIDAY] = 1498.52;    // Stores 1498.52 in sales[4].
```

This code stores values in all five elements of the sales array. Because enumerator values can be used as array subscripts, you can use an enum variable in a loop to step through the elements of an array. However, using an enum variable for this purpose is not as straightforward as using an int variable. This is because you cannot use the ++ or -- operators directly on an enum variable. To understand what I mean, first look at the following code taken from Program 11-11:

```
for (index = MONDAY; index <= FRIDAY; index++)
{
   cout << "Enter the sales for day "
        << index << ": ";
   cin >> sales[index];
}
```

In this code, index is an int variable used to step through each element of the array. It is reasonable to expect that we could use a Day variable instead, as shown in the following code.

```
Day workDay;  // Define a Day variable

// ERROR!!! This code will NOT work.
for (workDay = MONDAY; workDay <= FRIDAY; workDay++)
{
   cout << "Enter the sales for day "
        << workDay << ": ";
   cin >> sales[workDay];
}
```

Notice that the `for` loop's update expression uses the `++` operator to increment `workDay`. Although this works fine with an `int` variable, the `++` operator cannot be used with an `enum` variable. Instead, you must convert `workDay++` to an equivalent expression that will work. The expression `workDay++` attempts to do the same thing as:

```
workDay = workDay + 1;  // Good idea, but still won't work.
```

However, this still will not work. We have to use a cast to explicitly convert the expression `workDay + 1` to the `Day` data type, like this:

```
workDay = static_cast<Day>(workDay + 1);
```

This is the expression that we must use in the `for` loop instead of `workDay++`. The corrected `for` loop looks like this:

```
for (workDay = MONDAY; workDay <= FRIDAY;
                workDay = static_cast<Day>(workDay + 1))
{
   cout << "Enter the sales for day "
        << workDay << ": ";
   cin >> sales[workDay];
}
```

Program 11-12 is a version of Program 11-11 that is modified to use a `Day` variable to step through the elements of the `sales` array.

Program 11-12

```
1  // This program demonstrates an enumerated data type.
2  #include <iostream>
3  #include <iomanip>
4  using namespace std;
5
6  enum Day { MONDAY, TUESDAY, WEDNESDAY, THURSDAY, FRIDAY };
7
8  int main()
9  {
10     const int NUM_DAYS = 5;     // The number of days
11     double sales[NUM_DAYS];     // To hold sales for each day
12     double total = 0.0;         // Accumulator
13     Day workDay;                // Loop counter
14
```

(program continues)

Program 11-12 *(continued)*

```
15       // Get the sales for each day.
16       for (workDay = MONDAY; workDay <= FRIDAY;
17                              workDay = static_cast<Day>(workDay + 1))
18       {
19            cout << "Enter the sales for day "
20                 << workDay << ": ";
21            cin >> sales[workDay];
22       }
23
24       // Calculate the total sales.
25       for (workDay = MONDAY; workDay <= FRIDAY;
26                              workDay = static_cast<Day>(workDay + 1))
27            total += sales[workDay];
28
29       // Display the total.
30       cout << "The total sales are $" << setprecision(2)
31            << fixed << total << endl;
32
33       return 0;
34  }
```

Program Output with Example Input Shown in Bold

```
Enter the sales for day 0: 1525.00 [Enter]
Enter the sales for day 1: 1896.50 [Enter]
Enter the sales for day 2: 1975.63 [Enter]
Enter the sales for day 3: 1678.33 [Enter]
Enter the sales for day 4: 1498.52 [Enter]
The total sales are $8573.98
```

Using Enumerators to Output Values

As you have already seen, sending an enumerator to `cout` causes the enumerator's integer value to be displayed. For example, assuming we are using the `Day` type previously described, the following statement displays 0.

```
cout << MONDAY << endl;
```

If you wish to use the enumerator to display a string such as "Monday," you'll have to write code that produces the desired string. For example, in the following code assume that `workDay` is a `Day` variable that has been initialized to some value. The `switch` statement displays the name of a day, based upon the value of the variable.

