Varieties of Polymorphism (B12.1)

- pure polymorphism
  - one function body, several interpretations
- overloading /ad hoc polymorphism
  - many function bodies with the same name
- overriding
  - general method in superclass
  - subclasses may provide a method with the same name and parameters
- deferred methods / abstract methods
  - defined in superclass
  - implemented in subclasses

Overloading (B12.3)

- several methods with same name, different parameters
- code executed depends on arguments given
- varieties:
  - ad hoc overloading
    - same method name in 2 or more classes unrelated by inheritance
    - e.g. `isEmpty` for `LinkedList`, `Rectangle`
  - parametric overloading
    - multiple methods with name within a single class
    - e.g. constructors for `Rectangle`

Overriding

(B12.4)

- general method defined in superclass
- subclass defines new body with equivalent semantics
- 2 varieties
  - replacement semantics
    - completely new body
  - refinement semantics
    - also executes superclass method
      - `addCard` in `DiscardPile`
    - constructors always use refinement semantics
      - `DeckPile` constructor
      - default constructor

```
class DiscardPile extends CardPile {

  public void addCard(Card aCard) {
    if (!aCard.faceUp())
      aCard.flip();
    super.addCard(aCard);
  }
}

class DeckPile extends CardPile {

  DeckPile(int x, int  y) {
    super(x,y);
    for(int i = 0; i < 4; i++)
      for(int j = 0; j <= 12; j++)
        addCard(new Card(i,j));

     Collections.shuffle(thePile);
  }
}
```

Abstract Methods (B12.5)

- abstract methods
  - also called deferred
  - essentially null implementation that must be overridden in subclass
- interfaces
  - all methods are abstract
- e.g. abstract class `Shape`
  - defines a `draw` method even though cannot provide any reasonable implementation
  - subclasses `Circle`, `Triangle` & `Square` implement draw
  - can have a polymorphic variable of type `Shape` that can perform `draw`

Pure Polymorphism (B12.6)

- multiple effects by deferring to subclass
  - e.g. `byteValue` in `Number`

```
public abstract class Number {
  public abstract int intValue ( );
      :
  public byte byteValue ( ) {
    { return (byte) intValue(); };
      :
}  // Number
public class Double extends Number {
  public int intValue ( ) { … };
    :
}  // Double
```

Polymorphism & Dynamic Binding Overview

- polymorphism is achieved via dynamic binding

```
Person p1 = new Person("Fred");
Student sp = new Student("George",204503);
String s1 = p1.getInfo();
String s2 = sp.getInfo();
Person p2 = sp;
String s3 = p2.getInfo();
```

- on method call, the method body executed is determined by the class of the object not the class of the variable

- Java: default is dynamic binding
  - `final`: static binding
  - all objects accessed by reference
- C++: default is static binding
  - `virtual`: dynamic binding, method may be overridden
  - polymorphic variables require pointers
  - slicing

```
Student sp(“George”,204503);
Person p2 = sp;
```

- Delphi:
  - `virtual` for methods that may be overridden, and
  - `override` for the overriding method

Type Checking

- full type checking at compile time still possible
- based on static type (i.e. type of variable)
- polymorphic variable can only be assigned a subclass object
- principle of substitutability says that if method exists in the superclass it exists in the subclass

```
p2.getInfo()
```

  - must be valid for any object that `p2` can reference
- cannot reference methods that exist solely in subclass since may not exist in all subclasses
- use cast to access new operations in subclass:

```
Student s = (Student) p2;
```

- can determine run-time type via `instanceof`

```
if (p2 instanceof Student) ...
```

