# Chapter 3: Data Abstraction

- Abstraction, modularity, information hiding
- Abstract data types
- Example-1: List ADT
- Example-2: Sorted list ADT
- C++ Classes
- C++ Namespaces
- C++ Exceptions



# Modularity and Abstraction

- Important when developing large programs.
- Divide program in small *manageable* modules
  – each module understood individually
  – easier to write, understand, modify, and debug
- Modules communicate using *well-defined* interfaces
  – different module implementations use same interface
  – provide a different and easier interface to communicating modules – abstraction



# Fundamental Concepts

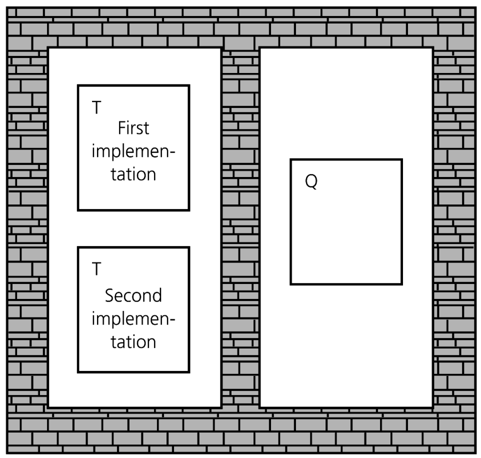
- Modularity
  – manages complexity of large programs
  – isolates errors
  – eliminates redundancies
  – program is easier to read, write, and modify
- Information hiding
  – hides certain implementation details within a module
  – makes these details inaccessible from outside the module



# Abstraction

- Functional abstraction
  – separates the purpose and use of a module from its implementation
  – module's specifications only details its behavior, independent of the module's implementation
- Data abstraction
  – asks you to think what you can do to a collection of data independently of how you do it
  – allows you to develop each data structure in relative isolation from the rest of the solution

## Isolated Tasks






## Isolation of Modules is Not Total

- A function's specification, or contract, governs how it interacts with other modules

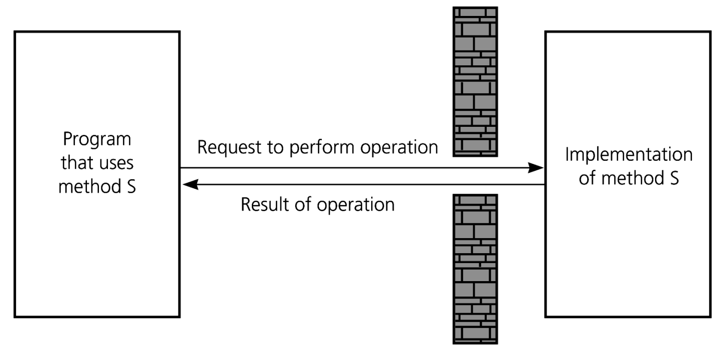



***Figure 3-2*** A slit in the wall



## Abstract Data Type (ADT)

- An ADT is composed of
  - collection of data
  - set of operations on that data
- Specifications of an ADT indicate
  - what the ADT operations do, not how to implement them
- Implementation of an ADT
  - includes choosing a particular data structure



## Abstract Data Types

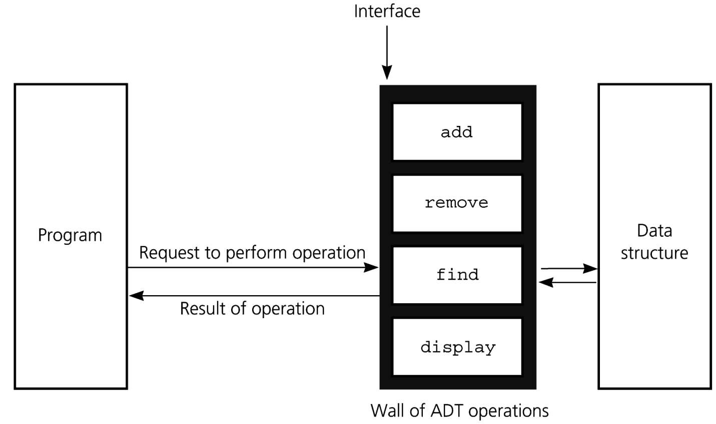



***Figure 3-4***

A wall of ADT operations isolates a data structure from the program that uses it

# Designing an ADT

- The design of an ADT should evolve naturally during the problem-solving process
- Questions to ask when designing an ADT
  - What data does a problem require?
  - What operations does a problem require?