```
switch(workDay)
{
   case MONDAY    : cout << "Monday";
                    break;
   case TUESDAY   : cout << "Tuesday";
                    break;
   case WEDNESDAY : cout << "Wednesday";
                    break;
   case THURSDAY  : cout << "Thursday";
                    break;
   case FRIDAY    : cout << "Friday";
}
```

Program 11-13 shows this type of code used in a function. Instead of asking the user to enter the sales for day 0, day 1, and so forth, it displays the names of the days.

Program 11-13

```
1  // This program demonstrates an enumerated data type.
2  #include <iostream>
3  #include <iomanip>
4  using namespace std;
5
6  enum Day { MONDAY, TUESDAY, WEDNESDAY, THURSDAY, FRIDAY };
7
8  // Function prototype
9  void displayDayName(Day);
10
11 int main()
12 {
13     const int NUM_DAYS = 5;     // The number of days
14     double sales[NUM_DAYS];     // To hold sales for each day
15     double total = 0.0;         // Accumulator
16     Day workDay;                // Loop counter
17
18     // Get the sales for each day.
19     for (workDay = MONDAY; workDay <= FRIDAY;
20                            workDay = static_cast<Day>(workDay + 1))
21     {
22         cout << "Enter the sales for day ";
23         displayDayName(workDay);
24         cout << ": ";
25         cin >> sales[workDay];
26     }
27
28     // Calculate the total sales.
29     for (workDay = MONDAY; workDay <= FRIDAY;
30                            workDay = static_cast<Day>(workDay + 1))
31         total += sales[workDay];
32
33     // Display the total.
34     cout << "The total sales are $" << setprecision(2)
35          << fixed << total << endl;
36
37     return 0;
38 }
39
40 //********************************************************
41 // Definition of the displayDayName function             *
42 // This function accepts an argument of the Day type and  *
43 // displays the corresponding name of the day.           *
44 //********************************************************
45
```

(program continues)

Program 11-13 *(continued)*

```
46  void displayDayName(Day d)
47  {
48       switch(d)
49       {
50            case MONDAY    : cout << "Monday";
51                             break;
52            case TUESDAY   : cout << "Tuesday";
53                             break;
54            case WEDNESDAY : cout << "Wednesday";
55                             break;
56            case THURSDAY  : cout << "Thursday";
57                             break;
58            case FRIDAY    : cout << "Friday";
59       }
60  }
```

Program Output with Example Input Shown in Bold

```
Enter the sales for Monday: 1525.00 [Enter]
Enter the sales for Tuesday: 1896.50 [Enter]
Enter the sales for Wednesday: 1975.63 [Enter]
Enter the sales for Thursday: 1678.33 [Enter]
Enter the sales for Friday: 1498.52 [Enter]
The total sales are $8573.98
```

Specifying Integer Values for Enumerators

By default, the enumerators in an enumerated data type are assigned the integer values 0, 1, 2, and so forth. If this is not appropriate, you can specify the values to be assigned, as in the following example.

```
enum Water { FREEZING = 32, BOILING = 212 };
```

In this example, the FREEZING enumerator is assigned the integer value 32 and the BOILING enumerator is assigned the integer value 212. Program 11-14 demonstrates how this enumerated type might be used.

Program 11-14

```
1   // This program demonstrates an enumerated data type.
2   #include <iostream>
3   #include <iomanip>
4   using namespace std;
5
6   int main()
7   {
8        enum Water { FREEZING = 32, BOILING = 212 };
9        int waterTemp; // To hold the water temperature
10
```

```
11      cout << "Enter the current water temperature: ";
12      cin >> waterTemp;
13      if (waterTemp <= FREEZING)
14          cout << "The water is frozen.\n";
15      else if (waterTemp >= BOILING)
16          cout << "The water is boiling.\n";
17      else
18          cout << "The water is not frozen or boiling.\n";
19
20      return 0;
21  }
```

Program Output with Example Input Shown in Bold

