

Chapter 11:

Structured Data



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11.1

Abstract Data Types



Abstract Data Types

- A data type that specifies
 - values that can be stored
 - operations that can be done on the values
- User of an abstract data type does not need to know the implementation of the data type, *e.g.*, how the data is stored
- ADTs are created by programmers

Abstraction and Data Types

- Abstraction: a definition that captures general characteristics without details
 - Ex: An abstract triangle is a 3-sided polygon. A specific triangle may be scalene, isosceles, or equilateral
- Data Type defines the values that can be stored in a variable and the operations that can be performed on it

11.2



Combining Data into Structures

Combining Data into Structures

- Structure: C++ construct that allows multiple variables to be grouped together
- General Format:

```
struct <structName>
{
    type1 field1;
    type2 field2;
    . . .
};
```

Example struct Declaration

```
struct Student
```

```
{
```

```
    int studentID;
```

```
    string name;
```

```
    short yearInSchool;
```

```
    double gpa;
```

```
};
```

structure tag



structure members

struct Declaration Notes

- Must have ; after closing }
- struct names commonly begin with uppercase letter
- Multiple fields of same type can be in comma-separated list:

```
string name,  
    address;
```


Defining Variables

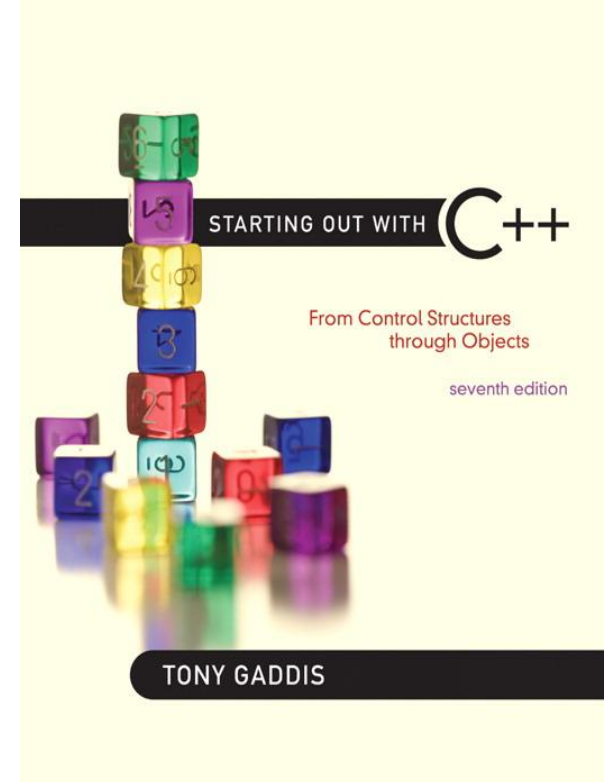
- `struct` declaration does not allocate memory or create variables
- To define variables, use structure tag as type name:

```
Student bill;
```

bill

studentID	<input type="text"/>
name	<input type="text"/>
yearInSchool	<input type="text"/>
gpa	<input type="text"/>

11.3



Accessing Structure Members

Accessing Structure Members

- Use the dot (.) operator to refer to members of struct **variables**:

```
cin >> stu1.studentID;  
getline(cin, stu1.name);  
stu1.gpa = 3.75;
```

- Member variables can be used in any manner appropriate for their data type

Program 11-1

```
1  // This program demonstrates the use of structures.
2  #include <iostream>
3  #include <string>
4  #include <iomanip>
5  using namespace std;
6
7  struct PayRoll
8  {
9      int empNumber;    // Employee number
10     string name;      // Employee's name
11     double hours;     // Hours worked
12     double payRate;   // Hourly payRate
13     double grossPay;  // Gross pay
14 };
15
16 int main()
17 {
18     PayRoll employee; // employee is a PayRoll structure.
19
20     // Get the employee's number.
21     cout << "Enter the employee's number: ";
22     cin >> employee.empNumber;
23
24     // Get the employee's name.
25     cout << "Enter the employee's name: ";
```

```
26     cin.ignore(); // To skip the remaining '\n' character
27     getline(cin, employee.name);
28
29     // Get the hours worked by the employee.
30     cout << "How many hours did the employee work? ";
31     cin >> employee.hours;
32
33     // Get the employee's hourly pay rate.
34     cout << "What is the employee's hourly payRate? ";
35     cin >> employee.payRate;
36
37     // Calculate the employee's gross pay.
38     employee.grossPay = employee.hours * employee.payRate;
39
40     // Display the employee data.
41     cout << "Here is the employee's payroll data:\n";
42     cout << "Name: " << employee.name << endl;
43     cout << "Number: " << employee.empNumber << endl;
44     cout << "Hours worked: " << employee.hours << endl;
45     cout << "Hourly payRate: " << employee.payRate << endl;
46     cout << fixed << showpoint << setprecision(2);
47     cout << "Gross Pay: $" << employee.grossPay << endl;
48     return 0;
49 }
```

