11 Structures and Abstract Data Types

PURPOSE	1. To introduce the concept of an abstract data type
	2. To introduce the concept of a structure
	3. To develop and manipulate an array of structures
	4. To use structures as parameters
	5. To use hierarchical (nested) structures
PROCEDURE	1. Students should read the Pre-lab Reading Assignment before coming to lab.
	2. Students should complete the Pre-lab Writing Assignment before coming to lab.
	3. In the lab, students should complete labs assigned to them by the instructor.

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Pre-lab Reading Assignment		20 min.	196	
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LESSON 11 A				
Lab 11.1 Working with Basic Structures	Knowledge of previous chapters	15 min.	205	
Lab 11.2 Initializing Structures	Basic understanding of structures	15 min.	206	
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PRE-LAB READING ASSIGNMENT

So far we have learned of data types such as `float`, `int`, `char`, etc. In some applications the programmer needs to create their own data type. A user defined data type is often an **abstract data type (ADT)**. The programmer must decide which values are valid for the data type and which operations may be performed on the data type. It may even be necessary for the programmer to design new operations to be applied to the data. We will study this style of programming extensively when we introduce *object-oriented programming* in the lesson set from Chapter 13.

As an example, suppose you want to create a program to simulate a calendar. The program may contain the following ADTs: `year`, `month`, and `day`. Note that `month` could take on values January, February, . . . , December or even 1,2, . . . ,12 depending on the wishes of the programmer. Likewise, the range of values for `day` could be Monday, Tuesday, . . . , Sunday or even 1,2, . . . ,7. There is much more flexibility in the choice of allowable values for `year`. If the programmer is thinking short term they may wish to restrict `year` to the range 1990–2010. Of course there are many other possibilities.

In this lab we study the **structure**. Like arrays, structures allow the programmer to group data together. However, unlike an array, structures allow you to group together items of *different* data types. To see how this could be useful in practice, consider what a student must do to register for a college course. Typically, one obtains the current list of available courses and then selects the desired course or courses. The following is an example of a course you may choose:

```
CHEM 310          Physical Chemistry          4 Credits
```

Note that there are four items related to this course: the course discipline (CHEM), the course number (310), the course title (Physical Chemistry), and the number of credit hours (4). We could define variables as follows:

Variable Definition	Information Held
`string discipline`	4-letter abbreviation for discipline
`int courseNumber`	Integer valued course number
`string courseTitle`	First 20 characters of course title
`short credits`	Number of credit hours

All of these variables are related because they can hold information about the same course. We can package these together by creating a structure. Here is the declaration:

```
struct course
{
     string discipline;
     int    courseNumber;
     string courseTitle;
     short  credits;
};   //note the semi-colon here
```

The **tag** is the name of the structure, `course` in this case. The tag is used like a data type name. Inside the braces we have the variable declarations that are the **members** of the structure. So the code above declares a structure named `course` which has four members: `discipline`, `courseNumber`, `courseTitle`, and `credits`.

The programmer needs to realize that the structure declaration does not define a variable. Rather it lets the compiler know what a course structure is composed of. That is, the declaration creates a new data type called course. We can now define variables of type course as follows:

```
course pChem;
course colonialHist;
```

Both pChem and colonialHist will contain the four members previously listed. We could have also defined these two structure variables on a single line:

```
course pChem, colonialHist;
```

Both pChem and colonialHist are called **instances** of the course structure. In other words, they are both user defined variables that exist in computer memory. Each structure variable contains the four structure members.

Access to Structure Members

Certainly the programmer will need to assign the members values and also keep track of what values the members have. C++ allows you to access structure members using the **dot operator**. Consider the following syntax:

```
colonialHist.credits = 3;
```

In this statement the integer 3 is assigned to the credits member of colonialHist. The dot operator is used to connect the member name to the structure variable it belongs to.

Now let us put all of these ideas together into a program. Sample Program 11.1 below uses the course structure just described. This interactive program allows a student to add requested courses and keeps track of the number of credit hours for which they have enrolled. The execution is controlled by a do-while loop.