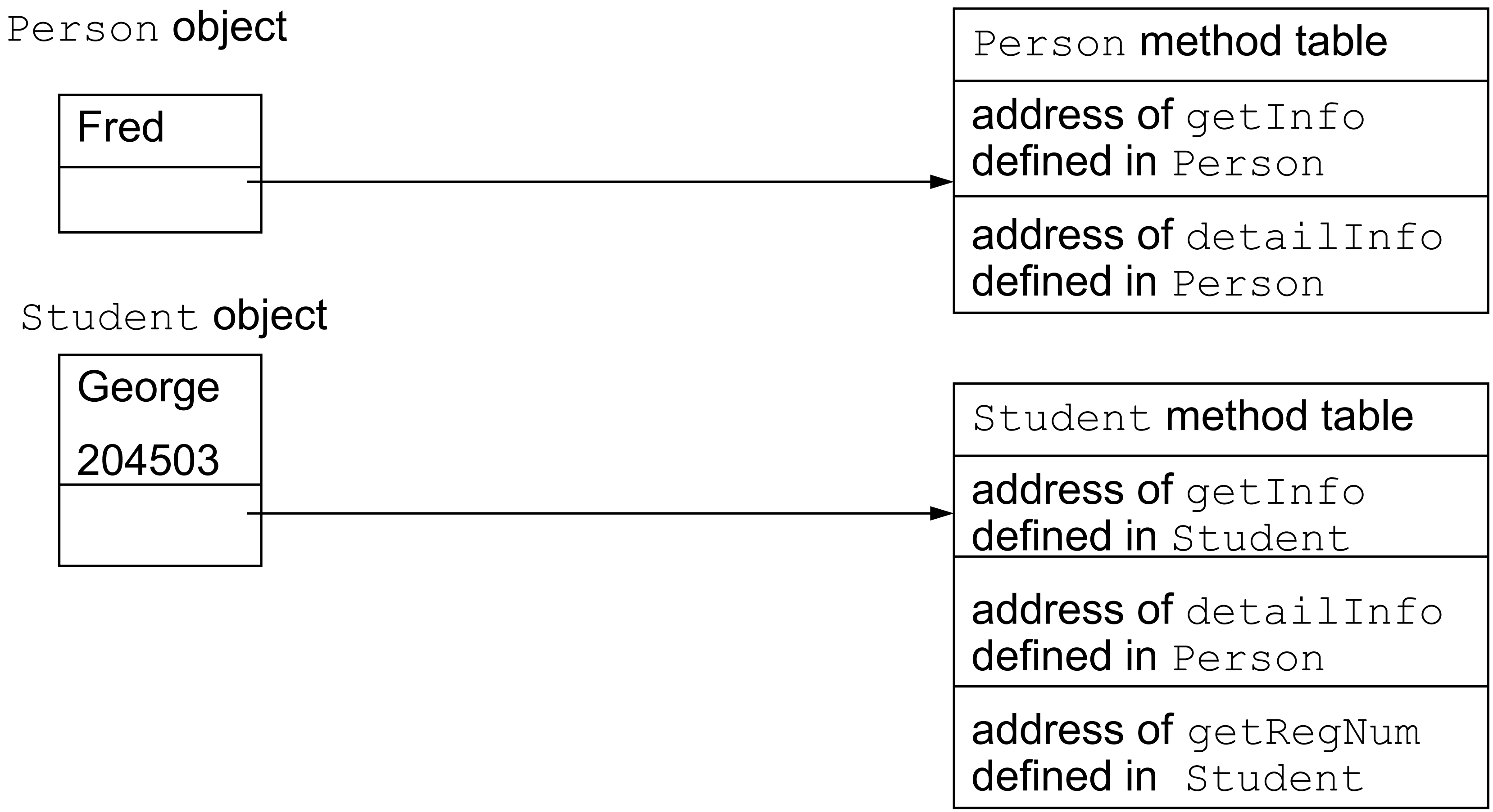
Heterogeneous Data Structures

- array of polymorphic variables
  - each element can contain objects from declared type or any subtype, e.g.

```
Person[] pList = new Person [100];
for (int i = 0; i < 100; i++) {
  String st = pList[i].getInfo();
}
```

Implementation of Dynamic Binding

- method access tables
  - required calling information for each method in class
  - includes inherited (not redefined) methods
  - created at compile time
    - property of class
  - each object has link to method access table for its class


Person object
Fred
Student object
George
204503
Person method table
address of getInfo defined in Person
address of detailInfo defined in Person
Student method table
address of getInfo defined in Student
address of detailInfo defined in Person
address of getRegNum defined in Student

Procedural vs. Object-Oriented

- e.g. operations on different kinds of shapes
- procedural approach
  - one procedure per operation
  - shape specified as parameter
  - check type of shape in procedure
- object-oriented approach
  - one class per type of shape
  - common superclass with common operations
  - override operations as needed