```
Enter the current water temperature: 10 [Enter]
The water is frozen.
```

Program Output with Example Input Shown in Bold

```
Enter the current water temperature: 300 [Enter]
The water is boiling.
```

Program Output with Example Input Shown in Bold

```
Enter the current water temperature: 92 [Enter]
The water is not frozen or boiling.
```

If you leave out the value assignment for one or more of the enumerators, it will be assigned a default value. Here is an example:

```
enum Colors { RED, ORANGE, YELLOW = 9, GREEN, BLUE };
```

In this example the enumerator `RED` will be assigned the value 0, `ORANGE` will be assigned the value 1, `YELLOW` will be assigned the value 9, `GREEN` will be assigned the value 10, and `BLUE` will be assigned the value 11.

Enumerators Must Be Unique Within the Same Scope

Enumerators are identifiers just like variable names, named constants, and function names. As with all identifiers, they must be unique within the same scope. For example, an error will result if both of the following enumerated types are declared within the same scope. The reason is that `ROOSEVELT` is declared twice.

```
enum Presidents { MCKINLEY, ROOSEVELT, TAFT };
enum VicePresidents { ROOSEVELT, FAIRBANKS, SHERMAN };  // Error!
```

The following declarations will also cause an error if they appear within the same scope.

```
enum Status { OFF, ON };
const int OFF = 0;        // Error!
```

Declaring the Type and Defining the Variables in One Statement

The following code uses two lines to declare an enumerated data type and define a variable of the type.

```
enum Car { PORSCHE, FERRARI, JAGUAR };
Car sportsCar;
```

C++ allows you to declare an enumerated data type and define one or more variables of the type in the same statement. The previous code could be combined into the following statement:

```
enum Car { PORSCHE, FERRARI, JAGUAR } sportsCar;
```

The following statement declares the `Car` data type and defines two variables: `myCar` and `yourCar`.

```
enum Car { PORSCHE, FERRARI, JAGUAR } myCar, yourCar;
```

Using Strongly Typed `enum`s in C++ 11

Earlier we mentioned that you cannot have multiple enumerators with the same name, within the same scope. In C++ 11, you can use a new type of `enum`, known as a *strongly typed enum* (also known as an *enum class*), to get around this limitation. Here are two examples of a strongly typed `enum` declaration:

```
enum class Presidents { MCKINLEY, ROOSEVELT, TAFT };
enum class VicePresidents { ROOSEVELT, FAIRBANKS, SHERMAN };
```

These statements declare two strongly typed `enum`s: `Presidents` and `VicePresidents`. Notice that they look like regular `enum` declarations, except that the word `class` appears after `enum`. Although both `enum`s contain the same enumerator (`ROOSEVELT`), these declarations will compile without an error.

When you use a strongly typed enumerator, you must prefix the enumerator with the name of the `enum`, followed by the `::` operator. Here are two examples:

```
Presidents prez = Presidents::ROOSEVELT;
VicePresidents vp = VicePresidents::ROOSEVELT;
```

The first statement defines a `Presidents` variable named `prez`, and initializes it with the `Presidents::ROOSEVELT` enumerator. The second statement defines a `VicePresidents` variable named `vp`, and initializes it with the `VicePresidents::ROOSEVELT` enumerator. Here is an example of an `if` statement that compares the `prez` variable with an enumerator:

```
if (prez == Presidents::ROOSEVELT)
   cout << "Roosevelt is president!\n";
```

Strongly typed enumerators are stored as integers like regular enumerators. However, if you want to retrieve a strongly typed enumerator's underlying integer value, you must use a cast operator. Here is an example:

```
int x = static_cast<int>(Presidents::ROOSEVELT);
```

This statement assigns the underlying integer value of the `Presidents::ROOSEVELT` enumerator to the variable `x`. Here is another example:

```
cout << static_cast<int>(Presidents::TAFT) << endl
     << static_cast<int>(Presidents::MCKINLEY) << endl;
```

This statement displays the integer values for the `Presidents::TAFT` and the `Presidents::MCKINLEY` enumerators.

When you declare a strongly typed `enum`, you can optionally specify any integer data type as the underlying type. You simply write a colon (:) after the enum name, followed by the desired data type. For example, the following statement declares an `enum` that uses the `char` data type for its enumerators:

```
enum class Day : char { MONDAY, TUESDAY, WEDNESDAY, THURSDAY, FRIDAY };
```

The following statement shows another example. This statement declares an `enum` named `Water` that uses `unsigned` as the data type of its enumerators. Additionally, values are assigned to the enumerators.

```
enum class Water : unsigned { FREEZING = 32, BOILING = 212 };
```

Checkpoint

11.21 Look at the following declaration.

```
enum Flower { ROSE, DAISY, PETUNIA };
```

In memory, what value will be stored for the enumerator `ROSE`? For `DAISY`? For `PETUNIA`?

11.22 What will the following code display?

```
enum { HOBBIT, ELF = 7, DRAGON };
cout << HOBBIT << " " << ELF << " " << DRAGON << endl;
```

11.23 Does the enumerated data type declared in Checkpoint Question 11.22 have a name, or is it anonymous?

11.24 What will the following code display?

```
enum Letters { Z, Y, X };
if (Z > X)
   cout << "Z is greater than X. \n";
else
   cout << "Z is not greater than X. \n";
```

11.25 Will the following code cause an error, or will it compile without any errors? If it causes an error, rewrite it so it compiles.

```
enum Color { RED, GREEN, BLUE };
Color c;
c = 0;
```

11.26 Will the following code cause an error, or will it compile without any errors? If it causes an error, rewrite it so it compiles.

```
enum Color { RED, GREEN, BLUE };
Color c = RED;
c++;
```

NOTE: For an additional example of this chapter's topics, see the High Adventure Travel Part 2 Case Study on this book's companion Web site at pearsonhighered.com/gaddis.

Review Questions and Exercises

Short Answer

1. What is a primitive data type?
2. Does a structure declaration cause a structure variable to be created?
3. Both arrays and structures are capable of storing multiple values. What is the difference between an array and a structure?
4. Look at the following structure declaration.

```
struct Point
{
   int x;
   int y;
};
```

   Write statements that

   A) define a `Point` structure variable named `center`
   B) assign 12 to the `x` member of `center`
   C) assign 7 to the `y` member of `center`
   D) display the contents of the `x` and `y` members of `center`

5. Look at the following structure declaration.

```
struct FullName
{
   string lastName;
   string middleName;
   string firstName;
};
```

   Write statements that

   A) Define a `FullName` structure variable named `info`
   B) Assign your last, middle, and first name to the members of the `info` variable
   C) Display the contents of the members of the `info` variable

6. Look at the following code.

```
struct PartData
{
   string partName;
   int idNumber;
};
PartData inventory[100];
```

   Write a statement that displays the contents of the `partName` member of element 49 of the `inventory` array.

7. Look at the following code.

```
struct Town
{
   string townName;
   string countyName;
   double population;
   double elevation;
};
```

```
Town t = { "Canton", "Haywood", 9478 };
```

A) What value is stored in `t.townName`?

B) What value is stored in `t.countyName`?

C) What value is stored in `t.population`?

D) What value is stored in `t.elevation`?

8. Look at the following code.

```
structure Rectangle
{
   int length;
   int width;
};
Rectangle *r = nullptr
```

Write statements that

A) Dynamically allocate a `Rectangle` structure variable and use `r` to point to it.

B) Assign 10 to the structure's `length` member and 14 to the structure's `width` member.

9. What is the difference between a union and a structure?

10. Look at the following code.

```
union Values
{
   int ivalue;
   double dvalue;
};

Values v;
```

Assuming that an `int` uses four bytes and a `double` uses eight bytes, how much memory does the variable `v` use?

11. What will the following code display?