# List ADT Example

- ADT for a list of items: grocery list, TO-DO list
- What *operations* do we perform on/with a list?
  - add item, delete item, find item, read, etc.
  - cannot think of everything?
    - should refine iteratively!
- How to store the data
  - implementation detail hidden from users of the list
  - arrays or linked lists



# List ADT Example – Properties

- Except for the first and last items, each item has a unique predecessor and successor
- Items are referenced by their position in the list
- Specifications of the ADT operations
  - Define an operation contract for the ADT list
  - Do not specify how to store the list or how to perform the operations
- ADT operations can be used in an application without the knowledge of how the operations will be implemented



# List ADT Example – Operations

- Create an empty list
- Destroy a list
- Determine whether a list is empty
- Determine the number of items in a list
- Insert an item at a given position in the list
- Delete the item at a given position in the list
- Retrieve the item at a given position in the list

# List ADT – Operation Contract

- createList()
- destroyList()
- isEmpty():boolean {query}
- getLength():integer {query}
- insert(in index:integer, in newItem:ListItemType, out success:boolean)
- remove(in index:integer, out success:boolean)
- retrieve(in index:integer, dItem:ListItemType, out success:boolean) {query}



# List ADT Example – Operations

- Create the list -- milk, eggs, butter
  - aList.createList()
  - aList.insert(1, milk, success)
  - aList.insert(2, eggs, success)
  - aList.insert(3, butter, success)
- Insert bread after milk
  - aList.insert(2, bread, success)
    milk, bread, eggs, butter
- Insert juice at end of list
  - aList.insert(5, juice, success)
    milk, bread, eggs, butter, juice



# List ADT Example – Operations

- Remove eggs
  - aList.remove(3, success)
  - milk, bread, butter, juice
- Insert apples at beginning of list
  - aList.insert(1, apples, success)
  - apples, milk, bread, butter, juice



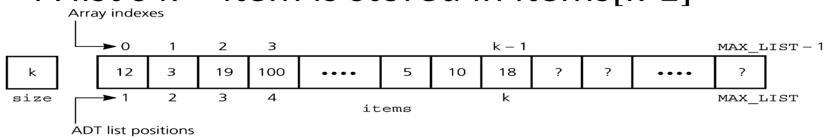
# List ADT Example -- Operations

- Algorithm description independent of list implementation, as long as each item has an index
- Pseudocode function that displays a list

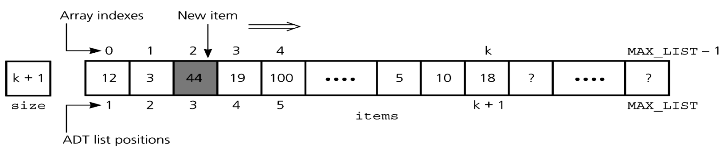
```
displayList(in aList:List){
   for (position=1 to aList.getLength()){
       aList.retrieve(position, dataItem, success)
        display dataItem
     }
}
```

# List ADT Example -- Implementation

- How to implement the List ADT ?
- A list's $k^{th}$ item is stored in items[k-1]




- To insert an item, make room in the array






# List ADT Example -- Implementation

- To delete an item, remove gap in array

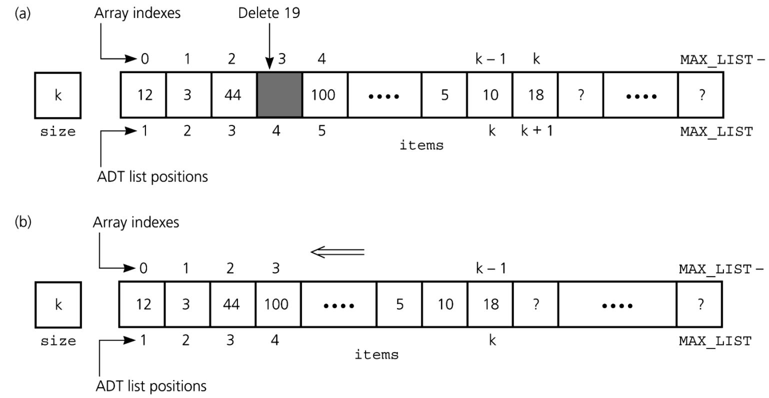



***Figure 3-13*** (a) Deletion causes a gap; (b) fill gap by shifting



# List ADT – Options

- Many other design options are possible
  – retrieve items by name, instead of by index
  – sort items by name or some other factor
  – display list in some sorted order
- Several data structures can be used during implementation
  – arrays, linked lists, trees, hash-tables, etc.
  – different advantages, restrictions, and costs



