Programming in the large

Engineering complex software systems

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Characteristics of RT Systems

- **Large and Complex**
- Concurrent control of system components
- Facilities for hardware control
- Extremely reliable and safe
- Real-time facilities
- Efficiency of execution

Aim

- Review of language support for programming in the large
- Illustrate the use of modules/packages to aid decomposition and abstraction
- Separate compilation
- Modules and separate compilation in C
- Child packages and OOP in Ada 95
- OOP and Java

Decomposition and Abstraction

- Decomposition — the systematic breakdown of a complex system into smaller and smaller parts until components are isolated that can be understood and engineered by individuals and small groups
  TOP DOWN DESIGN

- Abstraction — Allows detailed consideration of components to be postponed yet enables the essential part of the component to be specified
  BOTTOM UP DESIGN

Modules

- A collection of logically related objects and operations
- Encapsulation — the technique of isolating a system function within a module with a precise specification of the interface
  - information hiding
  - separate compilation
  - abstract data types
- How should large systems be decomposed into modules?

The answer to this is at the heart of all Software Engineering!

Information Hiding

- A module structure supports reduced visibility by allowing information to be hidden inside its body
- The specification and body of a module can be given separately
- Ideally, the specification should be compilable without the body being written
- E.g in Ada, there is a package specification and a package body; formal relationship; compile time errors
- In C, modules are not so well formalised. Typically, programmers use a separate .h file to contain the interface to a module and a .c file for the body. No formal relationship. Errors caught at link time
- Modules are not first class language entities

Information Hiding

- Java has interfaces and the concept of package
- There is no language syntax to represent the specification and body of a package
- A package is a directory where related classes are stored
- To add a class to the directory, simply put the package name (path name) at the beginning of the source file

Abstract data types

- A module can define both a type and the operations on the type.
- The details of the type must be hidden from the user.
- As modules are not first class, the type must be declared and instances of the type passed as a parameter to the operation.
- To ensure the user is not aware of the details of the type, it is either defined to be private (as in Ada) or always passed as a pointer (as you would do in C). An incomplete declaration of the type is given in the .h file.

Queue Example in Ada

```
package Queuemod is
  type Queue is limited private;
  procedure Create (Q : in out Queue);
  function Empty (Q : Queue) return Boolean;
  procedure Insert (Q : in out Queue; E : Element);
  procedure Remove (Q : in out Queue; E : out Element);
private
  -- none of the following declarations are externally visible
  type Queuenode;
  type Queueptr is access Queuenode;
  type Queuenode is
    record
      Contents : Processid; Next : Queueptr;
    end record;
  type Queue is
    record
      Front : Queueptr; Back : Queueptr;
    end record;
end Queuemod;
```

Queue Example in C

- From a header file:

```
typedef struct queue_t *queue_ptr_t;

queue_ptr_t create();
int empty(queue_ptr_t Q);

void insertE(queue_ptr_t Q, element E);
void removeE(queue_ptr_t Q, element *E);
```

Object-Oriented Programming

- OOP has:
  - type extensibility (inheritance)
  - automatic object initialisation (constructors)
  - automatic object finalisation (destructors)
  - run-time dispatching of operations (polymorphism)

- Ada 95 supports the above through tagged types and class-wide programming
- Java supports OOP though the use of classes

OOP and Ada

- Based on type extensions (tagged types) and dynamic polymorphism (class-wide types)

```
type A is record … end record;  -- normal record type
type EA is tagged record … end record; -- tagged type

procedure Op1(E : EA; Other_Param : Param);
  -- primitive operation
 procedure Op2(E : EA; Other_Param : Param);
  -- primitive operation
```

