Outline

- Class Scope
- Constructors and Destructors
- Copy Constructors
- const Members
- Member Initializer
- friend Functions and Classes
- Static Members
- Information Hiding and Abstract Data Types
- Q&A
Preprocessor Wrappers

- Prevents code from being included more than once
  ```
  #ifndef TIME_H
  #define TIME_H
  ...
  // code
  #endif
  ```

- Prevents multiple-definition errors
Stream Manipulator `setfill`

- Specifies the fill character
  - When an output field wider than the number of digits in the output value
  - Appears to the left of the digits in the number
- Applies for all subsequent values
#ifndef TIME_H
#define TIME_H

class Time {
    public:
        Time();
        void setTime(int,int,int);
        void printUniversal();
        void printStandard();

    private:
        int hour;
        int minute;
        int second;
    };

#endif

---------

#include <iostream>
using std::cout;
#include <iomanip>
using std::setfill;
using std::setw;
#include "Time.h"
#include <iostream>
using std::cout;
using std::endl;

#include "Time.h"

int main()
{  
    Time t;

    t.printUniversal();
    t.printStandard();

    t.setTime( 13, 27, 6 );
    t.printUniversal();
    t.printStandard();

    t.setTime( 99, 99, 99 );
    t.printUniversal();
    t.printStandard();
    cout << endl;

    return 0;
}
sizeof Operator for Classes

- Applying operator sizeof to a class name or to an object of that class
  - will report only the size of the class’s data members

- The compiler creates one copy (only) of the member functions for all objects of the class
  - All objects of the class share this copy

- Each object needs its own copy of the class’s data
Class Scope

Class scope contains
- Data members (variables declared in the class definition)
- Member functions (functions declared in the class definition)

Nonmember functions are defined at file scope

Within a class’s scope
- Class members are accessible by all member functions

Outside a class’s scope
- Public class members are referenced through a handle
  - An object name, a reference to an object, or a pointer to an object

Class Scope Cont’d

- Variables declared in a member function
  - Have block scope
  - Known only to that function

- Hiding a class-scope variable
  - In a member function, define a variable with the same name as a variable with class scope
  - To access the hidden class-scope variable, use the scope resolution operator (::)
Class Scope Cont’d

- **Dot member selection operator (.)**
  - Accesses the object’s members
  - Used with an object’s name or with a reference to an object

- **Arrow member selection operator (->)**
  - Accesses the object’s members
  - Used with a pointer to an object
Constructors with Default Arguments

- Can initialize data members to a consistent state
- Constructor that defaults all its arguments
  - A default constructor
  - Maximum of one default constructor per class
- Any change to the default argument values of a function requires the client code to be recompiled
Destructors

- A special member function
  - ~Time()

- Called implicitly when an object is destroyed
  - When program execution leaves the scope in which that object was instantiated
  - Performs “termination housekeeping”
  - Then the system reclaims the object’s memory
Destructors Cont’d

- Receives no parameters and returns no value
  - May not specify a return type—not even void
- A class may have only one destructor
- If the programmer does not explicitly provide a destructor, the compiler creates an “empty” destructor
When Constructors and Destructors are Called?

- Called implicitly by the compiler
- In general, destructor calls are made in the reverse order of the corresponding constructor calls
- Storage classes of objects can alter the order in which destructors are called
Objects Defined in Global Scope

- Constructors are called before any other function (including main) in that file begins execution.
- The corresponding destructors are called when main terminates.

- **Function exit**
  - Forces a program to terminate immediately.
  - Often used to terminate a program when an error is detected.

- **Function abort**
  - Forces the program to terminate immediately without allowing the destructors of any objects to be called.
  - Usually used to indicate an abnormal termination of the program.
Automatic Objects

- Constructors and destructors are called each time execution enters and leaves the scope of the object.
- Automatic object destructors are not called if the program terminates with an exit or abort function.
Static Local Objects

- Constructor is called only once
  - When execution first reaches where the object is defined

- Destructor is called when main terminates or the program calls function exit
  - Destructor is not called if the program terminates with a call to function abort

- Global and static objects are destroyed in the reverse order of their creation

#include <string>
using std::string;

#ifndef CREATE_H
#define CREATE_H

class CreateAndDestroy
{
    public:
        CreateAndDestroy( int, string );
        ~CreateAndDestroy();
    private:
        int objectID;
        string message;
};
#endif