Sample Program 11.1:

```cpp
#include <iostream>
#include <string>
#include <cctype>
using namespace std;

// This program demonstrates the use of structures

// structure declaration

struct course
{
      string discipline;
      int courseNumber;
      string courseTitle;
      short credits;
};
```

continues

```cpp
int main()
{
      course nextClass;  // next class is a course structure
      int numCredits = 0;
      char addClass;
      do
      {
         cout << "Please enter course discipline area:  ";
         cin >> nextClass.discipline;
         cout << endl << "Pleae enter the course number: ";
         cin >> nextClass.courseNumber;
         cout << endl << "Please enter the course title: ";
         cin.ignore();  // necessary for the next line
         getline(cin, nextClass.courseTitle);
         // use getline because course title may have a blank space
         cout << "Please enter the number of credit hours: ";
         cin >> nextClass.credits;

         numCredits = numCredits + nextClass.credits;

         // output the selected course and pertinent information

         cout << "You have been registered for the following: " << endl;
         cout << nextClass.discipline << "     " << nextClass.courseNumber
              << "     " << nextClass.courseTitle
              << "     " << nextClass.credits << "credits" << endl;

         cout << "Would you like to add another class? (Y/N)" << endl;
         cin >> addClass;

      } while(toupper(addClass) == 'Y');

      cout << "The total number of credit hours registered for is: "
           << numCredits << endl;

      return 0;
}
```

Make sure that you understand the logic of this program and, in particular, how structures are used. Notice the line at the end of the `while` loop that reads

```cpp
while(toupper(addclass) == 'Y');
```

What do you think the purpose of `toupper` is?

As a second example, suppose we would like a simple program that computes the area and circumference of two circles input by the user. Although we can easily do this using previously developed techniques, let us see how this can be done using structures. We will also determine which circle's center is further from the origin.

Sample Program 11.2:

```cpp
#include <iostream>
#include <cmath>     // necessary for pow function
#include <iomanip>
using namespace std;


struct circle       // declares the structure circle
{                   // This structure has 6 members
    float centerX; // x coordinate of center
    float centerY; // y coordinate of center
    float radius;
    float area;
    float circumference;
    float distance_from_origin;
};


const float PI = 3.14159;


int main()
{
        circle circ1, circ2; // defines 2 circle structure variables

        cout << "Please enter the radius of the first circle: ";
        cin >> circ1.radius;
        cout << endl
            << "Please enter the x-coordinate of the center: ";
        cin >> circ1.centerX;
        cout << endl
            << "Please enter the y-coordinate of the center: ";
        cin >> circ1.centerY;

        circ1.area = PI * pow(circ1.radius, 2.0);
        circ1.circumference = 2 * PI * circ1.radius;
        circ1.distance_from_origin = sqrt(pow(circ1.centerX,2.0)
            + pow(circ1.centerY,2.0));
        cout << endl << endl;

        cout << "Please enter the radius of the second circle: ";
        cin >> circ2.radius;
        cout << endl
            << "Please enter the x-coordinate of the center: ";
        cin >> circ2.centerX;
        cout << endl
            << "Please enter the y-coordinate of the center: ";
        cin >> circ2.centerY;

        circ2.area = PI * pow(circ2.radius, 2.0);
        circ2.circumference = 2 * PI * circ2.radius;
        circ2.distance_from_origin = sqrt(pow(circ2.centerX,2.0)
            + pow(circ2.centerY,2.0));
```

continues

```
                              cout << endl << endl;

                              // This next section determines which circle's center is
                              // closer to the origin

                              if (circ1.distance_from_origin > circ2.distance_from_origin)
                              {
                                 cout << "The first circle is further from the origin"
                                      << endl << endl;
                              }
                              else if (circ1.distance_from_origin < circ2.distance_from_origin)
                              {
                                 cout << "The first circle is closer to the origin"
                                      << endl << endl;
                              }
                              else
                                 cout << "The two circles are equidistant from the origin";
                              cout << endl << endl;

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

                              cout << "The area of the first circle is : ";
                              cout << circ1.area << endl;
                              cout << "The circumference of the first circle is: ";
                              cout << circ1.circumference << endl << endl;

                              cout << "The area of the second circle is : ";
                              cout << circ2.area << endl;
                              cout << "The circumference of the second circle is: ";
                              cout << circ2.circumference << endl << endl;

                              return 0;
                           }
```