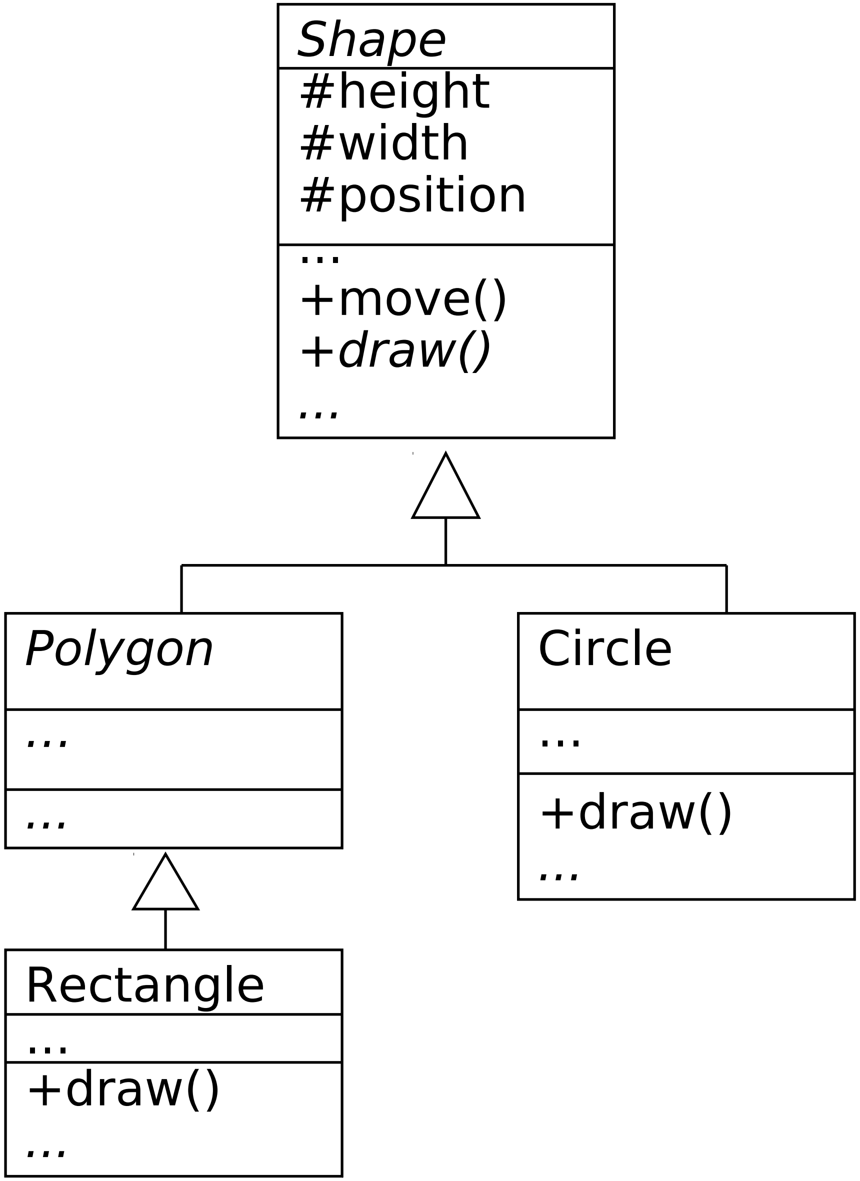
Procedural Shapes

```
void draw (Shape s) {
  switch (s.kind) {
    case LINE: /* code to draw a line */ …
    case RECTANGLE:
       /* code to draw a rectangle */ …
    case CIRCLE: /* code to draw a circle */ …
    default: /* error message */ …
  }
}
```

Object-Oriented Shapes

- `Shape` is abstract class
  - abstract method `draw`
    - defined in `Shape`
    - implementation in `Rectangle`, `Circle`
- abstract class:
  - contains 1 or more abstract methods
  - cannot create objects of that class
  - subclasses are:
    - concrete if they implement all abstract methods,
    - else they too are abstract

OO Hierarchy for Shapes



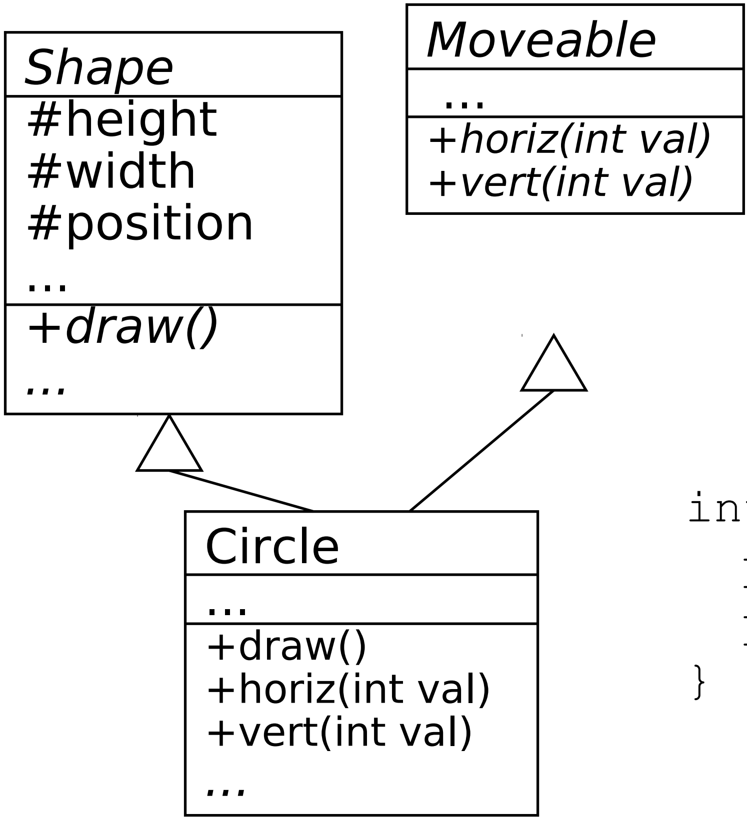
OO Shapes

```
public abstract class Shape {
  // declaration of protected attributes and
  // public operations common to all shapes
  …
  public abstract void draw();
  // definition of other abstract methods
  …
}

class Line extends Shape {
  …
  public void draw() {
    // code to draw a line …
  } // draw
} // Line

...
Shape ashape;
ashape = new Line(…);
ashape.draw();
ashape.length();       // not valid
```