#include <iostream>
using std::cout;
using std::endl;

#include "CreateAndDestroy.h"

CreateAndDestroy::CreateAndDestroy( int ID, string messageString )
{
    objectID = ID;
    message = messageString;
    cout << "Object " << objectID;
    cout << " constructor runs ";
    cout << message << endl;
}

CreateAndDestroy::~CreateAndDestroy()
{
    cout << "Object " << objectID;
    cout << " destructor runs ";
    cout << message << endl;
}

```cpp
#include <iostream>
using std::cout;
using std::endl;
#include "CreateAndDestroy.h"

void create( void );
CreateAndDestroy first( 1,
    "(global before main)" );

int main()
{
    cout << "EXECUTION BEGINS" << endl;
    CreateAndDestroy second( 2,
        "(local automatic in main)" );
    static CreateAndDestroy third( 3, "(local static in main)" );
    create();
    cout << "EXECUTION RESUMES" << endl;
    CreateAndDestroy fourth( 4,
        "(local automatic in main)" );
    cout << "EXECUTION ENDS" << endl;
    return 0;
}

void create( void )
{
    cout << "CREATE BEGINS" << endl;
    CreateAndDestroy fifth( 5,
        "(local automatic in create)" );
    static CreateAndDestroy sixth( 6, "(local static in create)" );
    CreateAndDestroy seventh( 7,
        "(local automatic in create)" );
    cout << "CREATE ENDS" << endl;
}
```
Class CreateAndDestroy Cont’d

1. Object 1 constructor runs
2. EXECUTION BEGINS
3. Object 2 constructor runs
4. Object 3 constructor runs
5. CREATE BEGINS
6. Object 5 constructor runs
7. Object 6 constructor runs
8. Object 7 constructor runs
9. CREATE ENDS
10. Object 7 destructor runs

1. Object 5 destructor runs
2. EXECUTION RESUMES
3. Object 4 constructor runs
4. EXECUTION ENDS
5. Object 4 destructor runs
6. Object 2 destructor runs
7. Object 6 destructor runs
8. Object 3 destructor runs
9. Object 1 destructor runs

Returning a Reference to an Object

- **Alias for the name of an object**
  - May be used on the left side of an assignment statement
  - A const reference cannot be used as a modifiable lvalue

- A public member function of a class returns a reference to a private data member of that class
  - Client code could alter private data
  - Same problem would occur if a pointer to private data were returned

Default Memberwise Assignment

- **Assignment operator** (=)
- **Can be used to assign an object to another object of the same type**
  - Each data member of the right object is assigned to the same data member in the left object
  - Shallow copy
- **When data members contain pointers to dynamically allocated memory**
  - May cause serious problems

#ifndef DATE_H
#define DATE_H

class Date
{
    public:
        Date( int = 1, int = 1, int = 2000 );
        void print();

    private:
        int month;
        int day;
        int year;
};
#endif

#include <iostream>
using std::cout;
using std::endl;

#include "Date.h"

Date::Date( int m, int d, int y )
{
    month = m;
    day = d;
    year = y;
}

void Date::print()
{
    cout << month << '/'
        << day << '/'
        << year;
}
```cpp
#include <iostream>
using std::cout;
using std::endl;

#include "Date.h"

int main()
{
    Date date1( 7, 4, 2004 );
    Date date2;

    cout << "date1 = ";
    date1.print();
    cout << "\ndate2 = ";
    date2.print();

    date2 = date1;

    date2.print();
    cout << endl;

    return 0;
}
```
Copy Constructors

- Enables pass-by-value for objects
  - Used to copy original object’s values into new object to be passed to a function or returned from a function

- Compiler provides a default copy constructor
  - Copies each member of the original object into the corresponding member of the new object (i.e., memberwise assignment)
  - Shallow copy
When data members contain pointers to dynamically allocated memory

- May cause serious problems
  - Need to have a deep copy
  - May need a destructor and operator=
class Point
{
public:
    ... Point();
    Point(const Point& p);
    ... 
private:
    int x;
    int y;
};

