CS 211

Computers and Programming

http://www.cs.cornell.edu/courses/cs211/2005su

Lecture 7: Interfaces, Subtypes, and Comparable

Announcements

- Assignment 2 is finally up. Look through it before tomorrow, so you can ask questions.
- Quiz tomorrow on OOP, Inheritance, and Interfaces.
- Assignment 1 will be graded soon.
- Prelim 1 on first two weeks of material, in class on Tuesday.
- Assignment 2 is due Wednesday, but it’s a good idea to complete it before the exam.

Interfaces

- So far, we have talked about *interfaces* informally, in the English sense of the word
  - an interface describes how a client interacts with a class
  - method names, argument/return types, fields

- Java has a construct called **`interface`** which can be used formally for this purpose

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 implements this interface by implementing public instance methods as specified in the interface
- the class may implement other methods

Notes

- An interface is not a class!
  - cannot be instantiated
  - incomplete specification
- class header must assert **`implements I`** for Java to recognize that the class implements interface **`I`**
- A class may implement several interfaces:

```
class X implements IPuzzle, IPod {
 ... }
```

Why an `interface` construct?

- good software engineering
  - specify and enforce boundaries between different parts of a team project
- can use interface as a type
  - allows more generic code
  - 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
  - perhaps for benchmarking both implementations to pick the best one
  - client code has a display method 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.println(p.tile(r,c));
  }

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

Code duplicated because **`IntPuzzle`** and **`ArrayPuzzle`** are different

Observation

- Two display methods are needed because **`IntPuzzle`** and **`ArrayPuzzle`** are different types, and parameter **`p`** must be one or the other
- but the code inside the two methods is identical!
  - code relies only on the assumption that the object **`p`** has an instance method **`tile(int,int)`**.
- Is there a way to avoid this code duplication?

One Solution ? Abstract Classes

Puzzle code

```
abstract class Puzzle {
  abstract int tile(int r, int c);
  ...
}
class IntPuzzle extends Puzzle {
  public int tile(int r, int c) {...}
  ...
}
class ArrayPuzzle extends Puzzle {
  public int tile(int r, int c) {...}
  ...
}
```

