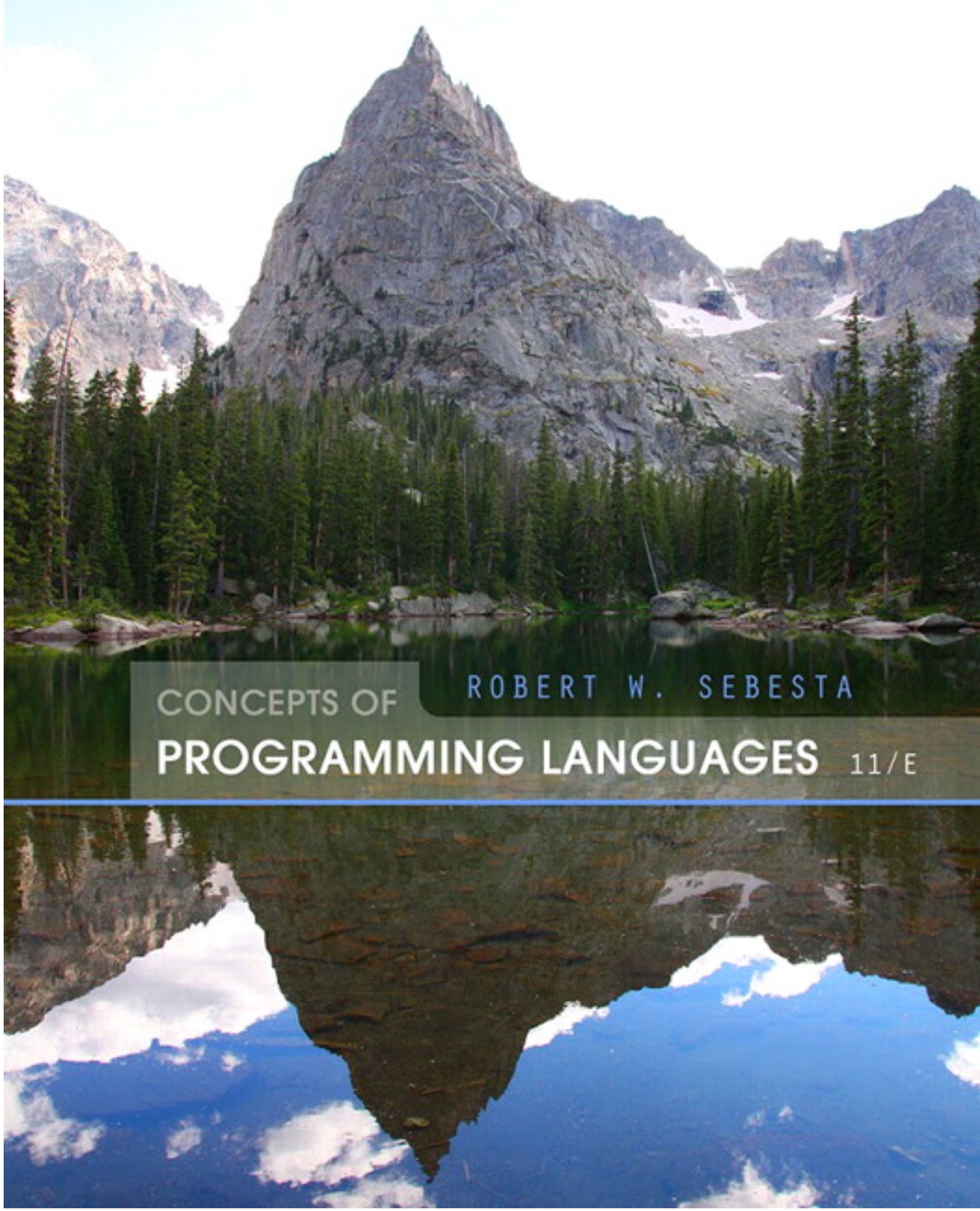
Chapter 11

Abstract Data Types and Encapsulation Concepts



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Chapter 11 Topics

- The Concept of Abstraction
- Introduction to Data Abstraction
- Design Issues for Abstract Data Types
- Language Examples
- Parameterized Abstract Data Types
- Encapsulation Constructs
- Naming Encapsulations