Point::Point(int px, int py)
{
    x = px;
    y = py;
}

Point::Point(const Point& p)
{
    x = p.x;
    y = p.y;
}
**Const Objects**

- **Keyword const**
- **The object is not modifiable**
  - compilation errors
  - Attempts to modify the object are caught at compile time rather than causing execution-time errors
- **A const object cannot be modified by assignment, so it must be initialized**
Const Member Functions

- Only for const objects
- Not allowed to modify the object
- Specified as const both in its prototype and in its definition
- Not allowed for constructors and destructors
- Can be overloaded with a non-const version

- The compiler chooses which overloaded member function to use based on the object on which the function is invoked

Class Time

class Time
{
    public:
        Time( int = 0, int = 0, int = 0 );

        void setTime( int, int, int );
        void setHour( int );
        void setMinute( int );
        void setSecond( int );

        int getHour() const;
        int getMinute() const;
        int getSecond() const;

        void printUniversal() const;
        void printStandard(); // const

    private:
        int hour;
        int minute;
        int second;
};

Time::Time( int hour, int minute, int second )
{
    setTime( hour, minute, second );
}

void Time::setTime( int hour, int minute, int second )
{
    setHour( hour );
    setMinute( minute );
    setSecond( second );
}

void Time::setHour( int h )
{
    hour = ( h >= 0 && h < 24 ) ? h : 0;
}

void Time::setMinute( int m )
{
    minute = ( m >= 0 && m < 60 ) ? m : 0;
}

void Time::setSecond( int s )
{
    second = ( s >= 0 && s < 60 ) ?
        s : 0;
}

int Time::getHour() const
{
    return hour;
}

int Time::getMinute() const
{
    return minute;
}

int Time::getSecond() const
{
    return second;
}

void Time::printUniversal() const
{
    cout << setfill( '0' )
        << setw( 2 ) << hour << ':'
        << setw( 2 ) << minute << ':'
        << setw( 2 ) << second;
}

void Time::printStandard() //
    const
{
    cout << ( ( hour == 0 || hour
        == 12 ) ? 12 : hour % 12 )
        << ':'
        << setfill( '0' )
        << setw( 2 ) << minute << ':'
        << setw( 2 ) << second
        << ( hour < 12 ? " AM" : " PM" );
}
int main()
{
    Time wakeUp(6,45,0);
    const Time noon(12,0,0);

    wakeUp.setHour(18);
    noon.setHour(12);
    wakeUp.getHour();
    noon.getMinute();
    noon.printUniversal();
    noon.printStandard();

    return 0;
}

Member Initializer

- Required for initializing,
  - Const data members
  - Data members that are references

- Can be used for any data member

- Member initializer list
  - Between a constructor’s parameter list and the constructor’s body
  - Separated from the parameter list with a colon (:
  - The data member name followed by parentheses containing the member’s initial value
Member Initializer

- Member initializer list
  - Multiple member initializers are separated by commas
  - Executes before the body of the constructor executes

- For a const data member of a class, a member initializer must be used to provide the constructor with the initial value of the data member for an object of the class
  - The same is true for references
class Increment
{
  public:
    Increment(int c=0, int i=1);
    void addIncrement();
    void print() const;
  
  private:
    int count;
    const int increment;
};

Increment::Increment( int c,
                       int i )
    : count( c ),
      increment( i )
    // initializer for
    // non-const member
    // required initializer
    // for const member
{ }

void Increment::print() const
{ }

  cout << "count = "
    << count << ", increment = "
    << increment << endl;
}
Composition

Has-a relationship

A class can have objects of other classes as members

Initializing member objects

- Member initializers pass arguments from the object’s constructor to member-object constructors

- Member objects are constructed in the order in which they are declared in the class definition
  - Not in the order they are listed in the constructor’s member initializer list
  - Before the enclosing class object (host object) is constructed

class Date
{
    public:
        Date( int = 1, int = 1, int = 1900 );
        void print() const;
        ~Date();

    private:
        int month;
        int day;
        int year;

        int checkDay( int ) const;
};

Date::Date( int mn, int dy, int yr )
{
    if ( mn > 0 && mn <= 12 )
        month = mn;
    else
    {
        month = 1;
        cout << "Invalid month (";
        cout << mn << ") set to 1.\n";
    }
    year = yr;
    day = checkDay( dy );

    cout << "Date object constructor for date ";
    print();
    cout << endl;
}
void Date::print() const
{
    cout << month << '/' << day
    << '/' << year;
}

