Principles of Software Construction: Objects, Design, and Concurrency

Designing classes

Delegation and inheritance and behavioral subtyping (oh my)

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Administrivia

- Homework 2 due Thursday

Key concepts from Thursday…

What is a contract?

- Agreement between an object and its user
- Includes
  - Method signature (type specifications)
  - Functionality and correctness expectations
  - Performance expectations
- **What the method does**, not how it does it
  - **Interface (API)**, not implementation

The == operator vs. `equals` method

- For primitives you *must* use ==
- For object reference types
  - The == operator provides *identity semantics*
    - Exactly as implemented by `Object.equals`
    - Even if `Object.equals` has been overridden
    - This is seldom what you want!
  - **you should (almost) always use `.equals`**
  - Using == on an object reference is a **bad smell in code**

```
if (input == "yes")   // A bug!!!
```

The `equals` contract in English

- **Reflexive** – every object is equal to itself
- **Symmetric** – `if a.equals(b)` then `b.equals(a)`
- **Transitive** – if `a.equals(b)` and `b.equals(c)`, then `a.equals(c)`
- **Consistent** – equal objects stay equal unless mutated
- **"Non-null"** – `a.equals(null)` returns false
- Taken together these ensure that equals is a global **equivalence relation** over all objects

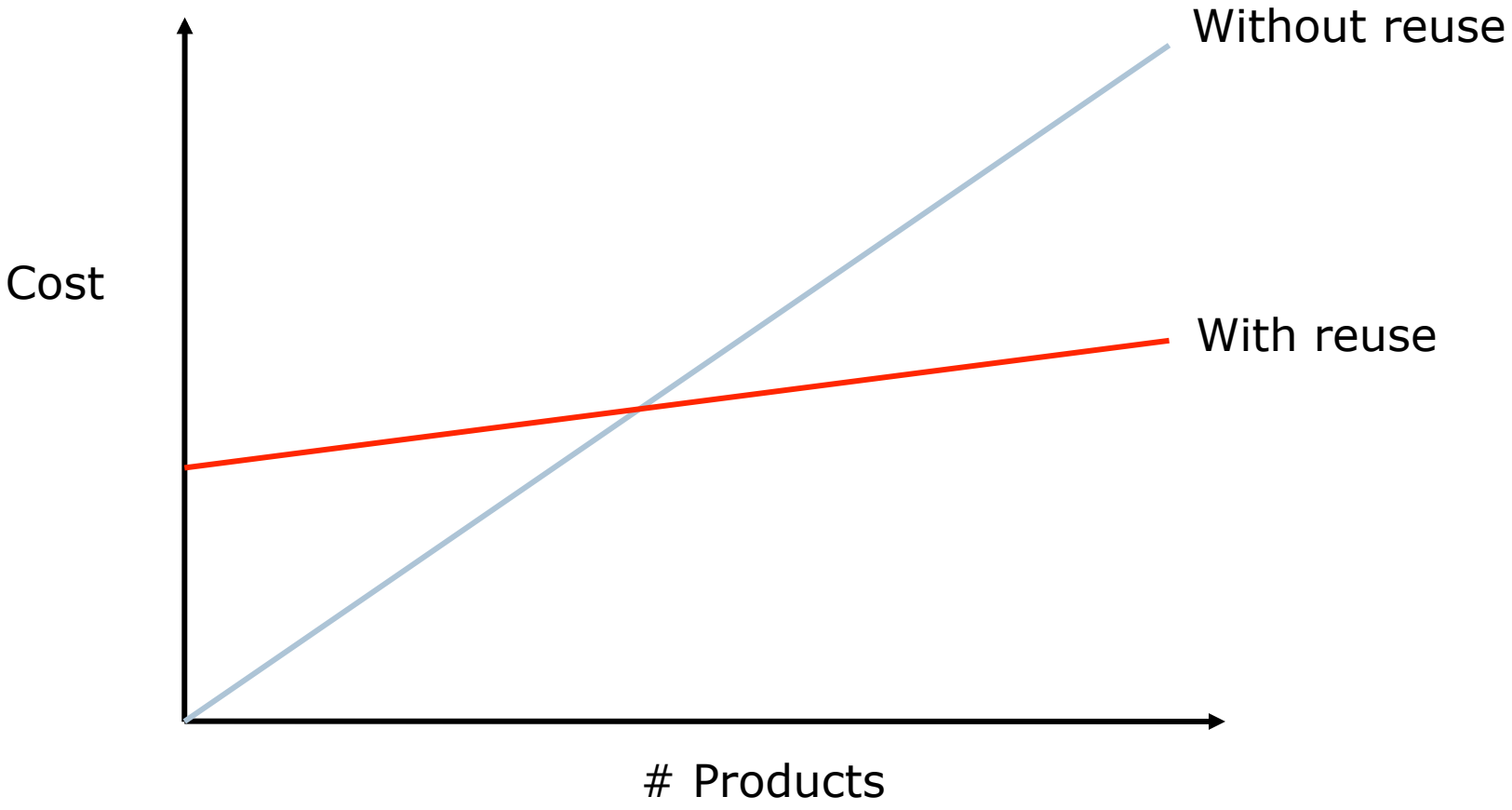
Learning goals for today

- Be able to explain inheritance and delegation
- Apply inheritance and delegation appropriately for reuse
  - Understand their tradeoffs
- Behavioral subtyping and implications for specification and testing

Today: Class-level reuse with delegation and inheritance

- Delegation
- Inheritance
  - Java-specific details for inheritance
- Behavioral subtyping: Liskov's Substitution Principle
- Thursday: Design patterns for improved class-level reuse
- Later in the course:
  - System-level reuse with libraries and frameworks

The promise of reuse:



COMPOSITION AND DELEGATION

Recall our earlier sorting example:

Version A:

```
static void sort(int[] list, boolean ascending) {
   …
   boolean mustSwap;
   if (ascending) {
      mustSwap = list[i] < list[j];
   } else {
      mustSwap = list[i] > list[j];
   }
   …
}
```

Version B':

```
interface Comparator {
  boolean compare(int i, int j);
}
final Comparator ASCENDING =  (i, j) -> i < j;
final Comparator DESCENDING = (i, j) -> i > j;

static void sort(int[] list, Comparator cmp) {
  …
  boolean mustSwap =
    cmp.compare(list[i], list[j]);
  …
}
```

Delegation

- *Delegation* is simply when one object relies on another object for some subset of its functionality
  - e.g. here, the `Sorter` is delegating functionality to some `Comparator`
- Judicious delegation enables code reuse

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interface Comparator {
