Interfaces and Sub-typing

Interfaces

- So far, we have talked about interfaces informally in the ordinary English sense of the word.
  - "interface to a class tells the client how to obtain the functionality implemented in that class"
- Java has a construct called interface which can be used formally for this purpose
  - and for doing some other really cool things…

Java interface

```
interface IPuzzle{
   void scramble();
    int tile(int r, int c);
    boolean move(char d);
}
```

```
Class IntPuzzle implements IPuzzle{
   ……
   public void scramble(){
      …..}
    public int tile(int r, int c){
      …..}
    public boolean move(char d){
      …..}
}
```

- Name of interface: IPuzzle
- A class can implement this interface by implementing public instance methods with the names and type signatures specified in the interface.
- The class may implement other methods.

Notes

- Interface itself cannot be instantiated.
  - incomplete specification
- It is not enough for a class to just have implementations of interface methods; class header must also assert "implements I" for Java to recognize that the class implements interface I.
- A class may implement several interfaces.
  - (eg) class X implements IPuzzle, IRaq {
    ……}

Why interface construct?

- One use of interfaces: software engineering
  - specifying and enforcing boundaries between different parts of a team project, as in Puzzle example.
- But interfaces can do much more.
  - Interfaces let you write more "generic" code that reduces code duplication.

Example of code duplication

- Suppose we have two implementations of puzzles:
  - Class IntPuzzle uses an *int* to hold state
  - Class ArrayPuzzle uses an array to hold state
- Assume client wants to use both implementations in code
  - perhaps for benchmarking both implementations to pick the best one?
  - client code has a display method as always to print out puzzles
- What would the display method look like?

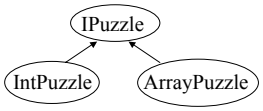
```
Class Client{
   IntPuzzle p1 = new IntPuzzle();
   ArrayPuzzle p2 = new ArrayPuzzle();
   ….display(p1)…display(p2)…

    public static void display(IntPuzzle p){
       for (int r = 0; r < 3; r++)
           for (int c = 0;c<3;c++) {
             System.out.print(p.tile(r,c));
             System.out.print(' ');
           }}
   public static void display(ArrayPuzzle p){
       for (int r = 0; r < 3; r++)
           for (int c = 0;c<3;c++) {
             System.out.print(p.tile(r,c));
             System.out.print(' ');
           }}
}
```

Code duplicated because types IntPuzzle and ArrayPuzzle are different.

Observation

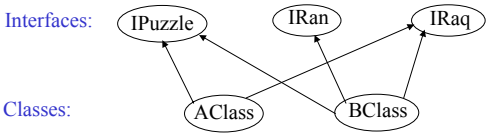
- Two display methods are needed because types IntPuzzle and ArrayPuzzle are different, and parameter p must have one type or the other.
- Ironically, the code inside the two methods is identical.
  - Code relies only on assumption that parameter p is passed an object that has an instance method tile(int,int).
- Is there a way to avoid this code duplication?
  - Use interfaces and sub-typing

Interfaces as types



- Name of an interface can be used as a variable type.
  - (eg) IPuzzle p1, p2;
- Class that implements the interface is said to be a sub-type of the interface type.
  - IntPuzzle and ArrayPuzzle are sub-types of IPuzzle.
- Interface is said to be a super-type of those classes.
  - IPuzzle is a super-type of type IntPuzzle and ArrayPuzzle.

Note



- Since a class can implement several interfaces, it may have many super-types.
- An interface can be implemented by several classes, so it may have many sub-types.

Paradox with interfaces as types

- We cannot instantiate an interface I.
  - Interface is a partial specification.
- If we cannot create objects of type I, why bother permitting interface names to be types?
  - (eg) IPuzzle p1,p2;
  - Fine, but what would we ever assign to p1 and p2?!!
- To understand this, let us look at a real-life analogy.