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

Displaying a struct Variable

- To display the contents of a struct variable, must display each field separately, using the dot operator:

```
cout << bill; // won't work
cout << bill.studentID << endl;
cout << bill.name << endl;
cout << bill.yearInSchool;
cout << " " << bill.gpa;
```

Comparing struct Variables

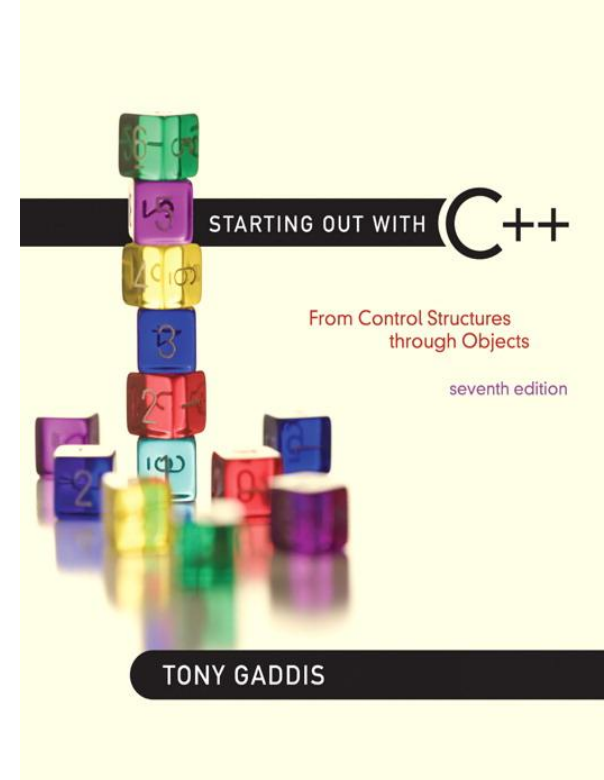
- Cannot compare struct variables directly:

```
if (bill == william) // won't work
```

- Instead, must compare on a field basis:

```
if (bill.studentID ==  
    william.studentID) ...
```


11.4



Initializing a Structure

Initializing a Structure

- `struct` variable can be initialized when defined:

```
Student s = {11465, "Joan", 2, 3.75};
```

- Can also be initialized member-by-member after definition:

```
s.name = "Joan";
```

```
s.gpa = 3.75;
```

More on Initializing a Structure

- May initialize only some members:

```
Student bill = {14579};
```

- Cannot skip over members:

```
Student s = {1234, "John", ,  
             2.83}; // illegal
```

- Cannot initialize in the structure declaration, since this does not allocate memory