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final Comparator ASCENDING =  (i, j) -> i < j;
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static void sort(int[] list, Comparator cmp) {
  …
  boolean mustSwap =
    cmp.compare(list[i], list[j]);
  …
}
```

Delegation

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  - e.g. here, the `Sorter` is delegating functionality to some `Comparator`
- Judicious delegation enables code reuse
  - `Sorter` can be reused with arbitrary sort orders
  - `Comparators` can be reused with arbitrary client code that needs to compare integers

Using delegation to extend functionality

- Consider the `java.util.List` (excerpted):

```
public interface List<E> {
  public boolean add(E e);
  public E       remove(int index);
  public void    clear();
  …
}
```

- Suppose we want a list that logs its operations to the console…

Using delegation to extend functionality

The `LoggingList` *is composed of* a `List`, and delegates (the non-logging) functionality to that `List`

- One solution:

```
public class LoggingList<E> implements List<E> {
  private final List<E> list;
  public LoggingList<E>(List<E> list) { this.list = list; }
  public boolean add(E e) {
      System.out.println("Adding " + e);
      return list.add(e);
  }
  public E remove(int index) {
      System.out.println("Removing at " + index);
      return list.remove(index);
  }
  …
```

Delegation and design

- Small interfaces with clear contracts
- Classes to encapsulate algorithms, behaviors
  - E.g., the `Comparator`

IMPLEMENTATION INHERITANCE AND ABSTRACT CLASSES

Variation in the real world: types of bank accounts

```
public interface CheckingAccount {
    public long getBalance();
    public void  deposit(long amount);
    public boolean withdraw(long amount);
    public boolean transfer(long amount, Account??? target);
    public long getFee();
}
```

```
public interface SavingsAccount {
    public long getBalance();
    public void  deposit(long amount);
    public boolean withdraw(long amount);
    public boolean transfer(long amount, Account??? target);
    public double getInterestRate();
}
```

Interface inheritance for an account type hierarchy

```
public interface Account {
    public long getBalance();
    public void  deposit(long amount);
    public boolean withdraw(long amount);
    public boolean transfer(long amount, Account target);
    public void monthlyAdjustment();
}

public interface CheckingAccount extends Account {
    public long getFee();
}

public interface SavingsAccount extends Account {
    public double getInterestRate();
}

public interface InterestCheckingAccount
                        extends CheckingAccount, SavingsAccount {
}
```

The power of object-oriented interfaces

- Subtype polymorphism
  - Different kinds of objects can be treated uniformly by client code
  - Each object behaves according to its type
    - e.g., if you add new kind of account, client code does not change:

```
If today is the last day of the month:
   For each acct in allAccounts:
      acct.monthlyAdjustment();
```

Implementation inheritance for code reuse

```
public abstract class AbstractAccount
        implements Account {
   protected long balance = 0;
   public long getBalance() {
        return balance;
   }
   abstract public void monthlyAdjustment();
   // other methods…
}

public class CheckingAccountImpl
        extends AbstractAccount
        implements CheckingAccount {
   public void monthlyAdjustment() {
        balance -= getFee();
   }
   public long getFee() { … }
}
```

Implementation inheritance for code reuse

```
public abstract class AbstractAccount
        implements Account {
   protected long balance = 0;
   public long getBalance() {
        return balance;
   }
   abstract public void monthlyAdjustment();
   // other methods…
}

public class CheckingAccountImpl
        extends AbstractAccount
        implements CheckingAccount {
   public void monthlyAdjustment() {
        balance -= getFee();
   }
   public long getFee() { … }
}
```

an abstract class is missing the implementation of one or more methods

protected elements are visible in subclasses

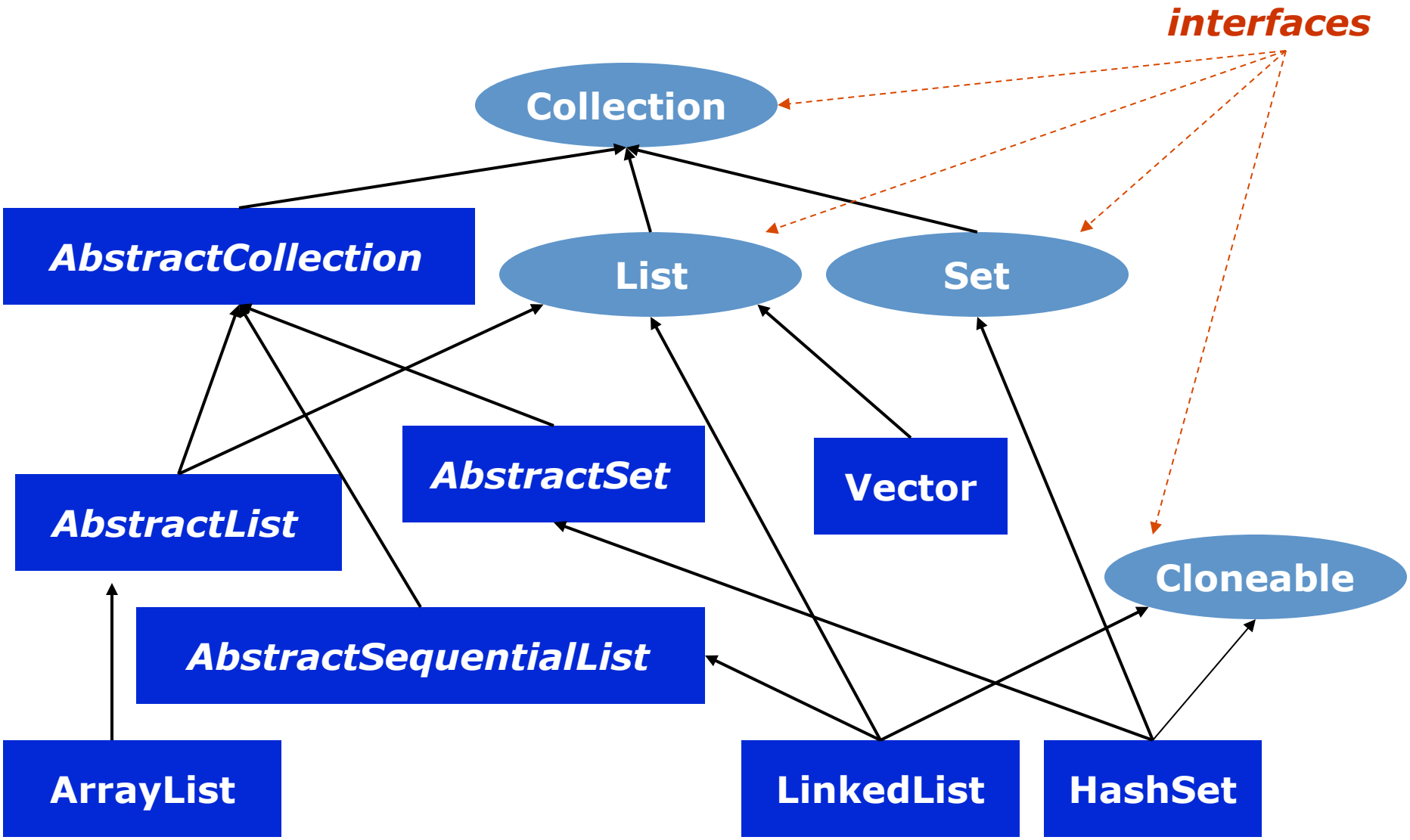
an abstract method is left to be implemented in a subclass

no need to define getBalance() – the code is inherited from AbstractAccount

Inheritance: a glimpse at the hierarchy

- Examples from Java
  - `java.lang.Object`
  - Collections library

Java Collections API (excerpt)



Benefits of inheritance

- Reuse of code
- Modeling flexibility
- A Java aside:
  - Each class can directly extend only one parent class
  - A class can implement multiple interfaces

Inheritance and subtyping

- Inheritance is for code reuse
  - Write code once and only once
  - Superclass features implicitly available in subclass