```
enum { POODLE, BOXER, TERRIER };
cout << POODLE << " " << BOXER << " " << TERRIER << endl;
```

12. Look at the following declaration.

```
enum Person { BILL, JOHN, CLAIRE, BOB };
Person p;
```

Indicate whether each of the following statements or expressions is valid or invalid.

A) `p = BOB;`

B) `p++;`

C) `BILL > BOB`

D) `p = 0;`

E) `int x = BILL;`

F) `p = static_cast<Person>(3);`

G) `cout << CLAIRE << endl;`

Fill-in-the-Blank

13. Before a structure variable can be created, the structure must be _____.
14. The _____ is the name of the structure type.
15. The variables declared inside a structure declaration are called _____.
16. A(n) _____ is required after the closing brace of a structure declaration.
17. In the definition of a structure variable, the _____ is placed before the variable name, just like the data type of a regular variable is placed before its name.
18. The _____ operator allows you to access structure members.

Algorithm Workbench

19. The structure `Car` is declared as follows:

```
struct Car
{
   string carMake;
   string carModel;
   int yearModel;
   double cost;
};
```

Write a definition statement that defines a `Car` structure variable initialized with the following data:

Make: Ford
Model: Mustang
Year Model: 1968
Cost: $20,000

20. Define an array of 25 of the `Car` structure variables (the structure is declared in Question 19).
21. Define an array of 35 of the `Car` structure variables. Initialize the first three elements with the following data:

Make	Model	Year	Cost
Ford	Taurus	1997	$ 21,000
Honda	Accord	1992	$ 11,000
Lamborghini	Countach	1997	$200,000

22. Write a loop that will step through the array you defined in Question 21, displaying the contents of each element.
23. Declare a structure named `TempScale`, with the following members:

```
fahrenheit: a double
centigrade: a double
```

Next, declare a structure named `Reading`, with the following members:

```
windSpeed: an int
humidity: a double
temperature: a TempScale structure variable
```

Next define a `Reading` structure variable.

24. Write statements that will store the following data in the variable you defined in Question 23.

    Wind Speed: 37 mph
    Humidity: 32%
    Fahrenheit temperature: 32 degrees
    Centigrade temperature: 0 degrees

25. Write a function called `showReading`. It should accept a `Reading` structure variable (see Question 23) as its argument. The function should display the contents of the variable on the screen.

26. Write a function called `findReading`. It should use a `Reading` structure reference variable (see Question 23) as its parameter. The function should ask the user to enter values for each member of the structure.

27. Write a function called `getReading`, which returns a `Reading` structure (see Question 23). The function should ask the user to enter values for each member of a `Reading` structure, then return the structure.

28. Write a function called `recordReading`. It should use a `Reading` structure pointer variable (see Question 23) as its parameter. The function should ask the user to enter values for each member of the structure pointed to by the parameter.

29. Rewrite the following statement using the structure pointer operator:

```
(*rptr).windSpeed = 50;
```

30. Rewrite the following statement using the structure pointer operator:

```
*(*strPtr).num = 10;
```

31. Write the declaration of a union called `Items` with the following members:

`alpha`	a character
`num`	an integer
`bigNum`	a `long` integer
`real`	a `float`

    Next, write the definition of an `Items` union variable.

32. Write the declaration of an anonymous union with the same members as the union you declared in Question 31.

33. Write a statement that stores the number 452 in the `num` member of the anonymous union you declared in Question 32.

34. Look at the following statement.