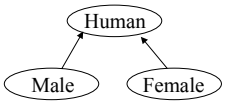
Names, Objects and Types

- In programming languages, like in real life, we attribute type both to names (variables) and to objects.
- Example from real life: gender
  - Two types: Male and Female
  - These types are assigned to people (objects):
    - The President of Cornell is a Male.
    - The Provost of Cornell is a Female.
  - These types are also assigned to names:
    - Male George, Sam, Helmut, Bubba;
    - Female Rie, Naomi, Indira, Melanie;

Unisex names

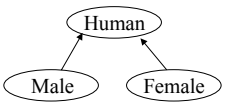
- Some names can refer to people of either gender:
  (eg): Sandy, Pat, Jackie
- How do we fit unisex names into our classification?
- Here is an idea….

Sub-typing in real life

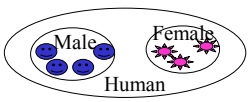


- Let us add a new type called Human.
- Humans have certain functionalities:
  - They walk upright.
  - They have juxtaposed thumbs.
  - They are intelligent….
- Male and female are sub-types of type Human because they implement this functionality although in different ways.
- Like an interface, type Human cannot be instantiated directly: every human must be either a male or a female.

Sub-types and subsets



Sub-types



Subsets

- Sub-types and subsets are distinct concepts.
- Sub-types are characterized by some common functionality.
  - Sub-type female in our example is characterized by ability to give birth.
- In this example, a mixture of males and females is a subset of type human, but it is not a sub-type.

Back to names

- Using these types, we can now give types to unisex names as well:
  - Male George, Sam, Helmut, Bubba;
  - Female Rie, Naomi, Indira, Melanie;
  - Human Jo, Sandy, Pat;

Naming people

- Simple picture without sub-typing:
  - Male objects get male names.
  - Female objects get female names.
- Examples:

```
//we created a new male object and named it George
    George = new Male(); //type checks
//give object named Sam the alias Bubba
    Bubba  = Sam; //type checks
//give object named Bubba the alias Melanie
    Melanie   = Bubba;//type mismatch
```

- In last example, we do not need to know anything about who Bubba is to see that there is a type mismatch.

Up-casting

- Situation is a little more complex with unisex names (sub-typing).
- Example: Sandy = new Female();
  - Type of reference returned by RHS is Female.
  - Type of LHS name is Human.
  - Nevertheless, no type error because Female is sub-type of Human.
- Up-casting: type of RHS reference is sub-type of type of LHS name.
- Up-casting is always type-correct.
- Example: Sandy = Laura;
  - You do not need to know the object named Laura to determine that the assignment is type-correct.

Down-casting

- Is this type-correct?

```
Bubba = Sandy;
```

- Answer: depends.
  - Type of RHS name (reference) Sandy is Human which is super-type of LHS name
  - Type of object named Sandy: either Male or Female
  - Whether or not the assignment is legal depends not on the type of the RHS reference but on the type of the actual object.
- Down-casting: Type of LHS name is sub-type of RHS reference.
- Down-casting may or may not be legal
  - need to look at object to determine legality

Resolution of paradox with interfaces as types

- Java allows up-casting:
  - IPuzzle p1 = new ArrayPuzzle();
  - IPuzzle p2 = new IntPuzzle();
- Note:
  - Type of reference returned by right-hand side expression of first statement is ArrayPuzzle.
  - Type of variable on left-hand side is IPuzzle.
  - Two types are different, but type of rhs reference is a sub-type of type of the variable.

Why up-casting?

- Sub-typing and up-casting allow you to avoid code duplication in many situations.
- Puzzle example: you and client agree on interface IPuzzle.

```
interface IPuzzle{
  void scramble();
   int   tile(int r, int c);
   boolean move(char d);
}
```

Your code

```
Class IntPuzzle implements IPuzzle{
  …scramble()…tile()…move()…twist()
}

Class ArrayPuzzle implements IPuzzle{
  ……scramble()...tile()…move()…
}
```

Class IntPuzzle implements a method called twist *which is not a method of interface IPuzzle.*