```
class A extends B
```

- Subtyping is for polymorphism
  - Accessing objects the same way, but getting different behavior
  - Subtype is substitutable for supertype

```
class A implements I
class A extends B
```

Typical roles for interfaces and classes

- An interface defines expectations / commitments for clients
- A class fulfills the expectations of an interface
  - An abstract class is a convenient hybrid
  - A subclass specializes a class's implementation

Java details: extended reuse with super

```
public abstract class AbstractAccount implements Account {
   protected long balance = 0;
   public boolean withdraw(long amount) {
       // withdraws money from account (code not shown)
   }
}

public class ExpensiveCheckingAccountImpl
      extends AbstractAccount implements CheckingAccount {
   public boolean withdraw(long amount) {
      balance -= HUGE_ATM_FEE;
      boolean success = super.withdraw(amount)
      if (!success)
         balance += HUGE_ATM_FEE;
      return success;
   }
}
```

Overrides `withdraw` but also uses the superclass `withdraw` method

Java details: constructors with `this` and `super`

```
public class CheckingAccountImpl
      extends AbstractAccount implements CheckingAccount {

   private long fee;

   public CheckingAccountImpl(long initialBalance, long fee) {
      super(initialBalance);
      this.fee = fee;
   }

   public CheckingAccountImpl(long initialBalance) {
      this(initialBalance, 500);
   }
   /* other methods… */ }
```

Invokes a constructor of the superclass. Must be the first statement of the constructor.

Invokes another constructor in this same class

Java details: `final`

- A final field: prevents reassignment to the field after initialization
- A final method: prevents overriding the method
- A final class: prevents extending the class
  - e.g., `public final class CheckingAccountImpl { …`

Note: type-casting in Java

- Sometimes you want a different type than you have
  - e.g.,
```
double pi = 3.14;
int indianaPi = (int) pi;
```
- Useful if you know you have a more specific subtype:
  - e.g.,
```
Account acct = …;
CheckingAccount checkingAcct =
                        (CheckingAccount) acct;
long fee = checkingAcct.getFee();
```
  - Will get a `ClassCastException` if types are incompatible
- Advice: avoid downcasting types
  - Never(?) downcast within superclass to a subclass

Note: `instanceof`

- Operator that tests whether an object is of a given class