Date::~Date()
{
    cout << "Date object destructor for date ";
    print();
    cout << endl;
}

int Date::checkDay( int testDay )
{
    static const int
daysPerMonth[ 13 ] =
    { 0, 31, 28, 31, 30, 31, 30,
    31, 31, 30, 31, 30, 31 };

    if ( testDay > 0 && testDay <=
    daysPerMonth[ month ] )
        return testDay;

    if ( month == 2 && testDay ==
    29 && ( year % 400 == 0 ||
    ( year % 4 == 0 && year %
    100 != 0 ) ) )
        return testDay;

    cout << "Invalid day (" 
    << testDay << ") set to 1.\n";
    return 1;
class Employee
{
    public:
        Employee( const char * const name,
                  const char * const last,
                  const Date & birthDate,
                  const Date & hireDate )
            : birthDate( birthDate ),
              hireDate( hireDate )
        {
            int length = strlen( name );
            length = ( length < 25 ? length : 24 );
            strncpy( firstName, name, length );
            firstName[ length ] = '\0';

            length = strlen( last );
            length = ( length < 25 ? length : 24 );
            strncpy( lastName, last, length );
            lastName[ length ] = '\0';

            cout << "Employee object constructor: " << endl;
            cout << firstName << ' ' << lastName << endl;
        }

private:
    char firstName[ 25 ];
    char lastName[ 25 ];
    const Date birthDate;
    const Date hireDate;
};
Class Employee Cont'd

```cpp
template

void Employee::print() const
{
    cout << lastName << ',', "
    << firstName << " Hired: ";
    hireDate.print();
    cout << " Birthday: ";
    birthDate.print();
    cout << endl;
}

Employee::~Employee()
{
    cout << "Employee object
    destructor: ";
    cout << lastName << ',', "
    << firstName << endl;
}
```

```cpp
int main()
{
    Date birth( 7, 24, 1949 );
    Date hire( 3, 12, 1988 );
    Employee manager( "Bob", "Blue", birth, hire );
    cout << endl;
    manager.print();
    cout << endl;
    cout << "Test Date constructor with invalid values:
    ";
    Date lastDayOff( 14, 35, 1994 );
    cout << endl;
    return 0;
}
```

Friend Functions and Classes of a Class

- Defined outside that class’s scope
- Has the right to access the non-public and public members of that class
- Standalone functions or entire classes
- Can enhance performance
- The function prototype in the class definition preceded by keyword friend
Friend Functions and Classes of a Class Cont’d

- Member access notions of private, protected, and public are not relevant to friend declarations
  - Friend declarations can be placed anywhere in a class definition

- Place a declaration of the form “friend class Class2;” in the definition of class Class1
  - All member functions of class Class2 are friends of class Class1
Class Count

class Count
{
    friend void setX( Count &, int );

    public
    Count()
        : x( 0 )
    {
    }

    void print() const
    {
        cout << x << endl;
    }

    private:
    int x;
};

void setX( Count &c, int val )
{
    c.x = val;
}

int main()
{
    Count counter;
    cout << "counter.x: ";
    counter.print();
    setX( counter, 8 );
    cout << "counter.x after call to setX friend function: ";
    counter.print();
    return 0;
}
Friend Functions and Classes of a Class Cont’d

- For class B to be a friend of class A, class A must explicitly declare (in its definition) that class B is its friend.
- Friendship relation
  - Neither symmetric nor transitive
- It is possible to specify overloaded functions as friends of a class
  - Each overloaded function intended to be a friend must be explicitly declared as a friend of the class.

**this Pointer**

- Access to an object itself through a pointer called `this` (keyword)
- `this` pointer is not part of the object itself
- Passed (by the compiler) as an implicit argument to each of the object’s non-static member functions
- Implicit access when accessing members directly
Class Test

Type of the this pointer

- Depends on the type of the object and whether the executing member function is const

```cpp
class Test
{
    public:
        Test( int = 0 );
        void print() const;  
    private:
        int x;
};

void Test::print() const
{
    cout << "x= " << x;
    cout << "\nthis->x=" << this->x;
    cout << "\n(*this).x=" << ( *this ).x << endl;
}

int main()
{
    Test testObject( 12 );
    testObject.print();
    return 0;
}
```