Client code

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

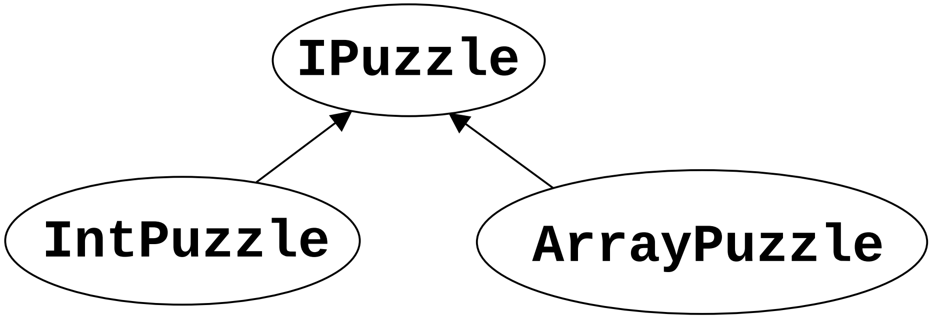
Another Solution ? Interfaces

Puzzle code

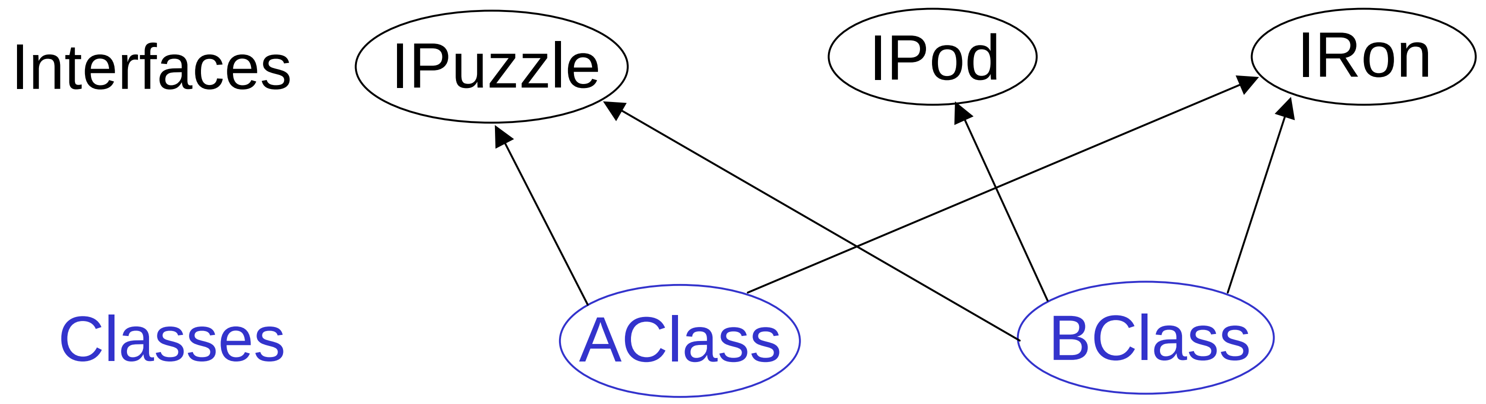
```
interface IPuzzle {
  int tile(int r, int c);
  ...
}
class IntPuzzle implements IPuzzle {
  public int tile(int r, int c) {...}
  ...
}
class ArrayPuzzle implements IPuzzle {
  public int tile(int r, int c) {...}
  ...
}
```

Client code

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



- interface names can be used in type declarations
  - **`IPuzzle p1, p2;`**
- a class that implements the interface is a subtype of the interface type
  - **`IntPuzzle`** and **`ArrayPuzzle`** are subtypes of **`IPuzzle`**
  - **`IPuzzle`** is a supertype of **`IntPuzzle`** and **`ArrayPuzzle`**



- Unlike classes, types do not form a tree!
  - a class may implement several interfaces
  - an interface may be implemented by several classes

Interfaces vs Inheritance

- A class can
  - implement many interfaces, but
  - extend only one class

- To share code between two classes
  - put shared code in a common superclass
  - interfaces cannot contain code

Types

Static vs Dynamic Types

- Every variable (more generally, every expression that denotes some kind of data) has a static* or compile-time type
  - derived from declarations – you can see it
  - known at compile time, without running the program
  - does not change
- Every object ever created has a dynamic or runtime type
  - obtained when the object is created using **`new`**
  - not known at compile time – you can't see it

---

* Warning! No relation to Java keyword **`static`**

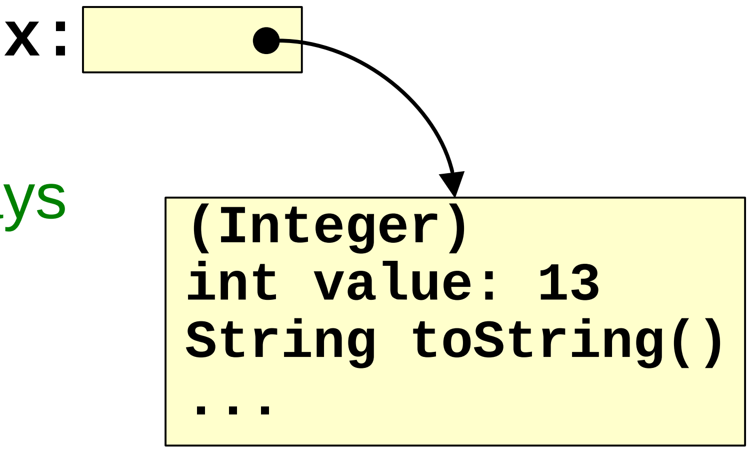
Example

```
int i = 3, j = 4;
Integer x = new Integer(i+3*j-1);
System.out.println(x.toString());
```

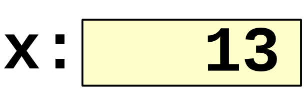
- static type of the variables **`i,j`** and the expression **`i+3*j-1`** is **`int`**
- static type of the variable **`x`** and the expression **`new Integer(i+3*j-1)`** is **`Integer`**
- static type of the expression **`x.toString()`** is **`String`** (because **`toString()`** is declared in the class **`Integer`** to have return type **`String`**)
- dynamic type of the object created by the execution of **`new Integer(i+3*j-1)`** is **`Integer`**

Reference vs Primitive Types

- Reference types
  - classes, interfaces, arrays
  - E.g.: **`Integer`**



- Primitive types
  - int, long, short, byte, boolean, char, float, double



Why Both `int` and `Integer`?