Arrays of Structures

In the previous sample program we were interested in two instances of the `circle` structure. What if we need a much larger number, say 100, instances of this structure? Rather than define each one separately, we can use an **array of structures**. An array of structures is defined just like any other array. For example suppose we already have the following structure declaration in our program:

```
struct circle
{
    float centerX;    // x coordinate of center
    float centerY;    // y coordinate of center
    float radius;
    float area;
    float circumference;
    float distance_from_origin;  // distance of center from origin
};
```

Then the following statement defines an array, `circn`, which has 100 elements. Each of these elements is a `circle` structure variable:

```
circle circn[100];
```

Like the arrays encountered in previous lessons, you can access an array element using its subscript. So `circn[0]` is the first structure in the array, `circn[1]` is the second, and so on. The last structure in the array is `circn[99]`. To access a member of one of these array elements, we still use the dot operator. For instance, `circn[9].circumference` gives the `circumference` member of `circn[9]`. If we want to display the center and distance from the origin of the first 30 cir- cles we can use the following:

```
for (int count = 0; count < 30; count++)
{
    cout << circn[count].centerX << endl;
    cout << circn[count].centerY << endl;
    cout << circn[count].distance_from_origin;
}
```

When studying arrays you may have seen two-dimensional arrays which allow one to have "a collection of collections" of data. An array of structures allows one to do the same thing. However, we have already noted that structures permit you to group together items of different data type, whereas arrays do not. So an array of structures can sometimes be used when a two-dimensional array cannot.

Initializing Structures

We have already seen numerous examples of initializing variables and arrays at the time of their definition in the previous labs. Members of structures can also be initialized when they are defined. Suppose we have the following structure declaration in our program:

```
struct course
{
    string  discipline;
    int courseNumber;
    string courseTitle;
    short credits;
};
```

A structure variable `colonialHist` can be defined and initialized:

```
course colonialHist = {"HIST",302,"Colonial History",3};
```

The values in this list are assigned to `course`'s members in the order they appear. Thus, the string `"HIST"` is assigned to `colonialHist.discipline`, the integer `302` is assigned to `colonialHist.courseNumber`, the string `"Colonial History"` is assigned to `colonialHist.courseTitle`, and the short value `3` is assigned to `colonialHist.credits`. It is not necessary to initialize all the members of a structure variable. For example, we could initialize just the first member:

```
course colonialHist = {"HIST"};
```

This statement leaves the last three members uninitialized. We could also initialize only the first two members:

```
course colonialHist = {"HIST",302};
```

There is one important rule, however, when initializing structure members. If one structure member is left uninitialized, then all structure members that follow it must be uninitialized. In other words, we cannot skip members of a structure during the initialization process.

It is also worth pointing out that you cannot initialize a structure member in the declaration of the structure. The following is an illegal declaration:

```
// illegal structure declaration
struct course
{
    string discipline = "HIST";              // illegal
    int courseNumber = 302;                  // illegal
    string courseTitle = "Colonial History"; // illegal
    short credits = 3;                       // illegal
};
```

If we recall what a structure declaration does, it is clear why the above code is illegal. A structure declaration simply lets the compiler know what a structure is composed of. That is, the declaration creates a new data type (called course in this case). So the structure declaration does not define any variables. Hence there is nothing that can be initialized there.