Client Code

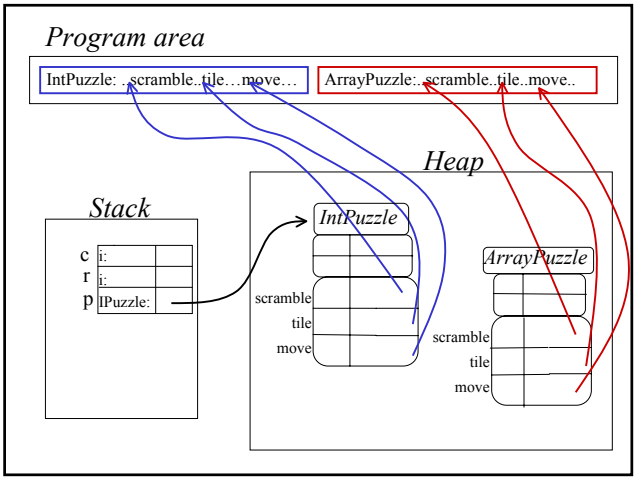
```
Class Client{
   IntPuzzle p1 = new IntPuzzle();
   ArrayPuzzle p2 = new ArrayPuzzle();
   ….display(p1)…display(p2)…

    public static void display(IPuzzle p){
       for (int r = 0; r < 3; r++)
          for (int c = 0;c<3;c++) {
            System.out.print(p.tile(r,c));
            System.out.print(‘ ‘);
            }}
}
```

Up-casting: Objects of type IntPuzzle and ArrayPuzzle are passed to parameter of type IPuzzle.

Method execution

```
public static void display(IPuzzle p){
      for (int r = 0; r < 3; r++)
         for (int c = 0;c<3;c++) {
           System.out.print(p.tile(r,c));
           System.out.print(‘ ‘);
           }}
```

- Subtle point: which tile method is invoked in code shown above?
  - tile method in IntPuzzle class??
    - What if object passed in is of type ArrayPuzzle?
  - tile method in ArrayPuzzle class??
    - What if object passed in is of type IntPuzzle?
  - tile method in IPuzzle interface??
    - Huh??
- To understand this, let us look again at execution model.



Resolving the name "p.tile"

- Stack frame for invocation of display has storage for variables p,r,c.
- Suppose method is passed an IntPuzzle object in parameter p as shown.
- Invocation "p.tile(r,c)" in body of display is executed as discussed earlier:
  - Look up method tile in object O referenced by p.
  - Invoke that method passing it this (object O), r,c.
  - In our example, therefore, we would invoke the tile method implemented in the IntPuzzle class.

Think

- Type of paramater p: IPuzzle
  - IPuzzle itself does not have a tile method!
- Actual method that gets invoked is implemented sometimes in the ArrayPuzzle class and sometimes in the IntPuzzle class!
- Dynamic method binding:
  - Name "p.tile" is not resolved to a single method.
  - In different invocations, name may be resolved to different methods.
- Method display is sometimes said to be a polymorphic/generic method.
  - Parameters are not restricted to be of a single type.

Note on type-checking

```
public static void display(IPuzzle p){
        for (int r = 0; r < 3; r++)
            for (int c = 0;c<3;c++) {
              System.out.print(p.tile(r,c));
              System.out.print(' ');
             }}
```

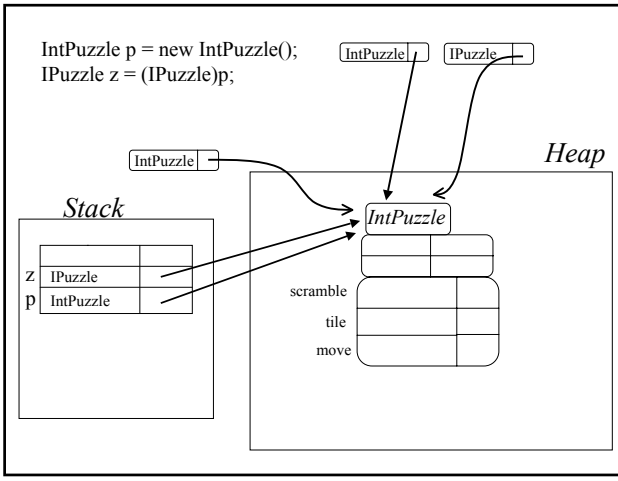
- Compile-time check: does type of reference p (IPuzzle) have a method called tile with the right type signature? If not, error.
- Runtime: go into object referred to by p and look up its tile method.
- Remember: type of reference MUST have appropriate method even though method that is invoked at runtime is in the class of the object.

