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Inheritance

Lecture 8
CS211 – Summer 2007

What is Inheritance?

- OO-programming = Encapsulation + Extensibility
- Encapsulation: permits code to be used without knowing implementation details
  - classes, objects
  - visibility declarations such as `private`, `protected`
- Extensibility: permits behavior of classes to be *changed* or *extended* without having to rewrite the code of the class
  - no need to involve the class implementer
  - promotes code reuse
- Mechanism for extensibility in OO-programming: *Inheritance*

Running Example: 8-Puzzle

1	3	
4	2	6
7	5	8

```
class Puzzle {

   //representation of a puzzle state
   private int state;

   //create a new random instance
   public void scramble() {...}

   //say which tile occupies a given position
   public int tile(int row, int col) {...}

   //move a tile
   public boolean move(char c) {...}
}
```


Representation of State

1	3	
4	2	6
7	5	8

→ 139426758

- One possibility: model puzzle state as an integer between 123456789 and 987654321
  - 9 represents the empty square
- To convert integer s into a grid representation:
  - Remainder `s%10`: tile in bottom right position: 8
  - Quotient `s/10`: encoding of remaining tiles: 13942675
  - Repeat remainder and quotient to extract remaining tiles
- A similar encoding is used for multidimensional arrays
- We declared `state` private, so only the `Puzzle` class knows we are using this representation -- *Encapsulation*

New Requirement

- Suppose you are the client. After receiving puzzle code, you decide you want the code to keep track of the number of moves made since the last scramble operation.
- Implementation is simple:
  - keep a counter `numMoves`, initialized to 0
  - method `move` should increment the counter
  - method `scramble` should reset the counter to 0
  - new method `printNumMoves` for printing value of counter

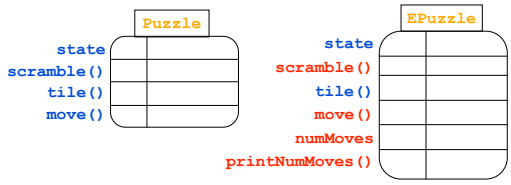
Implementation

- Three approaches:
  - Call supplier and send them a new specification. They implement it and charge you an extra $5K. ☹
  - Rewrite the supplier's code yourself. ☹
  - Use inheritance to define a new class that *extends* the behavior of the supplier's class. ☺

Goal

- Define a new class **EPuzzle** that extends **Puzzle**
- Tell Java that **EPuzzle** is just like **Puzzle**, except:
  - it has a new instance variable **numMoves**
  - it has a new instance method **printNumMoves**
  - it has modified versions of **scramble** and **move**

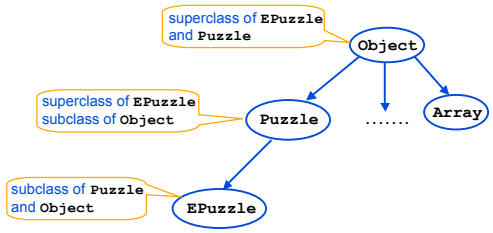
Picture




```
class EPuzzle extends Puzzle {
   private int numMoves = 0;
   public void scramble() {...}
   public boolean move(char d) {...}
   public void printNumMoves() {...}
}
```

- Class **EPuzzle** is a subclass of class **Puzzle**
- Class **Puzzle** is a superclass of class **EPuzzle**
- An **EPuzzle** object
  - *has its own* instance variable **numMoves** and instance method **printNumMoves**
  - *overrides* methods **scramble** and **move** of **Puzzle**
  - *inherits* method **tile** of **Puzzle**

Class Hierarchy



Every class (except **Object**) has a unique immediate superclass, called its *parent*

Overriding

- A method in a subclass *overrides* a method in superclass if:
  - both methods have the same name,
  - both methods have the same signature (number and type of parameters and return type), and
  - both are static methods or both are instance methods.

Single Inheritance

- Every class is implicitly a subclass of **Object**
- A class can have exactly one parent
  - **class Puzzle {…}**
    - implicitly extends **Object**
  - **class EPuzzle extends Puzzle {…}**
    - explicitly extends **Puzzle**, and implicitly extends **Object** since **Puzzle** is a subclass of **Object**
- Class hierarchy in Java is a tree
  - subclasses = descendants, superclasses = ancestors
- In C++, a class can have more than one superclass (multiple inheritance)
  - class hierarchy is a directed acyclic graph (dag)

Writing the `EPuzzle` Class

```
class EPuzzle extends Puzzle {
   private int numMoves = 0;

   public void printNumMoves() {
      System.out.println("Number of moves = "
        + numMoves);
   }

   public void scramble() {...}
   public boolean move(char d) {...}
}
```


`scramble` and `move`

How should we write `scramble` and `move`?
One option: write them from scratch.

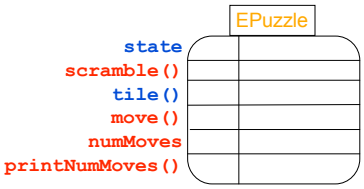
```
Class EPuzzle extends Puzzle {
   ...

   public void scramble() {
      state = "978654321";
      numMoves = 0;
   }

   public boolean move(char d) {...}
}
```

- Problem: `state` was declared `private` in the `Puzzle` class
- it is not accessible to `EPuzzle`!

