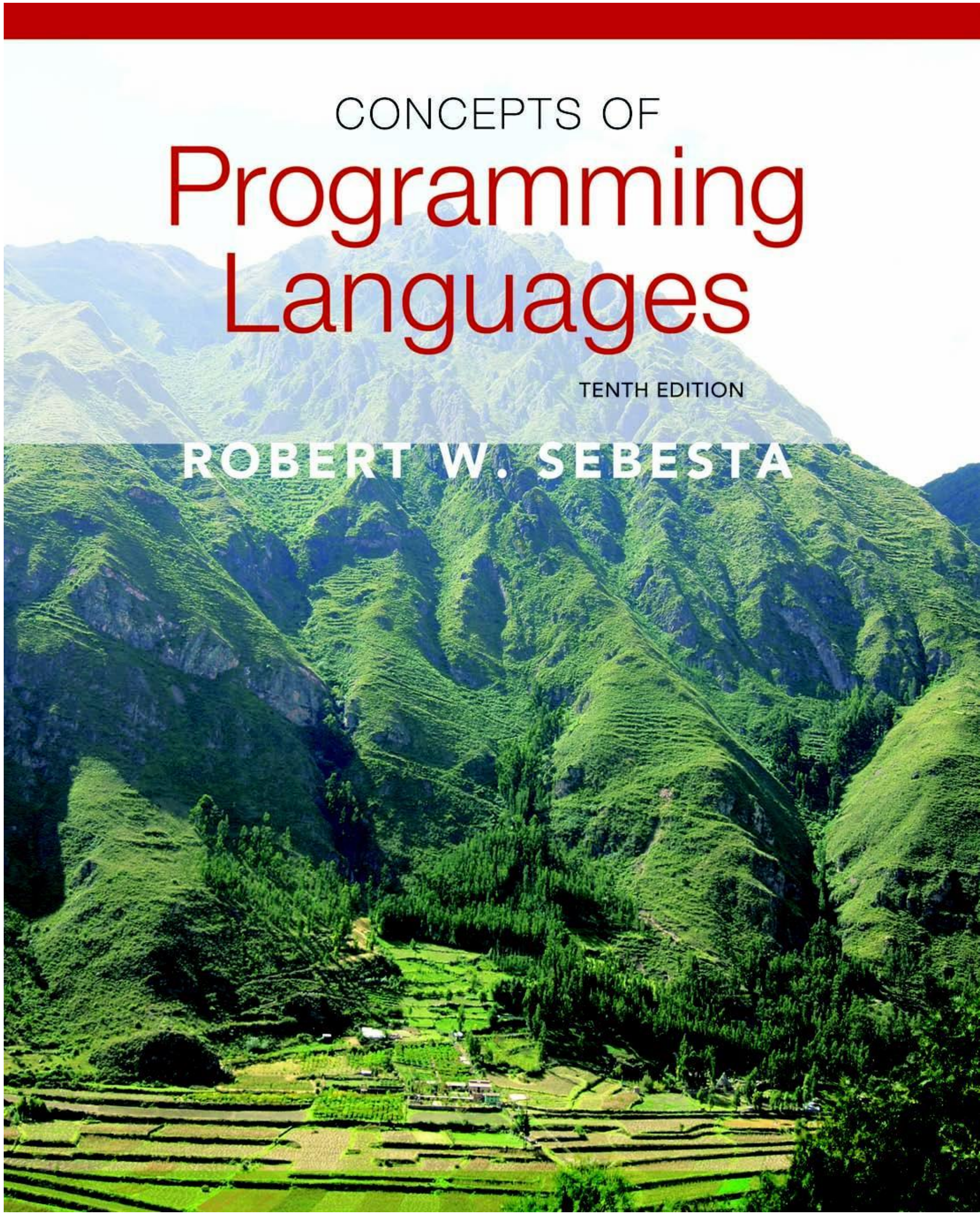
# Chapter 11

## Abstract Data Types and Encapsulation Concepts



# 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

- What is the form of the container for the interface to the type?
- Can abstract types be parameterized?
- What access controls are provided?
- Is the specification of the type physically separate from its implementation?

# Language Examples: Ada

- The encapsulation construct is called a *package*
  - Specification package (the interface)
  - Body package (implementation of the entities named in the specification)
- Information Hiding
  - The spec package has two parts, public and private
  - The name of the abstract type appears in the public part of the specification package. This part may also include representations of unhidden types
  - The representation of the abstract type appears in a part of the specification called the *private* part
    - More restricted form with *limited private types*
      Private types have built-in operations for assignment and comparison

      Limited private types have NO built-in operations

# Language Examples: Ada (continued)

- Reasons for the public/private spec package:

  1. The compiler must be able to see the representation after seeing only the spec package (it cannot see the private part)
  2. Clients must see the type name, but not the representation (they also cannot see the private part)

# An Example in Ada – Specification

```
package Stack_Pack is
   type stack_type is limited private;
   max_size: constant := 100;
   function empty(stk: in stack_type) return Boolean;
   procedure push(stk: in out stack_type; elem: in Integer);
   procedure pop(stk: in out stack_type);
   function top(stk: in stack_type) return Integer;

   private  -- hidden from clients
   type list_type is array (1..max_size) of Integer;
   type stack_type is record
       list: list_type;
       topsub: Integer range 0..max_size) := 0;
   end record;
end Stack_Pack
```

# An Example in Ada – Body

```
with Ada.Text_IO; use Ada.Text_IO;
package body Stack_Pack is
  function Empty(Stk : in Stack_Type) return Boolean is
    begin
    return Stk.Topsub = 0;
    end Empty;
  procedure Push(Stk: in out Stack_Type;
    Element : in Integer) is
    begin
    if Stk.Topsub >= Max_Size then
      Put_Line("ERROR – Stack overflow");
    else
      Stk.Topsub := Stk.Topsub + 1;
      Stk.List(Topsub) := Element;
    end if;
  end Push;
...
end Stack_Pack;
```

# 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
  - 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++, Ada, Java 5.0, and C# 2005 provide support for parameterized ADTs

# Parameterized ADTs in Ada

- Ada Generic Packages
  - Make the stack type more flexible by making the element type and the size of the stack generic

```
generic
  Max_Size: Positive;
  type Elem_Type is private;
package Generic_Stack is
  type Stack_Type is limited private;
  function Empty(Stk : in Stack_Type) return Boolean;
  function Top(Stk: in out StackType) return Elem_type;
  …
private
  type List_Type is array (1..Max_Size) of Element_Type;
  type Stack_Type is
    record
    List : List_Type;
    Topsub : Integer range 0 .. Max_Size := 0;
    end record;
end Generic_Stack;
```

# Parameterized ADTs in Ada (continued)

- Instantiations of the generic stack

```
package Integer_Stack is new Generic_Stack(100,Integer);
package Float_Stack is new Generic_Stack(100,Float);
```

# 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 Ada, Fortran 95+, 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: the linker does not check types between a header and associated implementation
- `#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

# Ada Packages

- Ada specification packages can include any number of data and subprogram declarations
- Ada packages can be compiled separately
- A package's specification and body parts can be compiled separately

# 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
- Ada Packages
  - Packages are defined in hierarchies which correspond to file hierarchies
  - Visibility from a program unit is gained with the `with` clause

# Naming Encapsulations (continued)

- 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++
- Ada, C++, Java 5.0, and C# 2005 support parameterized ADTs
- C++, C#, Java, Ada, and Ruby provide naming encapsulations