# ADT Sorted List -- Properties

- Maintains items in sorted order
- Inserts and deletes items by their values, not their positions

# ADT Sorted List – Operation Contract

- sortedIsEmpty():boolean{query}
- sortedGetLength():integer{query}
- sortedInsert(in nItem:ListItemType, out success:boolean)
- sortedRemove(in index:integer, out success :boolean)
- sortedRetrieve(in index:integer, out dItem:ListItemType,
  out success :boolean){query}
- locatePosition(in anItem:ListItemType,
  out isPresent:boolean):integer{query}



# Implementing ADTs

- Choosing the data structure to represent the ADT's data is a part of implementation
  - Choice of a data structure depends on
    - Details of the ADT's operations
    - Context in which the operations will be used
- Implementation details should be hidden behind a wall of ADT operations
  - A program (client) should only be able to access the data structure by using the ADT operations



# Hiding Data Structures and Code

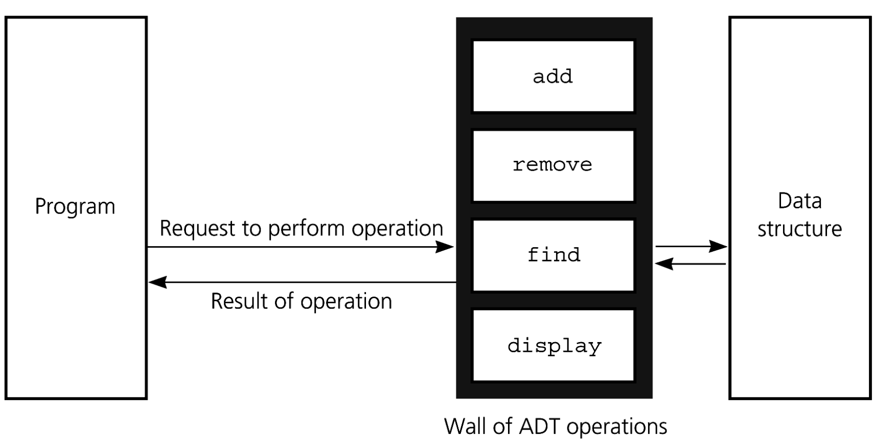



***Figure 3-8***

ADT operations provide access to a data structure



# Violating Information Hiding

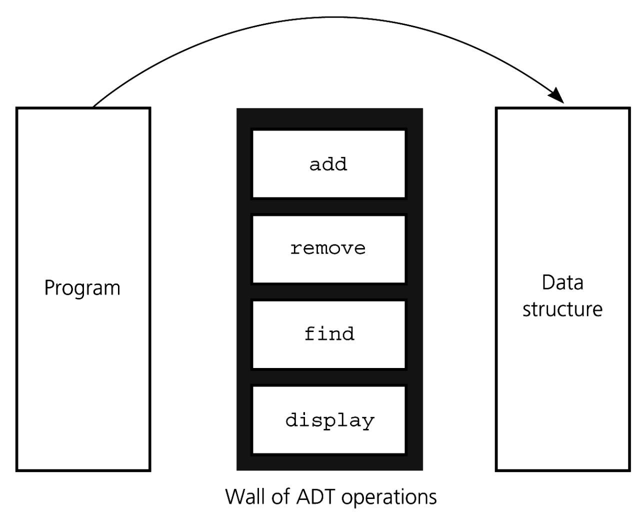



***Figure 3-9*** Violating the wall of ADT operations

## C++ Classes

- Encapsulation combines an ADT's data with its operations to form an object
  - an object is an instance of a class
  - a class defines a new data type
  - a class contains data members and methods (member functions)
  - by default, all data members in a class are private
    - but, can specify them as public
    - can only be accessed by other class members
  - some member functions have to be public
  - encapsulation hides implementation details