- Some data structures work only with reference types (`Hashtable, Vector, Stack,...`)
- Primitive types are more efficient

```
for (int i = 0; i < n; i++) {...}
```

Upcasting and Downcasting

- Applies to reference types only
- Used to assign the value of an expression of one (static) type to a variable of another (static) type
  - upcasting: subtype $\rightarrow$ supertype
  - downcasting: supertype $\rightarrow$ subtype
- A crucial invariant:

> If during execution, an expression *E* is ever evaluated and its value is an object *O*, then the dynamic type of *O* is a subtype of the static type of *E*.

Upcasting

- Example of upcasting:

```
Object x = new Integer(13);
```

  - static type of expression on rhs is **`Integer`**
  - static type of variable **`x`** on lhs is **`Object`**
  - **`Integer`** is a subtype of **`Object`**, so this is an upcast
- static type of expression on rhs must be a subtype of static type of variable on lhs – compiler checks this
- upcasting is always type correct – preserves the invariant automatically

Downcasting

- Example of downcasting:

```
Integer x = (Integer)y;
```

  - static type of **`y`** is **`Object`** (say)
  - static type of **`x`** is **`Integer`**
  - static type of expression **`(Integer)y`** is **`Integer`**
  - **`Integer`** is a subtype of **`Object`**, so this is a downcast
- In any downcast, dynamic type of object must be a subtype of static type of cast expression
- runtime check, **`ClassCastException`** if failure
- needed to maintain invariant (and only time it is needed)

Is the Runtime Check Necessary?

Yes, because dynamic type of object may not be known at compile time

```
void bar() {
  foo(new Integer(13));
}           String("x")

void foo(Object y) {
  int z = ((Integer)y).intValue();
  ...
}
```

Upcasting with Interfaces

- Java allows up-casting:

```
IPuzzle p1 = new ArrayPuzzle();
IPuzzle p2 = new IntPuzzle();
```

- Static types of right-hand side expressions are **`ArrayPuzzle`** and **`IntPuzzle`**, resp.
- Static type of left-hand side variables is **`IPuzzle`**
- Rhs static types are subtypes of lhs static type, so this is ok

Why Upcasting?

- Subtyping and upcasting can be used to avoid code duplication
- Puzzle example: you and client agree on interface **`IPuzzle`**

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

Solution

Puzzle code

```
interface IPuzzle {
  int tile(int r, int c);
  ...
}
class IntPuzzle implements IPuzzle {
  public int tile(int r, int c) {...}
  ...
}
class ArrayPuzzle implements IPuzzle {
  public int tile(int r, int c) {...}
  ...
}
```

Client code

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

Method Dispatch

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

- Which **`tile`** method is invoked?
  - depends on dynamic type of object **`p`** (**`IntPuzzle`** or **`ArrayPuzzle`**)
  - we don't know what it is, but whatever it is, we know it has a **`tile`** method (since any class that implements **`IPuzzle`** must have a **`tile`** method)

Method Dispatch

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

- Compile-time check: does the static type of **`p`** (namely **`IPuzzle`**) have a **`tile`** method with the right type signature? No → error
- Runtime: go to object that is the value of **`p`**, find its dynamic type, look up its **`tile`** method
- The compile-time check guarantees that an appropriate **`tile`** method exists

Note on Casting

- Up- and downcasting do not change the object — they merely allow it to be viewed at compile time as a different static type

Another Use of Upcasting

Heterogeneous Data Structures

- Example:

```
IPuzzle[] pzls = new IPuzzle[9];
pzls[0] = new IntPuzzle();
pzls[1] = new ArrayPuzzle();
```

- names **`pzls[i]`** are of type **`IPuzzle`**
- objects created on right hand sides are of subtypes of **`IPuzzle`**