Ada and OOP

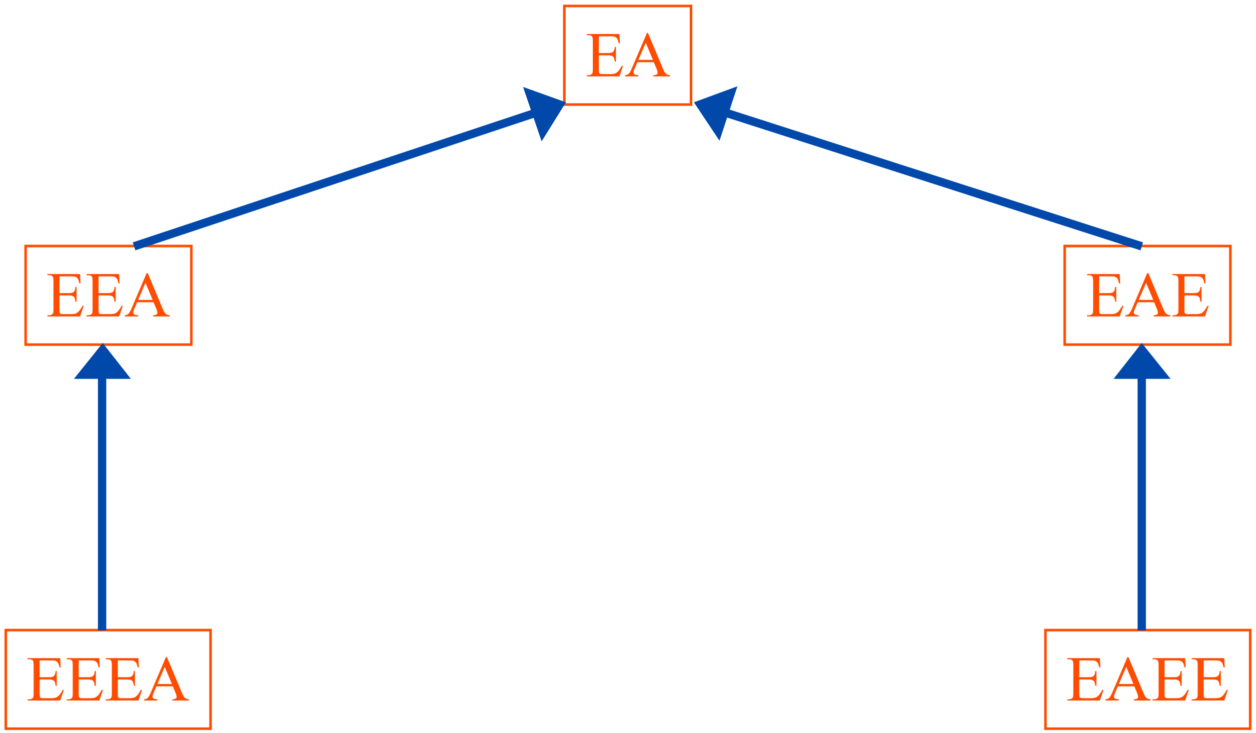
```
type EEA is new EA with record … end record;
-- inherit OP1

procedure Op2(E : EEA; Other_Param : Param);
-- override Op2

procedure Op3(E : EEA; Other_Param : Param);
-- add new primitive operation


type EEEA is new EA with record … end record;
...
type EAE is new EA with record … end record;
...
type EAEE is new EAE with record … end record;
...
```

Ada and OOP



Type Hierarchy routed at EA
called EA'Class

OOP and Java

- Based on the class construct
- Each class encapsulates data (instance variables) and operations on the data (methods including constructor methods)
- Each class can belong to a package
- It may be local to the package or visible to other packages (in which case it is labelled public)
- Other class modifiers are abstract and final
- Similarly, methods and instance variables have modifiers as being
  - public (visible outside the class)
  - protected (visible only within package or in a subclass)
  - private (visible only to the class)

Java Example

```java
import somepackage.Element; // import element type
package queues; // package name

class QueueNode // class local to package
{
  Element data;
  QueueNode next;
}

public class Queue // class available from outside the package
{
  QueueNode front, back; // instance variables
  public Queue() // public constructor
  {
    front = null;
    back = null;
  }
```

Java Example

```
public void insert(Element E) //  visible method
{
  QueueNode newNode = new QueueNode();
  newNode.data = E;  newNode.next = null;
  if(empty()) {front = newNode;}
  else { back.next = newNode; }
  back = newNode;
}
public Element remove() //visible method
{
  if(!empty()) { Element tmpE = front.data;
    front = front.next; if(empty)) back = null; }
  // garbage collection will free up the QueueNode object
  return tmpE;
}
public boolean empty() // visible method
{ return (front == null); }
}
```

Inheritance and Java

```
package coordinate;
public class Coordinate  // Java is case sensitive
{
  float X, Y;

  public Coordinate(float initial_X, float initial_Y) // constructor
  { X = initial_X;
    Y = initial_Y; }

  public void set(float F1, float F2)
  {  X = F1;
     Y = F2; }

  public float getX()
  { return X; }

  public float getY()
  { return Y; }

  public void plot() {
   // plot a two D point}
}
```

Inheritance and Java

```
package coordinate;
public class ThreeDimension extends Coordinate {
  // subclass of Coordinate

  float Z; // new field

  public ThreeDimension(float initialX, float initialY,
         float initialZ) // constructor
  { super(initialX, initialY); // call superclass constructor
    Z = initialZ;
  }

  public void set(float F1, float F2, float F3)  //new method
  {  super.set(F1, F2); // call superclass set
    Z = F3;
  }

  public float getZ() // new method
  { return Z;}

  public void plot() {//overridden method
   /* plot a three D point */}
}
```