## C++ Classes

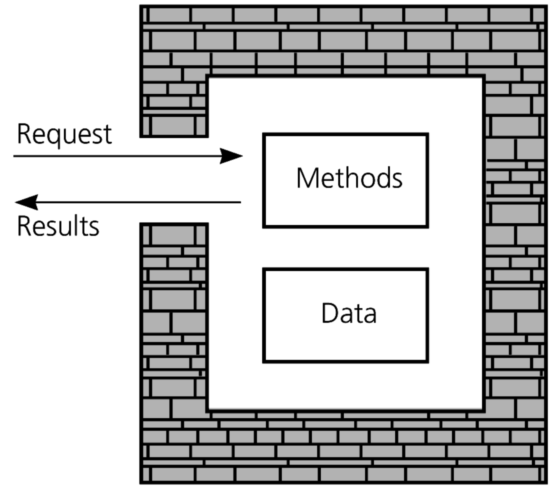



***Figure 3-10***
An object's data and methods are encapsulated



## C++ Classes

- Each class definition is placed in a header file
  - *Classname*`.h`
- The implementation of a class's methods are placed in an implementation file
  - *Classname*`.cpp`



## C++ Classes: Constructors

- Constructors
  - create and initialize new instances of a class
    - invoked when you declare an instance of the class
  - have the same name as the class
  - have no return type, not even void
- A class can have several constructors
  - a default constructor has no arguments
  - compiler will generate a default constructor if you do not define any constructors

# C++ Classes: Constructors

- The implementation of a method qualifies its name with the scope resolution operator ::
- The implementation of a constructor
  - sets data members to initial values
  - can use an initializer

    ```
    Sphere::Sphere() : theRadius(1.0)
    {
    }  // end default constructor
    ```
  - cannot use return to return a value



# C++ Classes: Destructors

- Destructor
  - destroys an instance of an object when the object's lifetime ends
  - called automatically for local variables on subroutine exit
  - called explicitly by *delete* operator
  - primary duty is to de-allocate dynamic memory
- Each class has one destructor
  - for many classes, you can omit the destructor
    - if they do not allocate any memory
  - the compiler will generate a destructor if you do not define one



# C++ Classes: The header file

```
/** @file Sphere.h */
const double PI = 3.14159;
class Sphere
{
public:
  Sphere();                      // Default constructor
  Sphere(double initialRadius); // Constructor
  void setRadius(double newRadius);
  double getRadius() const;  // can't change data members
  double getDiameter() const;
  double getCircumference() const;
  double getArea() const;
  double getVolume() const;
  void displayStatistics() const;
private:
 double theRadius;        // data members should be private
};  // end Sphere
```



# C++ Classes: The implementation file

```
/** @file Sphere.cpp */
#include <iostream>
#include "Sphere.h"   // header file
using namespace std;
Sphere::Sphere() : theRadius(1.0)
{
}  // end default constructor

Sphere::Sphere(double initialRadius)
{
   if (initialRadius > 0)
      theRadius = initialRadius;
   else
      theRadius = 1.0;
}  // end constructor
```

## C++ Classes: The implementation file

```
void Sphere::setRadius(double newRadius)
{
   if (newRadius > 0)
      theRadius = newRadius;
   else
      theRadius = 1.0;
}  // end setRadius
```

- The constructor could call `setRadius`



## C++ Classes: The implementation file

```
double Sphere::getRadius() const
{
   return theRadius;
}  // end getRadius
. . .

double Sphere::getArea() const
{
   return 4.0 * PI * theRadius * theRadius;
}  // end getArea
. . .
```



## C++ Classes: Using the class `Sphere`

```
#include <iostream>
#include "Sphere.h"   // header file
using namespace std;
int main()  // the client
{
   Sphere unitSphere;
   Sphere mySphere(5.1);
   cout << mySphere.getDiameter() << endl;
   . . .
}  // end main
```



## Inheritance in C++

- Inheritance is a way to reuse the code (and behavior) of existing classes
  - existing class is called the *base* or *super* or *parent* class
  - the new class is called *derived* or *sub* class
- Derived class inherits any of the publicly defined methods or data members of a base class
  - public members are accessible by any function
  - protected members are accessible only in base and derived classes