Java **`instanceof`**

- Example:
  `if (p instanceof IntPuzzle) {...}`
- true if dynamic type of **`p`** is a subtype of **`IntPuzzle`**
- usually used to check if a downcast will succeed

Example

- suppose **`twist`** is a method implemented only in **`IntPuzzle`**

```
void twist(IPuzzle[] pzls) {
  for (int i = 0; i < pzls.length; i++) {
    if (pzls[i] instanceof IntPuzzle) {
      IntPuzzle p = (IntPuzzle)pzls[i];
      p.twist();
}}}
```

Avoid Useless Downcasting

bad

```
void moveAll(IPuzzle[] pzls) {
  for (int i = 0; i < pzls.length; i++) {
    if (pzls[i] instanceof IntPuzzle)
      ((IntPuzzle)pzls[i]).move("N");
    else ((ArrayPuzzle)pzls[i]).move("N");
}}
```

good

```
void moveAll(IPuzzle[] pzls) {
  for (int i = 0; i < pzls.length; i++)
    pzls[i].move("N");
}
```

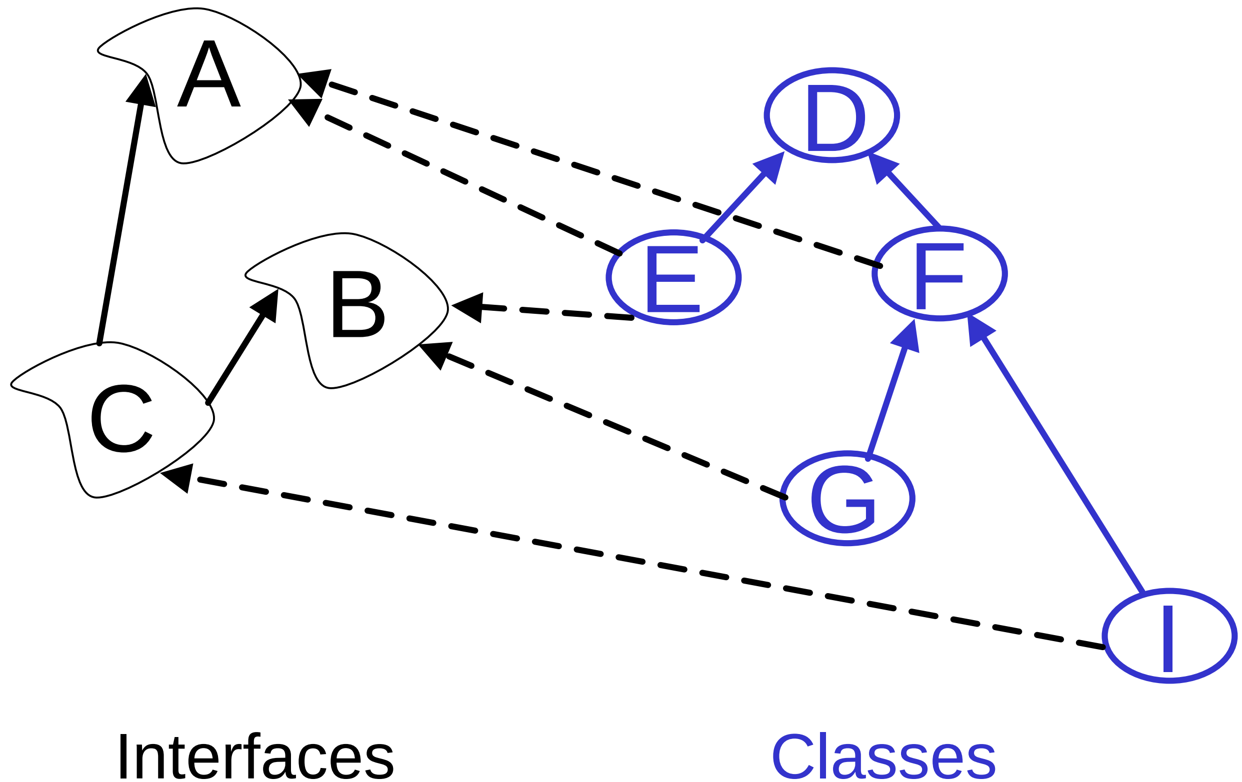
Subinterfaces

- Suppose you want to extend the interface to include more methods
  - **`IPuzzle`**: **`scramble, move, tile`**
  - **`ImprovedPuzzle`**: **`scramble, move, tile, SamLoyd`**
- Two approaches
  - start from scratch and write an interface
  - extend the **`IPuzzle`** interface