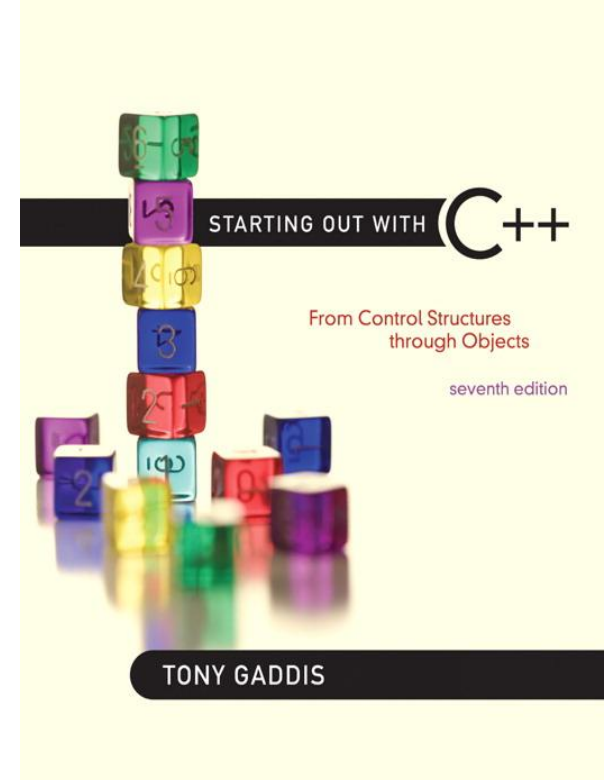
Excerpts From Program 11-3

```
8  struct EmployeePay
9  {
10     string name;           // Employee name
11     int empNum;            // Employee number
12     double payRate;        // Hourly pay rate
13     double hours;          // Hours worked
14     double grossPay;       // Gross pay
15 };
```

```
19     EmployeePay employee1 = {"Betty Ross", 141, 18.75};
20     EmployeePay employee2 = {"Jill Sandburg", 142, 17.50};
```

11.5

Arrays of Structures



Arrays of Structures

- Structures can be defined in arrays
- Can be used in place of parallel arrays
- Individual structures accessible using subscript notation
- Fields within structures accessible using dot notation:

```
const int NUM_STUDENTS = 20;  
Student stuList[NUM_STUDENTS];
```

```
cout << stuList[5].studentID;
```

Program 11-4

```
1  // This program uses an array of structures.
2  #include <iostream>
3  #include <iomanip>
4  using namespace std;
5
6  struct PayInfo
7  {
8      int hours;           // Hours worked
9      double payRate;     // Hourly pay rate
10 };
11
12 int main()
13 {
14     const int NUM_WORKERS = 3;    // Number of workers
15     PayInfo workers[NUM_WORKERS]; // Array of structures
16     int index;                    // Loop counter
17
```

```

18 // Get employee pay data.
19 cout << "Enter the hours worked by " << NUM_WORKERS
20     << " employees and their hourly rates.\n";
21
22 for (index = 0; index < NUM_WORKERS; index++)
23 {
24     // Get the hours worked by an employee.
25     cout << "Hours worked by employee #" << (index + 1);
26     cout << ": ";
27     cin >> workers[index].hours;
28
29     // Get the employee's hourly pay rate.
30     cout << "Hourly pay rate for employee #";
31     cout << (index + 1) << ": ";
32     cin >> workers[index].payRate;
33     cout << endl;
34 }
35
36 // Display each employee's gross pay.
37 cout << "Here is the gross pay for each employee:\n";
38 cout << fixed << showpoint << setprecision(2);
39 for (index = 0; index < NUM_WORKERS; index++)
40 {
41     double gross;
42     gross = workers[index].hours * workers[index].payRate;
43     cout << "Employee #" << (index + 1);
44     cout << ": $" << gross << endl;
45 }
46 return 0;
47 }

```


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

11.6

Nested Structures



Nested Structures

A structure can contain another structure as a member:

```
struct PersonInfo
{
    string name,
        address,
        city;
};
struct Student
{
    int studentID;
    PersonInfo pData;
    short yearInSchool;
    double gpa;
};
```

Members of Nested Structures

- Use the dot operator multiple times to refer to fields of nested structures:

```
Student s;  
s.pData.name = "Joanne";  
s.pData.city = "Tulsa";
```

11.7



Structures as Function Arguments

Structures as Function Arguments

- May pass members of `struct` variables to functions:

```
computeGPA (stu.gpa) ;
```

- May pass entire `struct` variables to functions:

```
showData (stu) ;
```

- Can use reference parameter if function needs to modify contents of structure variable

Excerpts from Program 11-6

```
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 };
```

```
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 }
```