Cascaded Member-Function Calls

- Enabled by member functions returning the dereferenced this pointer

```cpp
t.setMinute( 30 ).setSecond( 22 );
```
- Calls `t.setMinute( 30 );`
- Then calls `t.setSecond( 22 );`
Class Time

class Time
{
    public:
        Time( int = 0, int = 0, int = 0 );

        Time &setTime( int, int, int );
        Time &setHour( int );
        Time &setMinute( int );
        Time &setSecond( int );

        int getHour() const;
        int getMinute() const;
        int getSecond() const;

    private:
        int hour;
        int minute;
        int second;
};

Time::Time( int hr, int min, int sec )
{
    setTime( hr, min, sec );
}

Time &Time::setTime(int h, int m, int s)
{
    setHour( h );
    setMinute( m );
    setSecond( s );
    return *this;
}

Time &Time::setHour( int h )
{
    hour = ( h >= 0 && h < 24 ) ? h : 0;
    return *this;
}

Time &Time::setMinute( int m )
{
    minute = ( m >= 0 && m < 60 ) ? m : 0;
    return *this;
}
Class Time Cont’d

```cpp
void Time::printUniversal() const
{
    cout << setfill( '0' ) << setw( 2 ) << hour << ':'
    << setw( 2 ) << minute << ':' << setw( 2 ) << second;
}
```

```cpp
void Time::printStandard() const
{
    cout << ( ( hour == 0 || hour == 12 ) ? 12 : hour % 12 )
    << ':' << setfill( '0' ) << setw( 2 ) << minute
    << ':' << setw( 2 ) << second << ( hour < 12 ? " AM" : " PM" );
}
```

```cpp
Time &Time::setSecond( int s )
{
    second = ( s >= 0 && s < 60 ) ? s : 0;
    return *this;
}
```

```cpp
int Time::getHour() const
{
    return hour;
}
```

```cpp
int Time::getMinute() const
{
    return minute;
}
```

```cpp
int Time::getSecond() const
{
    return second;
}
```

int main()
{
    Time t;

    t.setHour(18).setMinute(30).setSecond(22);

    cout << "Universal time: ";
    t.printUniversal();

    cout << "\nStandard time: ";
    t.printStandard();

    cout << "\n\nNew standard time: ";

    t.setTime(20, 20, 20).printStandard();
    cout << endl;

    return 0;
}
Dynamic Memory Management

- To allocate and deallocate memory for any built-in or user-defined type
  - Operators `new` and `delete`

- `new`
  - Allocates (i.e., reserves) storage of the proper size for an object at execution time
  - Calls a constructor to initialize the object
  - Returns a pointer of the type specified
  - Works for any fundamental type or any class type

- Heap

Dynamic Memory Management

Cont’d

- **delete**
  - Destroys a dynamically allocated object
  - Calls the destructor for the object
  - Deallocates (i.e., releases) memory from the free store