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

interface ImprovedPuzzle extends IPuzzle {
   void SamLoyd();
}
```

- **`IPuzzle`** is a superinterface of **`ImprovedPuzzle`**
- **`ImprovedPuzzle`** is a subinterface of **`IPuzzle`**
- **`ImprovedPuzzle`** is a subtype of **`IPuzzle`**
- An interface can extend multiple superinterfaces
- A class that implements an interface must implement all methods declared in all superinterfaces




```
interface C extends A,B {...}
class F extends D implements A {...}
class E extends D implements A,B {...}
```

Comparison

- Something that we do a lot
- Can compare all kinds of data with respect to all kinds of comparison relations
  - identity
  - equality
  - order
  - lots of others

Identity vs Equality

- identity: == != (primitive and reference types)
- testing equality of objects: use **`equals`**
- **`equals`** is defined in class **`Object`**
- any class you create inherits **`equals`** from its parent class, but you can override it (and probably want to)

Identity vs Equality

- Quiz: What are the results of the following tests?
  - "hello".equals("hello") **`true`**
  - "hello" == "hello" **`true`**
  - new String("hello") == new String("hello") **`false`**

Order

- numeric primitives: use <, >, <=, >=
- objects?
  - **`Integer`** – compare by value
  - **`String`** – compare lexicographically (dictionary order)
  - cannot use <, >, <=, >=

Order

- for reference types, use **`Comparable`** interface

```
interface Comparable {
   int compareTo(Object x);
}
```

- (note: this is Java 1.4.2 – Java 5.0 has generics)
- **`x.compareTo(y)`** returns a negative, zero, or positive integer according as **`x`** is "less than", "equal to", or "greater than" **`y`**, respectively
- "less than", "equal to", and "greater than" are *defined* for that class by the implementation of **`compareTo`**

Example

- Compare people by weight:

```
class Person implements Comparable {
  private int weight;
  ...
  public int compareTo(Object obj) {
    return ((Person)obj).weight - weight;
  }
  public boolean equals(Object obj) {
    return obj instanceof Person &&
      ((Person)obj).weight == weight;
  }
}
```

Note

If a class has an **`equals`** method and also implements **`Comparable`**, then it is advisable (but not enforced) that

`a.equals(b)`

exactly when

`a.compareTo(b) == 0`.

Generic Code

- The **`Comparable`** interface allows generic code for sorting, searching, and other operations that only require comparisons

```
static void mergeSort(Comparable[] a) {...}
static void bubbleSort(Comparable[] a) {...}
```

- The sort methods do not need to know what they are sorting, only how to compare elements

Generic Code

- Finding the max element of an array

```
//return max element of an array
static Comparable max(Comparable[] a) {
  //throws ArrayIndexOutOfBoundsException
  Comparable max = a[0];
  for (Comparable x : a) {
    if (x.compareTo(max) > 0) max = x;
  }
  return max;
}
```

- What is the max element? Whatever **`compareTo`** says it is!

Another Example

- Lexicographic comparison of **`Comparable`** arrays
- for **`int`** arrays, **`a < b`** lexicographically iff either:
  - **`a[i] == b[i]`** for **`i < j`** and **`a[j] < b[j]`**; or
  - **`a[i] == b[i]`** for all **`i < a.length`**, and **`b`** is longer

```
//compare two Comparable arrays lexicographically
static int arrayCompare(Comparable[] a, Comparable[] b) {
  for (int i = 0; i < a.length && i < b.length; i++) {
    int x = a[i].compareTo(b[i]);
    if (x != 0) return x;
  }
  return b.length - a.length;
}
```

Conclusion

- Interfaces have two main uses
  - software engineering: good fences make good neighbors
  - subtyping
- Subtyping is a central idea in programming languages
  - inheritance and interfaces are two methods for creating subtype relationships
- **`Comparable`** is a useful standard interface that will make your life easier