Difficulty with Private Variables

- Variable `state` is declared *private*, so it is only accessible to methods in class `Puzzle`
- In an instance of class `EPuzzle`, the `tile` method can access this variable because the `tile` method is *inherited* from the superclass
- Method `Scramble` defined in class `Epuzzle` does *not* have access to `state`
- Similarly, any *private* methods in a superclass are not accessible to methods in subclass

Interesting Point



- `EPuzzle` objects have an instance variable `state` because `EPuzzle` extends `Puzzle`
- However, they cannot access it directly, because it is private!
- `state` is accessible to public methods inherited from `Puzzle` (such as `tile()`) but not to methods written in the `EPuzzle` class (such as `scramble()`)

Protected Access

- Access specifier: `protected`
- A protected instance variable in class `S` can be accessed by instance methods defined in `S` or in any subclass of `S`
- A protected method in class `S` can be invoked from an instance method defined in `S` or any subclass of `S`
- Access checks are done by compiler at compile time:
  - For an invocation `r.m()`:
    - Determine type of reference `r`
    - Does the corresponding class/interface have a method named `m` with appropriate arguments?
    - Are the access specifiers of that method appropriate?

Proper Code for `Puzzle` Class

says state is accessible from subclasses

```
class Puzzle {
   protected int state;
   public void scramble(){...}
   ...
}
```

Code for `EPuzzle`

```
class EPuzzle extends Puzzle {
   ...

   public void scramble() {
      state = "978654321"; //OK since state inherited
      numMoves = 0;
   }

   //similar code for move
}
```


Protected Access

- When should variables and methods be declared `protected` instead of `private`?
- Think about extensibility: if subclasses will want access to a member, it should be declared `protected`
- Analogy:
  - Which components of a car might a user want to upgrade?
  - What wires/subsystems need to be exposed to make the upgrade easy?

Another Solution

- Suppose a class `S` overrides a method `m` in its parent
- Methods in `S` can invoke the overridden method in the parent as

  `super.m()`

- In particular, can invoke the overridden method in the overriding method!
- Caveat: cannot compose super more than once as in `super.super.m()`

Another Definition of `EPuzzle`

```
class EPuzzle extends Puzzle {
   protected int numMoves = 0;
   ...
   public void scramble() {
      super.scramble();
      numMoves = 0;
   }
   public boolean move(char d){
      boolean p = super.move(d);
      if (p) numMoves++; //legal move?
      return p;
   }
}
```

Do not need `protected` access to `state` after all!

Subtypes

- Inheritance gives a mechanism for creating *subtypes*
  - (*Interfaces* are another such mechanism)
- If class `B` extends class `A` then `B` is a subtype of `A`
- Examples:
  - `Puzzle p = new EPuzzle(); //up-casting`
  - `EPuzzle e = (EPuzzle)p; //down-casting`

Unexpected Consequence

An overriding method cannot have more restricted access than the method it overrides

```
class A {
   public int m() {...}
}

class B extends A {
   private int m() {...} //illegal!
}

A supR = new B(); //upcasting
supR.m(); //would invoke private method in
class B at runtime!
```

Shadowing Variables

- Like overriding, but for fields instead of methods
  - Superclass: variable `v` of some type
  - Subclass: variable `v` perhaps *of some other type*
  - Method in subclass can access shadowed variable using `super.v`
- Variable references are resolved using *static binding* (i.e., at compile-time), not *dynamic binding* (i.e., not at runtime)
  - Variable reference `r.v` uses the *static type* (declared type) of the variable `r`, not the *runtime type* of the object referred to by `r`
- Shadowing variables is bad medicine and should be avoided

Constructors

- Each class has its own constructor
- No overriding of constructors
- Superclass constructor can be invoked explicitly within subclass constructor using `super()` with parameters as needed
- Can invoke other constructors of the same class using `this()`
- Call to `super()` or `this()` must occur *first* in the constructor

Abstract Classes

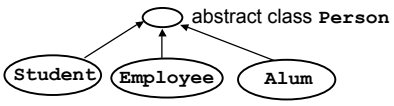
- An abstract class cannot be instantiated
- May have methods without bodies that *must be* overridden by a (non-abstract) subclass

```
abstract class Puzzle {
   protected int state;
   public void scramble() {
      state = 978654321;
   }

   //abstract methods (no code)
   abstract public int tile(int r, int c);
   abstract public void move(char d);
}
```


Abstract Classes

- An abstract class is an incomplete specification
  - Cannot be instantiated directly
  - Not all methods in abstract class need to be abstract — allows code sharing
  - Abstract classes are part of the class hierarchy and the usual subtyping rules apply

Use of Abstract Classes



- Variables/methods common to a bunch of related subclasses can be declared once in Dad and inherited by all subclasses
- If subclass wants to do something differently, it can override parent's methods as needed

Conclusion

- Key features of object-oriented programming
  - Encapsulation: classes and access control
  - Inheritance: extending or changing the behavior of classes without rewriting them from scratch
  - Dynamic storage allocation & garbage collection
  - Access control: public/private/protected
  - Subtyping