Hierarchical (Nested) Structures

Often it is useful to nest one structure inside of another structure. Consider the following:

Sample Program 11.3:

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

struct center_struct
{
    float x;    // x coordinate of center
    float y;    // y coordinate of center
};

struct circle
{
    float radius;
    float area;
    float circumference;
    center_struct coordinate;
};

const float PI = 3.14159;

int main()
{
    circle circ1, circ2; // defines 2 circle structure variables
```

```
    cout << "Please enter the radius of the first circle: ";
    cin >> circ1.radius;
    cout << endl
        << "Please enter the x-coordinate of the center: ";
    cin >> circ1.coordinate.x;
    cout << endl
        << "Please enter the y-coordinate of the center: ";
    cin >> circ1.coordinate.y;

    circ1.area = PI * pow(circ1.radius, 2.0);
    circ1.circumference = 2 * PI * circ1.radius;

    cout << endl << endl;

    cout << "Please enter the radius of the second circle: ";
    cin >> circ2.radius;
    cout << endl
        << "Please enter the x-coordinate of the center: ";
    cin >> circ2.coordinate.x;
    cout << endl
        << "Please enter the y-coordinate of the center: ";
    cin >> circ2.coordinate.y;

    circ2.area = PI * pow(circ2.radius, 2.0);
    circ2.circumference = 2 * PI * circ2.radius;

    cout << endl << endl;

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

    cout << "The area of the first circle is : ";
    cout << circ1.area << endl;
    cout << "The circumference of the first circle is: ";
    cout << circ1.circumference << endl;
    cout << "Circle 1 is centered at (" << circ1.coordinate.x
        << "," << circ1.coordinate.y << ")." << endl << endl;

    cout << "The area of the second circle is : ";
    cout << circ2.area << endl;
    cout << "The circumference of the second circle is: ";
    cout << circ2.circumference << endl ;
    cout << "Circle 2 is centered at (" << circ2.coordinate.x
        << "," << circ2.coordinate.y << ")." << endl << endl;

    return 0;
}
```

Note that the programs in this lesson so far have not been modularized. Everything is done within the `main` function. In practice, this is not good structured programming. It can lead to unreadable and overly repetitious code. To solve this problem, we need to be able to pass structures and structure members to functions. In this next section, you will see how to do this.

Structures and Functions

Just as we can use other variables as function arguments, structure members may be used as function arguments. Consider the following structure declaration:

```
struct circle
{
     float centerX;       // x coordinate of center
     float centerY;       // y coordinate of center
     float radius;
     float area;
};
```

Suppose we also have the following function definition in the same program:

```
float computeArea(float r)
{
      return PI * r * r;  // PI must previously be defined as a
                          // constant float
}
```

Let `firstCircle` be a variable of the `circle` structure type. The following function call passes `firstCircle.radius` into `r`. The return value is stored in `firstCircle.area`:

```
firstCircle.area = computeArea(firstCircle.radius);
```

It is also possible to pass an entire structure variable into a function rather than an individual member.

```
struct course
{
     string discipline;
     int courseNumber;
     string courseTitle;
     short credits;
};


course pChem;
```

Suppose the following function definition uses a `course` structure variable as its parameter:

```
void displayInfo(course c)
{
     cout << c.discipline << endl;
     cout << c.courseNumber << endl;
     cout << c.courseTitle << endl;
     cout << c.credits << endl;
}
```

Then the following call passes the `pChem` variable into `c`:

```
displayInfo(pChem);
```

There are many other topics relating to functions and structures such as returning a structure from a function and pointers to structures. Although we do not have time to develop these concepts in this lab, the text does contain detailed coverage of these topics for the interested programmer.

PRE-LAB WRITING ASSIGNMENT

Fill-in-the-Blank Questions

1. The name of a structure is called the _____.

2. An advantage of structures over arrays is that structures allow one to use items of _____ data types, whereas arrays do not.

3. One structure inside of another structure is an example of a _____.

4. The variables declared inside the structure declaration are called the _____ of the structure.

5. When initializing structure members, if one structure member is left uninitialized, then all the structure members that follow must be _____.

6. A user defined data type is often an _____.

7. Once an array of structures has been defined, you can access an array element using its _____.

8. The _____ allows the programmer to access structure members.

9. You may not initialize a structure member in the _____.

10. Like variables, structure members may be used as _____ arguments.

LESSON 11 A

LAB 11.1   Working with Basic Structures

Bring in program `rect_struct.cpp` from the Lab 11 folder. The code is shown below.

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


// This program uses a structure to hold data about a rectangle
// PLACE YOUR NAME HERE

// Fill in code to declare a structure named rectangle which has
// members length, width, area, and perimeter all of which are floats

int main()
{
    // Fill in code to define a rectangle variable named box

    cout << "Enter the length of a rectangle: ";

    // Fill in code to read in the length member of box

    cout << "Enter the width of a rectangle: ";
```