The Concept of Abstraction

- An *abstraction* is a view or representation of an entity that includes only the most significant attributes
- The concept of abstraction is fundamental in programming (and computer science)
- Nearly all programming languages support process abstraction with subprograms
- Nearly all programming languages designed since 1980 support *data abstraction*

Introduction to Data Abstraction

- An *abstract data type* is a user-defined data type that satisfies the following two conditions:
  - The representation of objects of the type is hidden from the program units that use these objects, so the only operations possible are those provided in the type's definition
  - The declarations of the type and the protocols of the operations on objects of the type are contained in a single syntactic unit. Other program units are allowed to create variables of the defined type.

Advantages of Data Abstraction

- Advantages the first condition
  - Reliability--by hiding the data representations, user code cannot directly access objects of the type or depend on the representation, allowing the representation to be changed without affecting user code
  - Reduces the range of code and variables of which the programmer must be aware
  - Name conflicts are less likely
- Advantages of the second condition
  - Provides a method of program organization
  - Aids modifiability (everything associated with a data structure is together)
  - Separate compilation

Language Requirements for ADTs

- A syntactic unit in which to encapsulate the type definition
- A method of making type names and subprogram headers visible to clients, while hiding actual definitions
- Some primitive operations must be built into the language processor

Design Issues

- Can abstract types be parameterized?
- What access controls are provided?
- Is the specification of the type physically separate from its implementation?

Language Examples: C++

- Based on C `struct` type and Simula 67 classes
- The class is the encapsulation device
- A class is a type
- All of the class instances of a class share a single copy of the member functions
- Each instance of a class has its own copy of the class data members
- Instances can be static, stack dynamic, or heap dynamic

Language Examples: C++ (continued)

- Information Hiding
  - *Private* clause for hidden entities
  - *Public* clause for interface entities
  - *Protected* clause for inheritance (Chapter 12)

Language Examples: C++ (continued)

- Constructors:
  - Functions to initialize the data members of instances (they *do not* create the objects)
  - May also allocate storage if part of the object is heap-dynamic
  - Can include parameters to provide parameterization of the objects
  - Implicitly called when an instance is created
  - Can be explicitly called
  - Name is the same as the class name

Language Examples: C++ (continued)

- Destructors
  - Functions to cleanup after an instance is destroyed; usually just to reclaim heap storage
  - Implicitly called when the object's lifetime ends
  - Can be explicitly called
  - Name is the class name, preceded by a tilde (~)

An Example in C++

```
class Stack {
   private:
        int *stackPtr, maxLen, topPtr;
   public:
        Stack() { // a constructor
               stackPtr = new int [100];
               maxLen = 99;
               topPtr = -1;
        };
        ~Stack () {delete [] stackPtr;};
        void push (int number) {
           if (topSub == maxLen)
             cerr << "Error in push - stack is full\n";
           else stackPtr[++topSub] = number;
        };
        void pop () {…};
        int top () {…};
        int empty () {…};
}
```

A `Stack` class header file

```
// Stack.h - the header file for the Stack class
#include <iostream.h>
class Stack {
private: //** These members are visible only to other
//** members and friends (see Section 11.6.4)
  int *stackPtr;
  int maxLen;
  int topPtr;
public: //** These members are visible to clients
  Stack(); //** A constructor
  ~Stack(); //** A destructor
  void push(int);
  void pop();
  int top();
  int empty();
}
```