```
enum Color { RED, ORANGE, GREEN, BLUE };
```

    A) What is the name of the data type declared by this statement?
    B) What are the enumerators for this type?
    C) Write a statement that defines a variable of this type and initializes it with a valid value.

35. A pet store sells dogs, cats, birds, and hamsters. Write a declaration for an anonymous enumerated data type that can represent the types of pets the store sells.

True or False

36. T F A semicolon is required after the closing brace of a structure or union declaration.
37. T F A structure declaration does not define a variable.
38. T F The contents of a structure variable can be displayed by passing the structure variable to the `cout` object.
39. T F Structure variables may not be initialized.
40. T F In a structure variable's initialization list, you do not have to provide initializers for all the members.
41. T F You may skip members in a structure's initialization list.
42. T F The following expression refers to element 5 in the array `carInfo`: `carInfo.model[5]`
43. T F An array of structures may be initialized.
44. T F A structure variable may not be a member of another structure.
45. T F A structure member variable may be passed to a function as an argument.
46. T F An entire structure may not be passed to a function as an argument.
47. T F A function may return a structure.
48. T F When a function returns a structure, it is always necessary for the function to have a local structure variable to hold the member values that are to be returned.
49. T F The indirection operator has higher precedence than the dot operator.
50. T F The structure pointer operator does not automatically dereference the structure pointer on its left.
51. T F In a `union`, all the members are stored in different memory locations.
52. T F All the members of a `union` may be used simultaneously.
53. T F You may define arrays of `unions`.
54. T F You may not define pointers to `unions`.
55. T F An anonymous `union` has no name.
56. T F If an anonymous `union` is defined globally (outside all functions), it must be declared `static`.

Find the Errors

Each of the following declarations, programs, and program segments has errors. Locate as many as you can.

57.
```
struct
{
   int x;
   float y;
};
```

58.
```
struct Values
{
   string name;
   int age;
}
```

59.
```
struct TwoVals
{
   int a, b;
};
int main ()
{
   TwoVals.a = 10;
   TwoVals.b = 20;
   return 0;
}
```

60.
```
#include <iostream>
using namespace std;

struct ThreeVals
{
   int a, b, c;
};
int main()
{
   ThreeVals vals = {1, 2, 3};
   cout << vals << endl;
   return 0;
}
```

61.
```
#include <iostream>
#include <string>
using namespace std;

struct names
{
   string first;
   string last;
};
int main ()
{
   names customer = "Smith", "Orley";
   cout << names.first << endl;
   cout << names.last << endl;
   return 0;
}
```

62.
```
struct FourVals
{
   int a, b, c, d;
};
int main ()
{
   FourVals nums = {1, 2, , 4};
   return 0;
}
```

63.
```
#include <iostream>
using namespace std;
```

```
struct TwoVals
{
   int a = 5;
   int b = 10;
};
int main()
{
   TwoVals v;

   cout << v.a << " " << v.b;
   return 0;
}
```

64.
```
struct TwoVals
{
   int a = 5;
   int b = 10;
};

int main()
{
   TwoVals varray[10];

   varray.a[0] = 1;
   return 0;
}
```

65.
```
struct TwoVals
{
   int a;
   int b;
};
TwoVals getVals()
{
   TwoVals.a = TwoVals.b = 0;
}
```

66.
```
struct ThreeVals
{
   int a, b, c;
};
int main ()
{
   TwoVals s, *sptr = nullptr;
   sptr = &s;
   *sptr.a = 1;
   return 0;
}
```

67.
```
#include <iostream>
using namespace std;