continues

```
    // Fill in code to read in the width member of box


    cout << endl << endl;


    // Fill in code to compute the area member of box
    // Fill in code to compute the perimeter member of box


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


    // Fill in code to output the area with an appropriate message
    // Fill in code to output the perimeter with an appropriate message


    return 0;
}
```

Exercise 1: Fill in the code as indicated by the comments in bold.

Exercise 2: Add code to the program above so that the modified program will determine whether or not the rectangle entered by the user is a square.

Sample Run:

```
Enter the length of a rectangle: 7
Enter the width of a rectangle: 7
The area of the rectangle is 49.00
The perimeter of the rectangle is 28.00
The rectangle is a square.
```

LAB 11.2   Initializing Structures

Bring in program `init_struct.cpp` from the Lab 11 folder. The code is shown below.

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


// This program demonstrates partially initialized structure variables

// PLACE YOUR NAME HERE

struct taxPayer
{
    string name;
    long  socialSecNum;
    float taxRate;
    float income;
    float taxes;
};

int main()
{
```

```
    // Fill in code to initialize a structure variable named citizen1 so that
    // the first three members are initialized.  Assume the name is Tim
    // McGuiness, the social security number is 255871234, and the tax rate is .35

    // Fill in code to initialize a structure variable named citizen2 so that
    // the first three members are initialized.  Assume the name is John Kane,
    // the social security number is 278990582, and the tax rate is .29

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

    // calculate taxes due for citizen1

    // Fill in code to prompt the user to enter this year's income for the citizen1
    // Fill in code to read in this income to the appropriate structure member

    // Fill in code to determine this year's taxes for citizen1

    cout << "Name: " << citizen1.name << endl;
    cout << "Social Security Number: " << citizen1.socialSecNum << endl;

    cout << "Taxes due for this year: $" << citizen1.taxes << endl << endl;

    // calculate taxes due for citizen2

    // Fill in code to prompt the user to enter this year's income for citizen2
    // Fill in code to read in this income to the appropriate structure member

    // Fill in code to determine this year's taxes for citizen2

    cout << "Name: " << citizen2.name << endl;
    cout << "Social Security Number: " << citizen2.socialSecNum << endl;

    cout << "Taxes due for this year: $" << citizen2.taxes << endl << endl;

    return 0;
}
```

Exercise 1: Fill in the code as indicated by the comments in bold.

Sample Run:

```
Please input the yearly income for Tim McGuiness: 30000
Name: Tim McGuiness
Social Security Number: 255871234
Taxes due for this year: $10500.00

Please input the yearly income for John Kane: 60000
Name: John Kane
Social Security Number: 278990582
Taxes due for this year: $17400.00
```

LAB 11.3   Arrays of Structures

Bring in program `array_struct.cpp` from the Lab 11 folder. The code is shown below.

```cpp
#include <iostream>
#include <iomanip>

using namespace std;


// This program demonstrates how to use an array of structures
// PLACE YOUR NAME HERE

// Fill in code to declare a structure called taxPayer that has three
// members:  taxRate, income, and taxes — each of type float


int main()
{
    // Fill in code to define an array named citizen which holds
    // 5 taxPayers structures

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

    cout << "Please enter the annual income and tax rate for 5 tax payers: ";
    cout << endl << endl << endl;

    for(int count = 0;count < 5;count++)
    {

       cout << "Enter this year's income for tax payer " << (count + 1);
       cout << ": ";

       // Fill in code to read in the income to the appropriate place

       cout << "Enter the tax rate for tax payer # " << (count + 1);
       cout << ": ";