The code file for `Stack`

```
// Stack.cpp - the implementation file for the Stack class
#include <iostream.h>
#include "Stack.h"
using std::cout;
Stack::Stack() { //** A constructor
  stackPtr = new int [100];
  maxLen = 99;
  topPtr = -1;
}
Stack::~Stack() {delete [] stackPtr;}; //** A destructor
void Stack::push(int number) {
  if (topPtr == maxLen)
  cerr << "Error in push--stack is full\n";
  else stackPtr[++topPtr] = number;
}
...
```

Language Examples: C++ (continued)

- Friend functions or classes – to provide access to private members to some unrelated units or functions
  - Necessary in C++

Language Examples – Objective-C

- Interface containers

```
@interface class-name: parent-class {
    instance variable declarations
 }
    method prototypes
@end
```

- Implementation containers

```
@implementation class-name
method definitions
@end
```

- Classes are types

Language Examples – Objective-C (continued)

- Method prototypes form

  (+ | -) (return-type) method-name [: (formal-parameters)];

  - Plus indicates a class method
  - Minus indicates an instance method
  - The colon and the parentheses are not included when there are no parameters
  - Parameter list format is different
    - If there is one parameter (name is `meth1:`)
      - `-(void) meth1: (int) x;`
    - For two parameters
      - `-(int) meth2: (int) x second: (float) y;`
    - The name of the method is `meth2::`

Language Examples – Objective-C (continued)

- Method call syntax

  [object-name method-name];

  Examples:

```
[myAdder add1: 7];
[myAdder add1: 7: 5: 3];
```

  – For the method:

```
-(int) meth2: (int) x second: (float) y;
```

  the call would be like the following:

```
[myObject meth2: 7 second: 3.2];
```

Language Examples - Objective-C (continued)

- Constructors are called *initializers* – all they do is initialize variables
  - Initializers can have any name – they are always called explicitly
  - Initializers always return **`self`**
- Objects are created by calling **`alloc`** and the constructor

```
Adder *myAdder = [[Adder alloc] init];
```

- All class instances are heap dynamic

Language Examples – Objective-C (continued)

- To import standard prototypes (e.g., i/o)

```
#import <Foundation/Foundation.h>
```

- The first thing a program must do is allocate and initialize a pool of storage for its data (pool's variable is `pool` in this case)

```
NSAutoreleasePool * pool =
        [[NSAutoreleasePool alloc] init];
```

- At the end of the program, the pool is released with:

```
[pool drain];
```

Language Examples – Objective-C (continued)

- Information Hiding
  - The directives `@private` and `@public` are used to specify the access of instance variables.
  - The default access is protected (private in C++)
  - There is no way to restrict access to methods
  - The name of a getter method is always the name of the instance variable
  - The name of a setter method is always the word set with the capitalized variable's name attached
  - If the getter and setter for a variable does not impose any constraints, they can be implicitly generated (called *properties*)

Language Examples – Objective-C (continued)

```
// stack.m - interface and implementation for a simple stack
#import <Foundation/Foundation.h>
@interface Stack: NSObject {
  int stackArray[100], stackPtr,maxLen, topSub;
}
  -(void) push: (int) number;
  -(void) pop;
  -(int) top;
  -(int) empty;
@end
@implementation Stack
  -(Stack *) initWith {
    maxLen = 100;
    topSub = -1;
    stackPtr = stackArray;
    return self;
}
```

Language Examples – Objective-C (continued)

```
// stack.m - continued
  -(void) push: (int) number {
    if (topSub == maxLen)
      NSLog(@"Error in push - stack is full");
    else
      stackPtr[++topSub] = number;
  ...
}
```

Language Examples – Objective-C (continued)

- An example use of `stack.m`
  - Placed in the `@implementation` of `stack.m`

```
int main (int argc, char *argv[]) {
  int temp;
  NSAutoreleasePool *pool = [[NSAutoreleasePool alloc] init];
  Stack *myStack = [[Stack alloc] initWith];
  [myStack push: 5];
  [myStack push: 3];
  temp = [myStack top];
  NSLog(@"Top element is: %i", temp);
  [myStack pop];
  temp = [myStack top];
  NSLog(@"Top element is: %i", temp);
  temp = [myStack top];
  myStack pop];
  [myStack release];
  [pool drain];
  return 0;
}
```