- **Initializing an object allocated by new**
  - Initializer for a newly created fundamental-type variable
    ```cpp
double *ptr = new double( 3.14159 );
```
  - Specify a comma-separated list of arguments to the constructor of an object
    ```cpp
    Time *timePtr = new Time( 12, 45, 0 );
    ```

Dynamic Memory Management Cont’d

- Allocating arrays dynamically
  ```cpp
  int *gradesArray = new int[10];
  ```

- Delete a dynamically allocated array:
  ```cpp
  delete [] gradesArray;
  ```
  - This deallocates the array to which gradesArray points
  - If the pointer points to an array of objects
    - First calls the destructor for every object in the array
    - Then deallocates the memory
  - If the statement did not include the square brackets ([]) and gradesArray pointed to an array of objects
    - Only the first object in the array would have a destructor call

- After deleting dynamically allocated memory, set the pointer that referred to that memory to 0
**static Data Member**

- Only one copy of a variable shared by all objects of a class
  - Class-wide information
- Declaration begins with keyword `static`
- May seem like global variables but have class scope
- Can be declared public, private, or protected
- static data members of class types (i.e., static member objects) that have default constructors
  - Need not be initialized because their default constructors will be called

*C++ How to Program 6th Ed., P. Deitel and H. M. Deitel, Pearson Education, 2008*
static Data Member Cont’d

- Fundamental-type static data members
  - Initialized by default to 0
  - A static data member can be initialized once (and only once)

- A const static data member of int or enum type
  - Can be initialized in its declaration in the class definition

- All other static data members
  - Must be defined at file scope (i.e., outside the body of the class definition)
  - Can be initialized only in those definitions

---

static Data Member Cont’d

- Exists even when no objects of the class exist
  - To access a public static class member when no objects of the class exist
    - Prefix the class name and the binary scope resolution operator (::)

  Martian::martianCount
**static Member Function**

- Is a service of the class, not of a specific object of the class
- static applied to an item at file scope
  - That item becomes known only in that file
  - The static members of the class need to be available from any client code that accesses the file
  - We cannot declare them static in the .cpp file—we declare them static only in the .h file
**static Member Function Cont’d**

- **Declare a member function static**
  - If it does not access non-static data members or non-static member functions of the class

- **Does not have a this pointer**

- **Static data members and static member functions exist independently of any objects of a class**
  - When a static member function is called, there might not be any objects of its class in memory

- **Sometimes it is recommended that all calls to static member functions be made using the class name**
  - not an object handle

- **A const static member function is a compilation error**
#ifndef EMPLOYEE_H
#define EMPLOYEE_H

class Employee {

public:
  Employee( const char * const, const char * const );
  ~Employee();
  const char *getFirstName() const;
  const char *getLastName() const;
  static int getCount();

private:
  char *firstName;
  char *lastName;

  static int count;
};

#include <iostream>
#include <cstring>

int Employee::count = 0;

int Employee::getCount()
{
  return count;
}
Class Employee Cont'd

Employee::Employee( const char * const first, const char * const last )
{
    firstName = new char[ strlen( first ) + 1 ];
    strcpy( firstName, first );

    lastName = new char[ strlen( last ) + 1 ];
    strcpy( lastName, last );

    count++; cout << "Employee constructor for "
    << firstName << ' ' << lastName << " called." << endl;
}

const char *Employee::getFirstName() const
{
    return firstName;
}

Employee::~Employee()
{
    cout << "~Employee() called for "
    << firstName << ' ' << lastName << endl;
    delete [] firstName;
    delete [] lastName;
    count--;}

const char *Employee::getLastName() const
{
    return lastName;
}

#include <iostream>
using std::cout;
using std::endl;

#include "Employee.h"

int main()
{
    cout << "Number of employees before instantiation of any objects is "
         << Employee::getCount() << endl;

    Employee *e1Ptr = new Employee( "Susan", "Baker" );
    Employee *e2Ptr = new Employee( "Robert", "Jones" );

    cout << "Number of employees after objects are instantiated is "
         << e1Ptr->getCount();

    delete e1Ptr;
    delete e2Ptr;

    cout << "\n\nEmployee 1: "
         << e1Ptr->getFirstName() << " "
         << e1Ptr->getLastName()
         << "\nEmployee 2: "
         << e2Ptr->getFirstName() << " "
         << e2Ptr->getLastName() << "\n";

    return 0;
}
Data Abstraction and Information Hiding

- Information Hiding
- Data abstraction
  - Client cares about what functionality a class offers, not about how that functionality is implemented

- Primary activities of object-oriented programming in C++
  - Creation of types (i.e., classes)
  - Expression of the interactions among objects of those types

Abstract data types (ADTs)

- Improve the program development process

- Representing real-world notions

  Types like `int`, `double`, `char` and others are all ADTs
  - e.g., `int` is an abstract representation of an integer

- Capture two notions:
  - Data representation
  - Operations that can be performed on the data
Array Abstract Data Type

- Many array operations not built into C++
  - e.g., subscript range checking
- Programmers can develop an array ADT as a class that is preferable to primitive arrays
- C++ Standard Library class template vector
Container Classes

- Collection classes
- Classes designed to hold collections of objects
- Services such as insertion, deletion, searching, sorting, and member testing
- Arrays, Vectors, Stacks, Queues, Trees, Linked lists
Iterators

- Iterator objects
- Commonly associated with container classes
- An object that walks through a collection, returning the next item (or performing some action on the next item)
- A container class can have several iterators operating on it at once
- Each iterator maintains its own position information

```cpp
vector<int> v; // fill up v with data...
vector<int>::iterator it;
for ( it = v.begin(); it != v.end(); it++ ) {
    cout << *it << endl;
}
```