Structures as Function Arguments - Notes

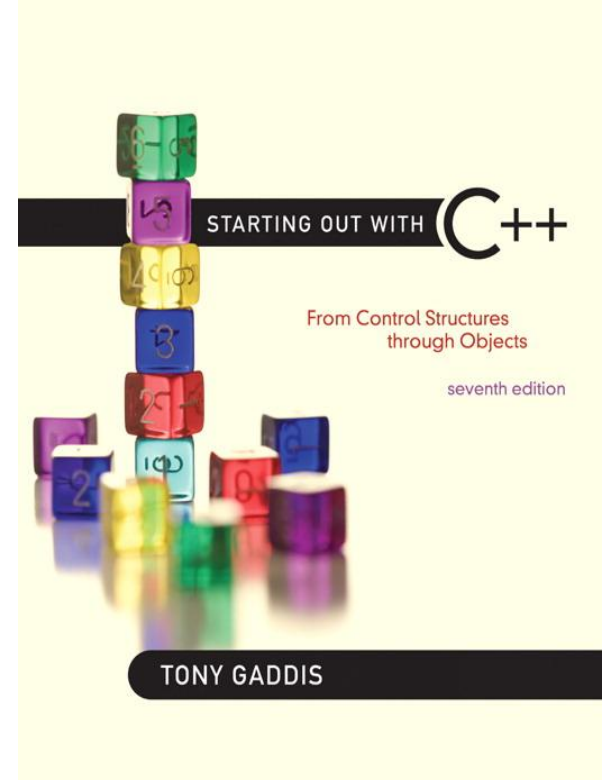
- Using value parameter for structure can slow down a program, waste space
- Using a reference parameter will speed up program, but function may change data in structure
- Using a `const` reference parameter allows read-only access to reference parameter, does not waste space, speed

Revised showItem Function

```
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;
}
```

11.8

Returning a Structure from a Function



Returning a Structure from a Function

- Function can return a `struct`:

```
Student getStudentData();    // prototype  
stu1 = getStudentData();    // call
```

- Function must define a local structure
 - for internal use
 - for use with `return` statement

Returning a Structure from a Function - Example

```
Student getStudentData()  
{  
    Student tempStu;  
    cin >> tempStu.studentID;  
    getline(cin, tempStu.pData.name);  
    getline(cin, tempStu.pData.address);  
    getline(cin, tempStu.pData.city);  
    cin >> tempStu.yearInSchool;  
    cin >> tempStu.gpa;  
    return tempStu;  
}
```

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();
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

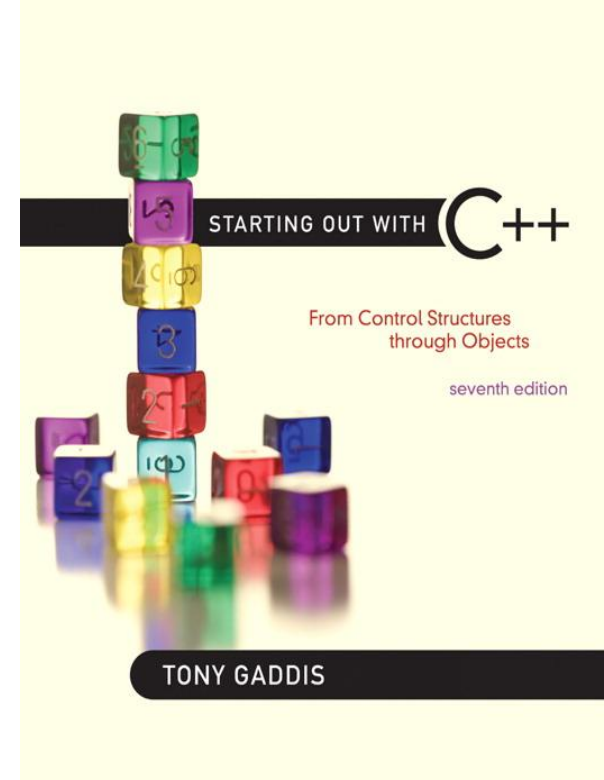
```

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

```

11.9

Pointers to Structures



Pointers to Structures

- A structure variable has an address
- Pointers to structures are variables that can hold the address of a structure:

```
Student *stuPtr;
```