Language Examples: Java

- Similar to C++, except:
  - All user-defined types are classes
  - All objects are allocated from the heap and accessed through reference variables
  - Individual entities in classes have access control modifiers (private or public), rather than clauses
  - Implicit garbage collection of all objects
  - Java has a second scoping mechanism, package scope, which can be used in place of friends
    - All entities in all classes in a package that do not have access control modifiers are visible throughout the package

An Example in Java

```
class StackClass {
  private:
      private int [] *stackRef;
      private int [] maxLen, topIndex;
      public StackClass() { // a constructor
            stackRef = new int [100];
            maxLen = 99;
            topPtr = -1;
      };
      public void push (int num) {…};
      public void pop () {…};
      public int top () {…};
      public boolean empty () {…};
}
```

Language Examples: C#

- Based on C++ and Java
- Adds two access modifiers, *internal* and *protected internal*
- All class instances are heap dynamic
- Default constructors are available for all classes
- Garbage collection is used for most heap objects, so destructors are rarely used
- **`structs`** are lightweight classes that do not support inheritance

Language Examples: C# (continued)

- Common solution to need for access to data members: accessor methods (getter and setter)
- C# provides *properties* as a way of implementing getters and setters without requiring explicit method calls

C# Property Example

```
public class Weather {
   public int DegreeDays { //** DegreeDays is a property
      get {return degreeDays;}
      set {
        if (value < 0 || value > 30)
          Console.WriteLine(
              "Value is out of range: {0}", value);
        else degreeDays = value;}
   }
   private int degreeDays;
   ...
   }
...
Weather w = new Weather();
int degreeDaysToday, oldDegreeDays;
...
w.DegreeDays = degreeDaysToday;
...
oldDegreeDays = w.DegreeDays;
```

Abstract Data Types in Ruby

- Encapsulation construct is the class
- Local variables have “normal” names
- Instance variable names begin with “at” signs (`@`)
- Class variable names begin with two “at” signs (`@@`)
- Instance methods have the syntax of Ruby functions (`def … end`)
- Constructors are named `initialize` (only one per class)—implicitly called when `new` is called
  - If more constructors are needed, they must have different names and they must explicitly call `new`
- Class members can be marked private or public, with public being the default
- Classes are dynamic

Abstract Data Types in Ruby (continued)

```
class StackClass {
   def initialize
    @stackRef = Array.new
    @maxLen = 100
    @topIndex = -1
   end

   def push(number)
     if @topIndex == @maxLen
       puts " Error in push – stack is full"
     else
       @topIndex = @topIndex + 1
       @stackRef[@topIndex] = number
     end
   end
   def pop … end
   def top … end
   def empty … end
end
```

Parameterized Abstract Data Types

- Parameterized ADTs allow designing an ADT that can store any type elements – only an issue for static typed languages
- Also known as generic classes
- C++, Java 5.0, and C# 2005 provide support for parameterized ADTs

Parameterized ADTs in C++

- Classes can be somewhat generic by writing parameterized constructor functions

```
Stack (int size) {
  stk_ptr = new int [size];
  max_len = size - 1;
  top = -1;
};
```

A declaration of a stack object:

```
Stack stk(150);
```

Parameterized ADTs in C++ (continued)

- The stack element type can be parameterized by making the class a templated class

```
template <class Type>
class Stack {
  private:
    Type *stackPtr;
    const int maxLen;
    int topPtr;
  public:
    Stack() {  // Constructor for 100 elements
      stackPtr = new Type[100];
      maxLen = 99;
      topPtr = -1;
    }
    Stack(int size) {  // Constructor for a given number
      stackPtr = new Type[size];
      maxLen = size - 1;
      topSub = -1;
    }
  . . .
}
```