union Compound
{
   int x;
   float y;
};
```

```
int main()
{
    Compound u;
    u.x = 1000;
    cout << u.y << endl;
    return 0;
}
```

Programming Challenges

1. **Movie Data**

   Write a program that uses a structure named `MovieData` to store the following information about a movie:

   Title
   Director
   Year Released
   Running Time (in minutes)

   The program should create two `MovieData` variables, store values in their members, and pass each one, in turn, to a function that displays the information about the movie in a clearly formatted manner.

2. **Movie Profit**

   Modify the Movie Data program written for Programming Challenge 1 to include two additional members that hold the movie's production costs and first-year revenues. Modify the function that displays the movie data to display the title, director, release year, running time, and first year's profit or loss.

3. **Corporate Sales Data**

   Write a program that uses a structure to store the following data on a company division:

   Division Name (such as East, West, North, or South)
   First-Quarter Sales
   Second-Quarter Sales
   Third-Quarter Sales
   Fourth-Quarter Sales
   Total Annual Sales
   Average Quarterly Sales

   The program should use four variables of this structure. Each variable should represent one of the following corporate divisions: East, West, North, and South. The user should be asked for the four quarters' sales figures for each division. Each division's total and average sales should be calculated and stored in the appropriate member of each structure variable. These figures should then be displayed on the screen.

   Input Validation: Do not accept negative numbers for any sales figures.

4. Weather Statistics


VideoNote
Solving the Weather Statistics Problem

Write a program that uses a structure to store the following weather data for a particular month:

Total Rainfall
High Temperature
Low Temperature
Average Temperature

The program should have an array of 12 structures to hold weather data for an entire year. When the program runs, it should ask the user to enter data for each month. (The average temperature should be calculated.) Once the data are entered for all the months, the program should calculate and display the average monthly rainfall, the total rainfall for the year, the highest and lowest temperatures for the year (and the months they occurred in), and the average of all the monthly average temperatures.

Input Validation: Only accept temperatures within the range between –100 and +140 degrees Fahrenheit.

5. Weather Statistics Modification

Modify the program that you wrote for Programming Challenge 4 so it defines an enumerated data type with enumerators for the months (`JANUARY`, `FEBRUARY`, etc.). The program should use the enumerated type to step through the elements of the array.

6. Soccer Scores

Write a program that stores the following data about a soccer player in a structure:

Player's Name
Player's Number
Points Scored by Player

The program should keep an array of 12 of these structures. Each element is for a different player on a team. When the program runs it should ask the user to enter the data for each player. It should then show a table that lists each player's number, name, and points scored. The program should also calculate and display the total points earned by the team. The number and name of the player who has earned the most points should also be displayed.

Input Validation: Do not accept negative values for players' numbers or points scored.

7. Customer Accounts

Write a program that uses a structure to store the following data about a customer account:

Name
Address
City, State, and ZIP
Telephone Number
Account Balance
Date of Last Payment

The program should use an array of at least 10 structures. It should let the user enter data into the array, change the contents of any element, and display all the data stored in the array. The program should have a menu-driven user interface.

Input Validation: When the data for a new account is entered, be sure the user enters data for all the fields. No negative account balances should be entered.

8. **Search Function for Customer Accounts Program**

   Add a function to Programming Challenge 7 that allows the user to search the structure array for a particular customer's account. It should accept part of the customer's name as an argument and then search for an account with a name that matches it. All accounts that match should be displayed. If no account matches, a message saying so should be displayed.

9. **Speakers' Bureau**

   Write a program that keeps track of a speakers' bureau. The program should use a structure to store the following data about a speaker:

   Name
   Telephone Number
   Speaking Topic
   Fee Required

   The program should use an array of at least 10 structures. It should let the user enter data into the array, change the contents of any element, and display all the data stored in the array. The program should have a menu-driven user interface.

   Input Validation: When the data for a new speaker is entered, be sure the user enters data for all the fields. No negative amounts should be entered for a speaker's fee.

10. **Search Function for the Speakers' Bureau Program**

    Add a function to Programming Challenge 9 that allows the user to search for a speaker on a particular topic. It should accept a key word as an argument and then search the array for a structure with that key word in the Speaking Topic field. All structures that match should be displayed. If no structure matches, a message saying so should be displayed.