- Can use & operator to assign address:

```
stuPtr = & stu1;
```

- Structure pointer can be a function parameter

Accessing Structure Members via Pointer Variables

- Must use `()` to dereference pointer variable, not field within structure:

```
cout << (*stuPtr).studentID;
```

- Can use structure pointer operator to eliminate `()` and use clearer notation:

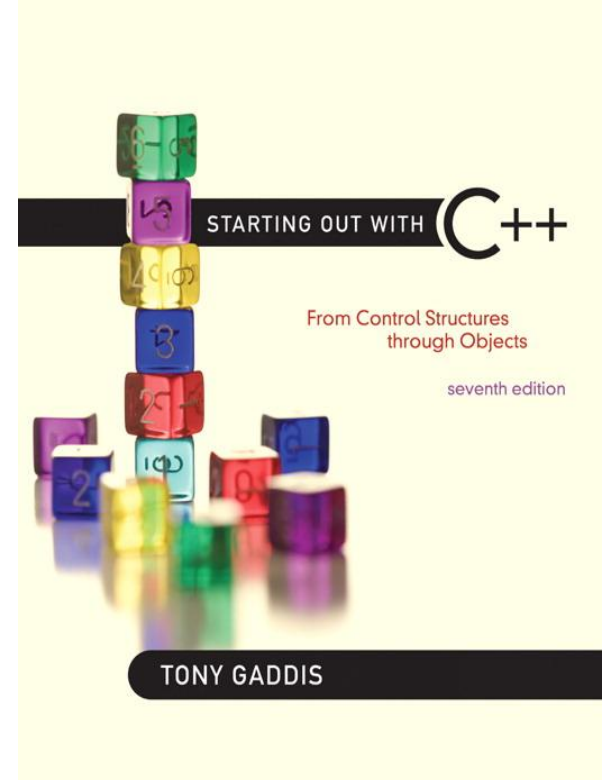
```
cout << stuPtr->studentID;
```

From Program 11-8

```
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 }
```

11.11

Unions



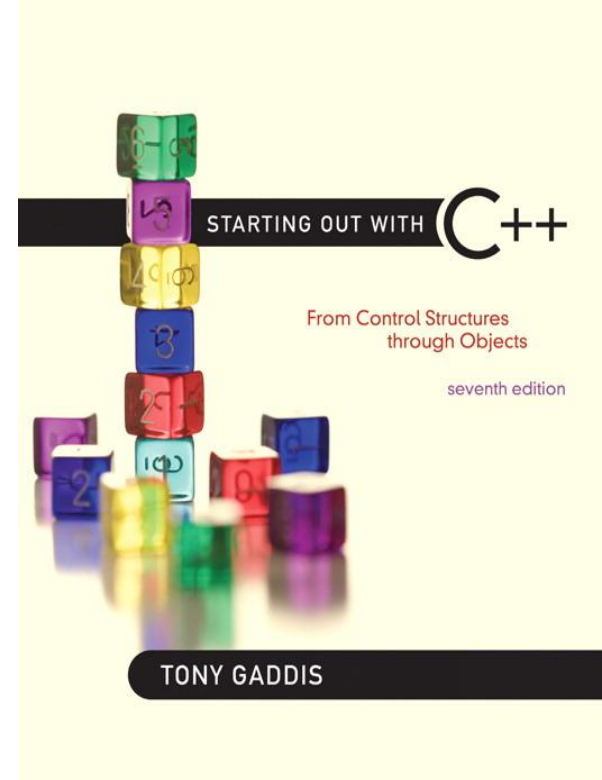
Unions

- Similar to a `struct`, but
 - all members share a single memory location, and
 - only one member of the union can be used at a time
- Declared using `union`, otherwise the same as `struct`
- Variables defined as for `struct` variables

Anonymous Union

- A union without a union tag:
`union { ... };`
- Must use `static` if declared outside of a function
- Allocates memory at declaration time
- Can refer to members directly without dot operator
- Uses only one memory location, saves space

11.12



Enumerated Data Types

Enumerated Data Types

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

Enumerated Data Types

- Example:

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

- **The identifiers** MONDAY, TUESDAY, WEDNESDAY, THURSDAY, **and** FRIDAY, which are listed inside the braces, are *enumerators*. They represent the values that belong to the `Day` data type.