  - Instantiation: `Stack<int> myIntStack;`

Parameterized Classes in Java 5.0

- Generic parameters must be classes
- Most common generic types are the collection types, such as `LinkedList` and `ArrayList`
- Eliminate the need to cast objects that are removed
- Eliminate the problem of having multiple types in a structure
- Users can define generic classes
- Generic collection classes cannot store primitives
- Indexing is not supported
- Example of the use of a predefined generic class:

```
ArrayList <Integer> myArray = new ArrayList <Integer> ();
myArray.add(0, 47);  // Put an element with subscript 0 in it
```

Parameterized Classes in Java 5.0 (continued)

```
import java.util.*;
public class Stack2<T> {
  private ArrayList<T> stackRef;
  private int maxLen;
  public Stack2)( {
    stackRef = new ArrayList<T> ();
    maxLen = 99;
  }
  public void push(T newValue) {
    if (stackRef.size() == maxLen)
      System.out.println(" Error in push - stack is full");
    else
      stackRef.add(newValue);
  ...
}
```

- Instantiation: `Stack2<string> myStack = new Stack2<string> ();`

Parameterized Classes in C# 2005

- Similar to those of Java 5.0, except no wildcard classes
- Predefined for Array, List, Stack, Queue, and Dictionary
- Elements of parameterized structures can be accessed through indexing

Encapsulation Constructs

- Large programs have two special needs:
  - Some means of organization, other than simply division into subprograms
  - Some means of partial compilation (compilation units that are smaller than the whole program)
- Obvious solution: a grouping of subprograms that are logically related into a unit that can be separately compiled (compilation units)
- Such collections are called *encapsulation*

Nested Subprograms

- Organizing programs by nesting subprogram definitions inside the logically larger subprograms that use them
- Nested subprograms are supported in Python, JavaScript, and Ruby

Encapsulation in C

- Files containing one or more subprograms can be independently compiled
- The interface is placed in a *header file*
- Problem 1: the linker does not check types between a header and associated implementation
- Problem 2: the inherent problems with pointers
- `#include` preprocessor specification – used to include header files in applications

Encapsulation in C++

- Can define header and code files, similar to those of C
- Or, classes can be used for encapsulation
  - The class is used as the interface (prototypes)
  - The member definitions are defined in a separate file
- *Friend*s provide a way to grant access to private members of a class

C# Assemblies

- A collection of files that appears to application programs to be a single dynamic link library or executable
- Each file contains a module that can be separately compiled
- A DLL is a collection of classes and methods that are individually linked to an executing program
- C# has an access modifier called `internal`; an `internal` member of a class is visible to all classes in the assembly in which it appears

Naming Encapsulations

- Large programs define many global names; need a way to divide into logical groupings
- A *naming encapsulation* is used to create a new scope for names
- C++ Namespaces
  - Can place each library in its own namespace and qualify names used outside with the namespace
  - C# also includes namespaces

Naming Encapsulations (continued)

- Java Packages
  - Packages can contain more than one class definition; classes in a package are *partial* friends
  - Clients of a package can use fully qualified name or use the ***`import`*** declaration

Naming Encapsulations (continued)

- *Ruby Modules:*
  - Ruby classes are name encapsulations, but Ruby also has modules
  - Typically encapsulate collections of constants and methods
  - Modules cannot be instantiated or subclassed, and they cannot define variables
  - Methods defined in a module must include the module's name
  - Access to the contents of a module is requested with the `require` method

Summary

- The concept of ADTs and their use in program design was a milestone in the development of languages
- Two primary features of ADTs are the packaging of data with their associated operations and information hiding
- Ada provides packages that simulate ADTs
- C++ data abstraction is provided by classes
- Java's data abstraction is similar to C++
- C++, Java 5.0, and C# 2005 support parameterized ADTs
- C++, C#, Java, and Ruby provide naming encapsulations