Other languages

- Dynamic method binding is a powerful mechanism that enables generic programming.
- In languages like C, effect of dynamic method binding can be obtained by passing function pointers, which may lead to weird bugs because it is not type-safe.
- Java-style dynamic method binding is more robust and less prone to errors.
  - Implementation of Java uses function pointers.
  - Java programmers cannot use function pointers directly.
  - Compare: GOTO vs. structured programming.

Note on casting of references

- Think of reference as a pair <type,address>.
- Type of reference is always a super-type of type of object.
- Up- and down-casting do not change either the object or the reference – they produce a new reference of a different type (analogy: arithmetic operators).



Another use of up-casting

- Sub-types and up-casting are useful for storing heterogeneous objects in data structures.
- Example:

  IPuzzle[] AP = new IPuzzle[0..9];

  AP[0] = new IntPuzzle();

  AP[1] = new ArrayPuzzle();
- Note up-casting:
  - names AP[0] etc. are of type IPuzzle
  - Objects created on right hand sides are of sub-types of IPuzzle.

instanceof

- Suppose we stick a bunch of ArrayPuzzle and IntPuzzle objects into an IPuzzle array AP.
- Suppose AP is passed to another method which walks over the array and counts how many IntPuzzle objects there are.
- How does this method examine the type of the objects stored in array AP?

```
boolean b = AP[i] instanceof IntPuzzle;
//b will be true if AP[i] refers to IntPuzzle object; false otherwise
//general syntax:  reference instanceof className
```

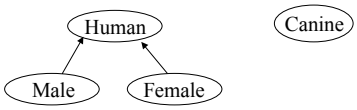
Down-casting in Java

- Java permits down-casting but casting is specified explicitly.

```
public static void foo (IPuzzle p){
    if (p instanceof IntPuzzle)
       IntPuzzle ip = (IntPuzzle)p;
    ….}
```

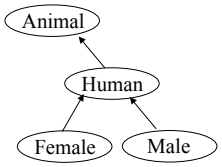
- Compile-time: check that type of reference p is super-type of type of LHS name ip.
  - Making you write cast explicitly forces you to document down-casting.
- Run-time: check that type of object referenced by RHS is a sub-type of type of LHS name.

Down-casting in real life



- Canine names
  Canine Spot, Rover;
- George = (Male)Sandy;
  - Compile-time: is type of reference Sandy (Human) a super-type of type of George (Male)? Yes.
  - Run-time: is object referenced on RHS a sub-type of Male?
    - No: error - throw class cast exception.
    - Yes: everything is cool.
- Spot = (Canine)Sandy;
  - Compile-time: is type of reference Sandy (Human) a super-type of type of Spot (Canine)? No. Compiler error.

Note on down-casting




```
Animal a = new Female();
Human h = (Human)a;
```

- In down-casting, the types of the lhs variable, the rhs reference, and the object the rhs reference points to could all be different as in this example.

Why down-casting?

- Sometimes you want to
  - access an array of heterogenous objects
  - invoke a method on objects of some sub-type of array element type
  - method is not one of the interface methods, but is implemented only by that sub-type.
- In this situation, you can use down-casting.