Enumerated Data Types

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

Note that the enumerators are not strings, so they aren't enclosed in quotes. They are identifiers.

Enumerated Data Types

- Once you have created an enumerated data type in your program, you can define variables of that type. Example:

```
Day workDay;
```

- This statement defines `workDay` as a variable of the `Day` type.

Enumerated Data Types

- We may assign any of the enumerators MONDAY, TUESDAY, WEDNESDAY, THURSDAY, or FRIDAY to a variable of the Day type. Example:

```
workDay = WEDNESDAY;
```

Enumerated Data Types

- So, what is an *enumerator*?
- Think of it as an integer named constant
- Internally, the compiler assigns integer values to the enumerators, beginning at 0.

Enumerated Data Types

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

In memory...

MONDAY = 0

TUESDAY = 1

WEDNESDAY = 2

THURSDAY = 3

FRIDAY = 4

Enumerated Data Types

- Using the `Day` declaration, the following code...

```
cout << MONDAY << " "  
      << WEDNESDAY << " "  
      << FRIDAY << endl;
```

...will produce this output:

```
0  2  4
```

Assigning an integer to an enum Variable

- You cannot directly assign an integer value to an enum variable. This will not work:

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

- Instead, you must cast the integer:

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


Assigning an Enumerator to an `int` Variable

- You CAN assign an enumerator to an `int` variable. For example:

```
int x;  
x = THURSDAY;
```

- This code assigns 3 to `x`.

Comparing Enumerator Values

- Enumerator values can be compared using the relational operators. For example, using the `Day` data type the following code will display the message "Friday is greater than Monday."

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

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     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 }
```

Program 11-12 (Continued)

```
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
```

Enumerated Data Types

- Program 11-12 shows enumerators used to control a loop:

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

Anonymous Enumerated Types

- An *anonymous enumerated type* is simply one that does not have a name. For example, in Program 11-13 we could have declared the enumerated type as:

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

Using Math Operators with `enum` Variables

- You can run into problems when trying to perform math operations with `enum` variables. For example:

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

- The third statement will not work because the expression `day1 + 1` results in the integer value 2, and you cannot store an int in an `enum` variable.

Using Math Operators with `enum` Variables

- You can fix this by using a cast to explicitly convert the result to `Day`, as shown here:

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


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:

```
enum Day { MONDAY, TUESDAY, WEDNESDAY,  
           THURSDAY, FRIDAY };  
const int NUM_DAYS = 5;  
double sales[NUM_DAYS];  
sales[MONDAY] = 1525.0;  
sales[TUESDAY] = 1896.5;  
sales[WEDNESDAY] = 1975.63;  
sales[THURSDAY] = 1678.33;  
sales[FRIDAY] = 1498.52;
```

Using an `enum` Variable to Step through an Array's Elements

- Remember, though, you cannot use the `++` operator on an `enum` variable. So, the following loop will NOT work.

```
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];
}
```

Using an `enum` Variable to Step through an Array's Elements

- You must rewrite the loop's update expression using a cast instead of `++`:

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

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  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 11-13 *(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

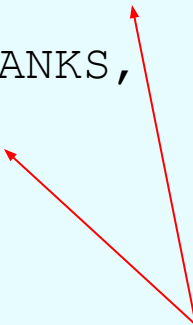
```
Enter the sales for day 0: 1525.00 [Enter]
Enter the sales for day 1: 1896.50 [Enter]
Enter the sales for day 2: 1975.63 [Enter]
Enter the sales for day 3: 1678.33 [Enter]
Enter the sales for day 4: 1498.52 [Enter]
The total sales are $8573.98
```

Enumerators Must Be Unique Within the same Scope

- Enumerators 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:

```
enum Presidents { MCKINLEY, ROOSEVELT, TAFT };
```

```
enum VicePresidents { ROOSEVELT, FAIRBANKS,  
                      SHERMAN };
```



ROOSEVELT is declared twice.

Declaring the Type and Defining the Variables in One Statement

- You can declare an enumerated data type and define one or more variables of the type in the same statement. For example:

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

This code declares the `Car` data type and defines a variable named `sportsCar`.