Multiple Inheritance

- class with more than one parent
  - inherits variables and methods from each parent
- C++, Eiffel: allowed
- Java, Ada: not allowed
- operation with same name, parameters inherited from >1 superclass:
  - Eiffel: one of methods must be renamed in subclass
  - C++: use scope resolution operator ::
- Java interfaces
  - class may inherit specification from more than one interface

Multiple Specification Inheritance




```
interface Moveable {
  public void horiz(int val);
  public void vert(int val);
} // Moveable


public class Circle extends Shape
  implements Moveable, Serializable
   {
  …
} // Circle
```

Information Hiding and Inheritance

- problems
  - subclass may provide methods to access or change protected attribute in superclass
  - set of related protected attributes may be changed independently in subclass

```
class Date {
  protected int day, month, year;
  public Date(int d, int m, int y) {
    // check that d, m and y make a sensible
    // date before creating the object
    …
    } // constructor
    public void tomorrow() {… //new date is valid }
    …
}
class NewDate extends Date {
  public void tomorrow ( ) { d = d+1 };
}
```

- solutions
  - private attributes with protected methods for access/update
  - methods that may not be overridden (`final`)
  - package visibility
- Eiffel
  - separation of inheritance and information hiding
  - subclass inherits all attributes and methods of superclasses
  - each class has export list
    - usable but not modifiable by client

Behavioural Inheritance

- weak form of principle of substitutability
  - `S` is a subtype of `T` if substituting an object of type `S` wherever an object of type `T` is expected does not introduce the possibility of type errors at run time.
- syntactic conditions
  - all services in superclass present in subclass
  - additional services, attributes may be present in subclass
  - if service redefined in subclass then it must be compatible with original service

Compatible Services

- redefined service is compatible with original service if:
  - it has same number of parameters
  - *contravariance rule:* type of each input parameter is supertype of (or same type as) corresponding parameter in original
  - type of each output parameter is subtype of (or same type as) corresponding parameter in original
  - Java example: car, vehicle
- *Covariance*:
  - type of parameter in redefined service may be subtype of corresponding parameter in original
  - used in Eiffel
  - second level of checking to detect possible run-time errors

```
public class Vehicle {
  protected int licNum;
  ...
  public int getNumV ()
    { return licNum; }

  public boolean eq(Vehicle v) {
    return v.getNumV == licNum;
  } // eq
} // Vehicle


public class Car extends Vehicle {
  private int numSeats;
  ...
  public int getNumS()
    { return numSeats; }

  public boolean eq(Car v) {  // overloads eq
    return (v.getNumS() == numSeats) && (v.getNumV == licNum);
  } // eq
} // Car

Car c1 = new Car(27,4); Car c2 = new Car(27,5);
Vehicle v1 = c1; Vehicle v2 = new Vehicle(27);
```

`// v1.eq(c2)` is the same as `v1.eq(v2)`

Implementation Inheritance

- primary concern: re-use of code
- example: stack, queue
- inclusion polymorphism does not guarantee behavioural inheritance
- strong form of principle of substitutability
  - `S` is a subtype of `T` if, for each object `s` of type `S`, there is an object `t` of type `T` such that, for all programs `P` defined in terms of `T`, the behaviour of `P` is unchanged when `s` is substituted for `t`
  - almost impossible to enforce

Implementation Inheritance - Example

```
public class Queue {
  protected int[] vals;
  protected int first, last, numElements;

  public Queue() { … }
  public void add(int item)
    { … // add element to back of Queue … }
  public int remove()
    { … // return front element of Queue … }
} // Queue

public class Stack extends Queue {
  public Stack() { … }
  public int remove()
    { … // return top element of Stack … }
} // Stack
```