# Inheritance in C++

- Derived classes can add new data members and member functions
  - methods with the same prototype (name as well as number and types of arguments) in the derived class *override* base class methods
  - distinct from *overloading* – same function name but different set of parameters
- An instance of a derived class is considered to also be an instance of the base class
  - can be used anywhere an instance of the base class can be used
- An instance of a derived class can invoke public methods of the base class



# Inheritance – Example

```
#include "Sphere.h"
enum Color {RED, BLUE, GREEN, YELLOW};
class ColoredSphere: public Sphere
{
public:
…
  Color getColor() const;
…
private:
   Color c;
}  // end ColoredSphere
```



# C++ Namespaces

- Mechanism for logically grouping declarations and definitions into one declarative region
- The contents of the namespace can be accessed by code inside or outside the namespace
  - use the scope resolution operator (::) to access elements from outside the namespace
  - alternatively, the using declaration allows the names of the elements to be used directly



# C++ Namespaces

- Creating a namespace

```
namespace smallNamespace
{
  int count = 0;
  void abc();
} // end smallNamespace
```

- Using a namespace

```
using namespace smallNamespace;
count +=1;
abc();
```

*see C3-namespace.cpp*

## C++ Exceptions

- Mechanism for handling errors at runtime
  - pre-defined as well as user-defined
  - default action is often to kill the program
- A function can indicate that an error has occurred by throwing an exception
- Code that deals with the exception is said to handle it
  - uses a try block and catch blocks



## C++ Exceptions

- Place a statement that might throw an exception within a try block

```
try { statement(s); }
```

- Write a catch block for each type of exception handled
  - order is not important

```
catch(ExceptionClass identifier) {
      statement(s);
}
catch(ExceptionClass identifier2) {
      statement(s);
}
```



## C++ Exceptions

- When a statement in a try block causes an exception
  - rest of try block is ignored
    - destructors of objects local to the block are called
  - control passes to catch block corresponding to the exception
  - after a catch block executes, control passes to statement after last catch block associated with the try block
  - if a catch block for the exception is not found, the program typically aborts

*see C3-exceptions.cpp*



## C++ Exceptions

- Throwing exceptions
  - A throw statement throws an exception
  - Methods that throw an exception have a throw clause

```
void myMethod(int x) throw(MyException)
{
  if (. . .)
     throw MyException("MyException: …");
  . . .
}  // end myMethod
```

- You can use an exception class in the C++ Standard Library or define your own

## List Implemented Using Exceptions

- We define two exception classes

```
#include <stdexcept>
#include <string>
using namespace std;
class ListIndexOutOfRangeException :
      public out_of_range
{
public:
   ListIndexOutOfRangeException(const string &
                             message = "")
                   : out_of_range(message.c_str())
   {}
}; // end ListException
```



## List Implemented Using Exceptions

```
#include <stdexcept>
#include <string>
using namespace std;
class ListException : public logic_error
{
public:
  ListException(const string & message = "")
                      : logic_error(message.c_str())
   {}
}; // end ListException
```



## List Implemented Using Exceptions

```
/** @file ListAexcept.h */
#include "ListException.h"
#include "ListIndexOutOfRangeException.h"
 . . .
class List
{
public:
   . . .
   void insert(int index,
               const ListItemType& newItem)
        throw(ListIndexOutOfRangeException,
              ListException);
   . . .
}  // end List
```



## List Implemented Using Exceptions

```
/** @file ListAexcept.cpp */
void List::insert(int index,
                  const ListItemType& newItem)
           throw(ListIndexOutOfRangeException,
                 ListException);
{
   if (size > MAX_LIST)
      throw ListException("ListException: " +
                          "List full on insert");
   . . .
}  // end insert
```

# Summary

- Data abstraction controls the interaction between a program and its data structures
- Abstract data type (ADT): a set of data-management operations together with the data values upon which they operate
- Define an ADT fully before making any decisions about an implementation
- C++ classes used to implement ADT
  - encapsulates both data and operations



# Summary

- Members of a class are private by default
  - data members are typically private
  - public methods can be provided to access them
- Namespace: a mechanism to group classes, functions, variables, types, and constants
- You can throw an exception if you detect an error during program execution
  - use *try* and *catch* blocks to handle exceptions