       // Fill in code to read in the tax rate to the appropriate place

       // Fill in code to compute the taxes for the citizen and store it
       // in the appropriate place


       cout << endl;
    }
```

```
cout << "Taxes due for this year: " << endl << endl;

// Fill in code for the first line of a loop that will output the
// tax information
{
        cout << "Tax Payer # " << (index + 1) << ": " << "$ "
              << citizen[index].taxes << endl;
}

return 0;
}
```

Exercise 1: Fill in the code as indicated by the comments in bold.

Exercise 2: In the previous code we have the following:

```
cout << "Tax Payer # " << (index+1) << ": " << "$ "
      << citizen[index].taxes << endl;
```

Why do you think we need `(index+1)` in the first line but `index` in the second?

Sample Run:

```
Enter this year's income for tax payer 1: 45000
Enter the tax rate for tax payer # 1: .19
Enter this year's income for tax payer 2: 60000
Enter the tax rate for tax payer # 2: .23
Enter this year's income for tax payer 3: 12000
Enter the tax rate for tax payer # 3: .01
Enter this year's income for tax payer 4: 104000
Enter the tax rate for tax payer # 4: .30
Enter this year's income for tax payer 5: 50000
Enter the tax rate for tax payer # 5: .22

Tax Payer # 1: $ 8550.00
Tax Payer # 2: $ 13800.00
Tax Payer # 3: $ 120.00
Tax Payer # 4: $ 31200.00
Tax Payer # 5: $ 11000.00
```

LESSON 11 B

LAB 11.4   Nested Structures

Bring in program `nestedRect_struct.cpp` from the Lab 11 folder. This code is very similar to the rectangle program from Lab 11.1. However, this time you will complete the code using nested structures. The code is shown below.

```
#include <iostream>
#include <iomanip>

using namespace std;
```

continues

```
// This program uses a structure to hold data about a rectangle
// It calculates the area and perimeter of a box

// PLACE YOUR NAME HERE

// Fill in code to declare a structure named dimensions that
// contains 2 float members, length and width

// Fill in code to declare a structure named rectangle that contains
// 3 members, area, perimeter, and sizes. area and perimeter should be
// floats, whereas sizes should be a dimensions structure variable

int main()
{
    // Fill in code to define a rectangle structure variable named box.

    cout << "Enter the length of a rectangle: ";

    // Fill in code to read in the length to the appropriate location

    cout << "Enter the width of a rectangle: ";

    // Fill in code to read in the width to the appropriate location

    cout << endl << endl;

    // Fill in code to compute the area and store it in the appropriate
    // location
    // Fill in code to compute the perimeter and store it in the
    // appropriate location

    cout << fixed << showpoint << setprecision(2);
    cout << "The area of the rectangle is " << box.attributes.area << endl;
    cout << "The perimeter of the rectangle is " <<  box.attributes.perimeter
         << endl;

    return 0;
}
```

Exercise 1: Fill in the code as indicated by the comments in bold.

Exercise 2: Modify the program above by adding a third structure named results which has two members area and perimeter. Adjust the rectangle structure so that both of its members are structure variables.

Exercise 3: Modify the program above by adding functions that compute the area and perimeter. The structure variables should be passed as arguments to the functions.

Sample Run:

```
Enter the length of a rectangle: 9
Enter the width of a rectangle: 6
The area of the rectangle is 54.00
The perimeter of the rectangle is 30.00
```

LAB 11.5   Student Generated Code Assignments

Option 1: Re-write Sample Program 11.2 so that it works for an array of structures. Write the program so that it compares 6 circles. You will need to come up with a new way of determining which circle's center is closest to the origin.

Option 2: Write a program that uses a structure to store the following information for a particular month at the local airport:

> Total number of planes that landed
> Total number of planes that departed
> Greatest number of planes that landed in a given day that month
> Least number of planes that landed in a given day that month

The program should have an array of twelve structures to hold travel information for the entire year. The program should prompt the user to enter data for each month. Once all data is entered, the program should calculate and output the average monthly number of landing planes, the average monthly number of departing planes, the total number of landing and departing planes for the year, and the greatest and least number of planes that landed on any one day (and which month it occurred in).