```
public void doSomething(Account acct) {
    long adj = 0;
    if (acct instanceof CheckingAccount) {
        checkingAcct = (CheckingAccount) acct;
         adj = checkingAcct.getFee();
    } else if (acct instanceof SavingsAccount) {
        savingsAcct = (SavingsAccount) acct;
         adj = savingsAcct.getInterest();
    }
    …
}
```

Warning: This code is bad.

- Advice: avoid `instanceof` if possible
  - Never(?) use `instanceof` in a superclass to check type against subclass

Java details: Dynamic method dispatch

1. (Compile time) Determine which class to look in
2. (Compile time) Determine method signature to be executed
    1. Find all accessible, applicable methods
    2. Select most specific matching method

Java details: Dynamic method dispatch

1. (Compile time) Determine which class to look in
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    1. Find all accessible, applicable methods
    2. Select most specific matching method
3. (Run time) Determine dynamic class of the receiver
4. (Run time) From dynamic class, locate method to invoke
    1. Look for method with the same signature found in step 2
    2. Otherwise search in superclass and etc.

Design with inheritance (or not)

- Favor composition over inheritance
  - Inheritance violates information hiding
- Design and document for inheritance, or prohibit it
  - Document requirements for overriding any method

BEHAVIORAL SUBTYPING

Behavioral subtyping

> Let q(x) be a property provable about objects x of type T. Then q(y) should be provable for objects y of type S where S is a subtype of T.
>
> Barbara Liskov

- e.g., Compiler-enforced rules in Java:
  - Subtypes can add, but not remove methods
  - Concrete class must implement all undefined methods
  - Overriding method must return same type or subtype
  - Overriding method must accept the same parameter types
  - Overriding method may not throw additional exceptions

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  - Overriding method must return same type or subtype
  - Overriding method must accept the same parameter types
  - Overriding method may not throw additional exceptions
- Also applies to specified behavior:
  - Same or stronger invariants
  - Same or stronger postconditions for all methods
  - Same or weaker preconditions for all methods

This is called the *Liskov Substitution Principle*.

Behavioral subtyping (Liskov Substitution Principle)

```
abstract class Vehicle {
        int speed, limit;

        //@ invariant speed < limit;




        //@ requires speed != 0;
        //@ ensures speed < \old(speed)
        void brake();
}
```

```
class Car extends Vehicle {
        int fuel;
        boolean engineOn;
        //@ invariant speed < limit;
        //@ invariant fuel >= 0;

        //@ requires fuel > 0 && !engineOn;
        //@ ensures engineOn;
        void start() { … }

        void accelerate() { … }

        //@ requires speed != 0;
        //@ ensures speed < \old(speed)
        void brake() { … }
}
```

Subclass fulfills the same invariants (and additional ones)
Overridden method has the same pre and postconditions

Behavioral subtyping (Liskov Substitution Principle)

```
class Car extends Vehicle {
        int fuel;
        boolean engineOn;
        //@ invariant fuel >= 0;

        //@ requires fuel > 0 && !engineOn;
        //@ ensures engineOn;
        void start() { … }

        void accelerate() { … }

        //@ requires speed != 0;
        //@ ensures speed < old(speed)
        void brake() { … }
}
```

```
class Hybrid extends Car {
        int charge;
        //@ invariant charge >= 0;

        //@ requires (charge > 0 || fuel > 0)
                        && !engineOn;
        //@ ensures engineOn;
        void start() { … }

        void accelerate() { … }

        //@ requires speed != 0;
        //@ ensures speed < \old(speed)
        //@ ensures charge > \old(charge)
        void brake() { … }
}
```

Subclass fulfills the same invariants (and additional ones)
Overridden method start has weaker precondition
Overridden method brake has stronger postcondition

Behavioral subtyping (Liskov Substitution Principle)

```
class Rectangle {
        int h, w;

        Rectangle(int h, int w) {
            this.h=h; this.w=w;
        }

        //methods
}
```

```
class Square extends Rectangle {
        Square(int w) {
            super(w, w);
        }
}
```

Is this Square a behavioral subtype of Rectangle?

Behavioral subtyping (Liskov Substitution Principle)

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}
```

```
class Square extends Rectangle {
        //@ invariant h>0 && w>0;
        //@ invariant h==w;
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        int h, w;

        Rectangle(int h, int w) {
            this.h=h; this.w=w;
        }

        //@ requires factor > 0;
        void scale(int factor) {
            w=w*factor;
            h=h*factor;
        }
}
```

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        }

        //@ requires factor > 0;
        void scale(int factor) {
            w=w*factor;
            h=h*factor;
        }
        //@ requires neww > 0;
        void setWidth(int neww) {
            w=neww;
        }
}
```

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class Square extends Rectangle {
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            super(w, w);
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        }

        void scale(int factor) {
            w=w*factor;
            h=h*factor;
        }

        void setWidth(int neww) {
            w=neww;
        }
}
```

```
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        //@ invariant h>0 && w>0;
        //@ invariant h==w;
        Square(int w) {
            super(w, w);
        }
}
```

```
class GraphicProgram {
   void scaleW(Rectangle r, int factor) {
      r.setWidth(r.getWidth() * factor);
   }
}
```

← **Invalidates stronger invariant (w==h) in subclass**

Yes? (But the Square is not actually a square…)

Summary: Designing reusable classes

- Reusable implementations with simple, clear contracts
- Inheritance for reuse, its pitfalls, and its alternatives
- Liskov's Substitution Principle for behavioral subtyping