Example

```
void  twister(IPuzzle[] AP) {
      for (int I = 0; I<AP.length; I++) {
          if (AP[I] instanceof IntPuzzle)
             {IntPuzzle p = (IntPuzzle)AP[I];
              p.Twist(); //method implemented only by IntPuzzle
             }
      }
}
```

Poor use of down-casting

```
void  mover(IPuzzle[] AP) {
      for (int I = 0; I<AP.length; I++) {
          if (AP[I] instanceof IntPuzzle)
            ((IntPuzzle)AP[I]).move('N');
          else ((ArrayPuzzle)AP[I]).move('N');
      }
}
```

```
void mover(IPuzzle[] AP) {
      for (int I = 0;I<AP.length;I++)
          AP[I].move('N');
}
```

- Heterogenous data in data structure AP.
- Do not use down-casting if you are invoking interface method (in this case, move) on objects in data structure.
- Code on left will have to be modified if you add another class that implements interface.
- Code on right works without modification: code reuse is promoted.

Super-interfaces

- Suppose you want to extend the specification of an interface to include more methods.
  - IPuzzle: scramble, move, tile
  - ImprovedPuzzle: scramble, move, tile, SamLoyd
- Two approaches to writing down extended interface:
  - Start from scratch and write an interface
  - Extend the IPuzzle interface

Extending interfaces

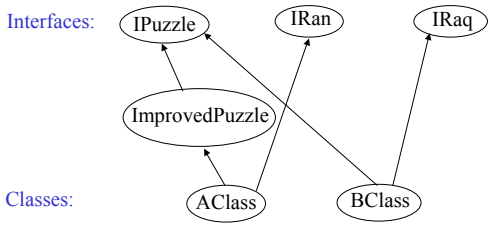
```
interface IPuzzle{
   void scramble();
   int tile(int r, int c);
   boolean move(char d);
}
interface ImprovedPuzzle extends IPuzzle{
void SamLoyd();
}
```

•IPuzzle is a super-interface of ImprovedPuzzle interface.
•ImprovedPuzzle interface is a sub-interface of IPuzzle.
•ImprovedPuzzle can be used as a type for variables like any other interface.
•It is a sub-type of IPuzzle type.

Super-interfaces

- Interface can extend multiple super-interfaces.
- Class that implements an interface must implement all methods declared in super-interfaces.

Type Hierarchy




```
class AClass  implements ImprovedPuzzle, IRan {
   ……}
//There is no need to specify explicitly that AClass implements
//interface IPuzzle.
```

- Suppose class C implements a sub-interface IB. There is no need to declare super-interfaces of IB in the “implements” clause of class C.
- Rules for up-casting and down-casting references stay the same as before.

Editorial comments

- Interfaces have two main uses:
  - Software engineering:
    - Good fences make good neighbors.
  - Sub-typing:
    - Type of interface is super-type of type of class implementing that interface.
    - Use sub-types to write more generic, polymorphic code.
- Sub-typing is a central idea in programming languages.
  - Inheritance gives another method for creating sub-types.
- Sub-typing is sometimes referred to informally as is-a relationship.
  - (eg) Every Female is-a Human.

- Up-casting: super-type name on lhs of assignment
  - Example: Sandy = Laura;
  - Used in writing polymorphic methods and for declaring data structures that can hold heterogenous data
  - Up-casting is always legal.
- Down-casting: sub-type name on lhs of assignment
  - Explicit cast required in Java.
  - Example: Laura = (Female) Sandy;
  - May or may not be legal:
    - Compile-time check: Is type of lhs reference a sub-type of rhs reference? (eg. Is Female a sub-type of Human?)
  - Runtime check inserted: may throw exception
    - Type of object on rhs may not be a sub-type of type of lhs reference.

      Human Sandy = new Female();

      Male George = (Male) Sandy;//class cast exception
  - Less common than up-casting

- Dynamic method binding
  - Method call r.m(..,..,..);
  - Remember that type of reference r may be different from type of object pointed to by r.
  - Compile-time check: does type of reference r have a method named m with appropriate parameter types?
  - Run-time: look inside object named by r and invoke method named m with the appropriate type signature.
- Sub-typing and dynamic method binding permit you to write polymorphic/generic methods to avoid duplicating code for each type.