Inheritance and Java

- Method calls are dispatching

```
{
  Coordinate A = new Coordinate(0f, 0f);
  A.plot();
}
```

would plot a two dimension coordinate; where as

```
{
  Coordinate A = new Coordinate(0f, 0f);
  ThreeDimension B = new ThreeDimension(0f, 0f, 0f);

  A = B;
  A.plot();
}
```

will plot a three D coordinate even though A was originally declared to be of type `Coordinate`. This is because `A` and `B` are reference types. By assigning `B` to `A` only the reference has changed not the object itself.

The Object Class

- All classes are implicit subclasses of the `Object` class

```
public class Object {
  ...
  public boolean equals(Object obj);

  // methods to support monitors
  public final void wait()throws IllegalMonitorStateException,
      InterruptedException;
  public final void wait(long millis)throws
     IllegalMonitorStateException, InterruptedException;
  public final void wait(long millis, int nanos) throws
     IllegalMonitorStateException, InterruptedException;
  public final void notify() throws IllegalMonitorStateException;
  public final void notifyAll() throws IllegalMonitorStateException;

  //override for finalization
  protected void finalize()
    throws Throwable;
}
```

Interfaces in Java

- Interfaces in Java augment classes to increase the reusability of code (compare with Ada's generics)
- An interface is a special form of class that defines the specification of a set of methods and constants
- They are by definition abstract so no instances of interfaces can be declared
- Instead, one or more classes can implement an interface, and objects implementing interfaces can be passed as arguments to methods by defining the parameter to be of the interface type
- Interfaces allow relationships to be constructed between classes outside of the class hierarchy

Interface Example

```
package interfaceExamples;

public interface Ordered {
  boolean lessThan (Ordered O);
}
```

- `lessThan` takes as a parameter any object that implements the `Ordered` interface

Interface Example

```
import interfaceExamples.*;
class ComplexNumber implements Ordered {
  protected float realPart;
  protected float imagPart;

  public boolean lessThan(Ordered O) // interface implementation
  {
    ComplexNumber CN = (ComplexNumber) O; // cast the parameter

    if((realPart*realPart + imagPart*imagPart) <
        (CN.getReal()*CN.getReal() + CN.getImag()*CN.getImag()))
    { return true; }
    return false;
  }

  public ComplexNumber (float I, float J) // constructor
  { realPart = I; imagPart = J; }

  public float getReal() { return realPart;}

  public float getImag() { return imagPart; }

}
```

Interface Example

```
package interfaceExamples;
public class ArraySort
{
  public static void sort (Ordered oa[], int size) //sort method
  {
    Ordered tmp;
    int pos;

    for (int i = 0; i < size - 1;  i++) {
      pos = i;
      for (int j = i + 1; j < size; j++) {
        if (oa[j].lessThan(oa[pos])) {
          pos = j;
        }
      }
      tmp = oa[pos];
      oa[pos] = oa[i];
      oa[i] = tmp;
    }
  }
```

Interface Example

```
  public static Ordered largest(Ordered oa[], int size)
    // largest method
  {
    Ordered tmp;
    int pos;

    pos = 0;
    for (int i = 1; i < size; i++) { // assumes size >=1
      if (! oa[i].lessThan(oa[pos])) {
        pos = i;
      }
    }
    return oa[pos];
  }
}
```

Interface Example

```
{

  ComplexNumber arrayComplex[] = { // say
                    new ComplexNumber(6f,1f),
                    new ComplexNumber(1f, 1f),
                    new ComplexNumber(3f,1f),
                    new ComplexNumber(1f, 0f),
                    new ComplexNumber(7f,1f),
                    new ComplexNumber(1f, 8f),
                    new ComplexNumber(10f,1f),
                    new ComplexNumber(1f, 7f)
  };
  // array unsorted
  ArraySort.sort(arrayComplex, 8);
  // array sorted
}
```

Summary

- Modules support: information hiding, separate compilation and abstract data types
- Ada and C have a static module structure
- C informally supports modules; Java has a dynamic module structure called a class
- Both packages in Ada (and Java) and classes in Java have well-defined specifications which act as the interface between the module and the rest of the program
- Separate compilation enables libraries of precompiled components to be constructed
- The decomposition of a large program into modules is the essence of programming in the large
- The use of abstract data types or object-oriented programming, provides one of the main tools programmers can use to manage large software systems