11. **Monthly Budget**

    A student has established the following monthly budget:

Housing	500.00
Utilities	150.00
Household Expenses	65.00
Transportation	50.00
Food	250.00
Medical	30.00
Insurance	100.00
Entertainment	150.00
Clothing	75.00
Miscellaneous	50.00

Write a program that has a `MonthlyBudget` structure designed to hold each of these expense categories. The program should pass the structure to a function that asks the user to enter the amounts spent in each budget category during a month. The program should then pass the structure to a function that displays a report indicating the amount over or under in each category, as well as the amount over or under for the entire monthly budget.

12. Course Grade

Write a program that uses a structure to store the following data:

Member Name	Description
Name	Student name
Idnum	Student ID number
Tests	Pointer to an array of test scores
Average	Average test score
Grade	Course grade

The program should keep a list of test scores for a group of students. It should ask the user how many test scores there are to be and how many students there are. It should then dynamically allocate an array of structures. Each structure's `Tests` member should point to a dynamically allocated array that will hold the test scores.

After the arrays have been dynamically allocated, the program should ask for the ID number and all the test scores for each student. The average test score should be calculated and stored in the `average` member of each structure. The course grade should be computed on the basis of the following grading scale:

Average Test Grade	Course Grade
91–100	A
81–90	B
71–80	C
61–70	D
60 or below	F

The course grade should then be stored in the `Grade` member of each structure. Once all this data is calculated, a table should be displayed on the screen listing each student's name, ID number, average test score, and course grade.

Input Validation: Be sure all the data for each student is entered. Do not accept negative numbers for any test score.

13. Drink Machine Simulator

Write a program that simulates a soft drink machine. The program should use a structure that stores the following data:

Drink Name
Drink Cost
Number of Drinks in Machine

The program should create an array of five structures. The elements should be initialized with the following data:

Drink Name	Cost	Number in Machine
Cola	.75	20
Root Beer	.75	20
Lemon-Lime	.75	20
Grape Soda	.80	20
Cream Soda	.80	20

Each time the program runs, it should enter a loop that performs the following steps: A list of drinks is displayed on the screen. The user should be allowed to either quit the program or pick a drink. If the user selects a drink, he or she will next enter the amount of money that is to be inserted into the drink machine. The program should display the amount of change that would be returned and subtract one from the number of that drink left in the machine. If the user selects a drink that has sold out, a message should be displayed. The loop then repeats. When the user chooses to quit the program it should display the total amount of money the machine earned.

Input Validation: When the user enters an amount of money, do not accept negative values or values greater than $1.00.

14. Inventory Bins

Write a program that simulates inventory bins in a warehouse. Each bin holds a number of the same type of parts. The program should use a structure that keeps the following data:

Description of the part kept in the bin
Number of parts in the bin

The program should have an array of 10 bins, initialized with the following data:

Part Description	Number of Parts in the Bin
Valve	10
Bearing	5
Bushing	15
Coupling	21
Flange	7
Gear	5
Gear Housing	5
Vacuum Gripper	25
Cable	18
Rod	12

The program should have the following functions:

AddParts: a function that increases a specific bin's part count by a specified number.

RemoveParts: a function that decreases a specific bin's part count by a specified number.

When the program runs, it should repeat a loop that performs the following steps: The user should see a list of what each bin holds and how many parts are in each bin. The user can choose to either quit the program or select a bin. When a bin is selected, the user can either add parts to it or remove parts from it. The loop then repeats, showing the updated bin data on the screen.

Input Validation: No bin can hold more than 30 parts, so don't let the user add more than a bin can hold. Also, don't accept negative values for the number of parts being added or removed.

15. Multipurpose Payroll

Write a program that calculates pay for either an hourly paid worker or a salaried worker. Hourly paid workers are paid their hourly pay rate times the number of hours worked. Salaried workers are paid their regular salary plus any bonus they may have earned. The program should declare two structures for the following data:

Hourly Paid:
HoursWorked
HourlyRate

Salaried:
Salary
Bonus

The program should also declare a `union` with two members. Each member should be a structure variable: one for the hourly paid worker and another for the salaried worker.

The program should ask the user whether he or she is calculating the pay for an hourly paid worker or a salaried worker. Regardless of which the user selects, the appropriate members of the `union` will be used to store the data that will be used to calculate the pay.

Input Validation: Do not accept negative numbers. Do not accept values greater than 80 for HoursWorked.