Principles of Software Construction: Objects, Design, and Concurrency
(Part 1: Designing Classes)

Design for Reuse (class level)

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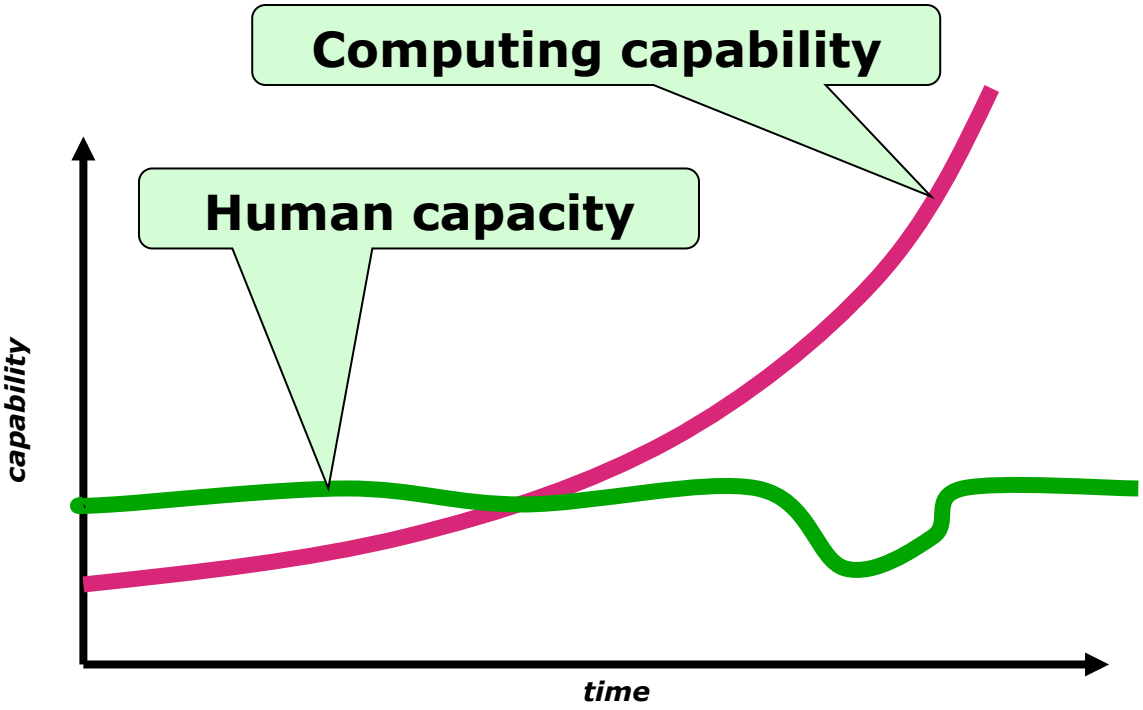
Learning goals for today

- Explain the need for and challenges of design for reuse
- Apply inheritance and delegation appropriately and understand their tradeoffs
- Behavioral subtyping and implications for specification and testing
  - The Object contracts in Java
- Identify applicability of and apply the decorator and template method design patterns
- Read and write UML interaction diagrams

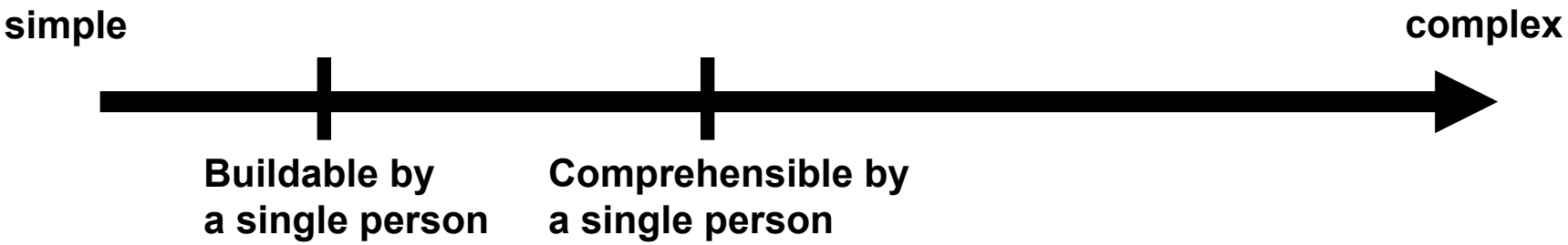
Design goals, principles, and patterns for reuse

- Design goals
  - Design for reuse
  - Design for division of labor
- Design principles
  - Small interfaces
  - Information hiding
- Design patterns
  - Decorator design pattern
  - Template method design pattern
- Language features that support reuse
  - Inheritance
  - Subtype polymorphism (dynamic dispatch)
  - Parametric polymorphism (generics)

The limits of exponentials



Building complex systems



- Division of labor
- Division of knowledge and design effort
- Reuse of existing implementations

Reuse and variation

15-214

Homework #0: A Friendship Graph

Due Tuesday, January 21st at 11:59 p.m.

The goals of this assignment are to familiarize you with our cou
let you practice Java object-oriented programming. To complete t
implement a simple graph class that could represent a network of f

Your learning goals for this assignment are to:

- Use Git and GitHub to revision and share work
- Get familiar with Java development environments
- Write a first Java program
- Practice Java style and coding conventions

Instructions

To begin your work, import the project into Eclipse from the homew
repository.

Implement and test a `FriendGraph` class that represents friendships
can compute the distance between two people in the graph. You s
network as an undirected graph where each person is connected to

For example, suppose you have the following social network:

1

Homework 0

15-214 Homework 1

Homework #1: Graph Algorithms for Social Networks

Due Tuesday, January 28th at 11:59 p.m.

In this assignment, you will implement a `Graph` interface using two different graph representations. You will then develop several algorithms that use the `Graph` interface that might be used in a social network.

Your goals for this assignment are to:

- Understand and apply the concepts of polymorphism and encapsulation
- Understand interfaces
- Familiarize yourself with Java and Eclipse
- Learn to compile, run, and debug Java programs
- Practice good Java coding practices and style

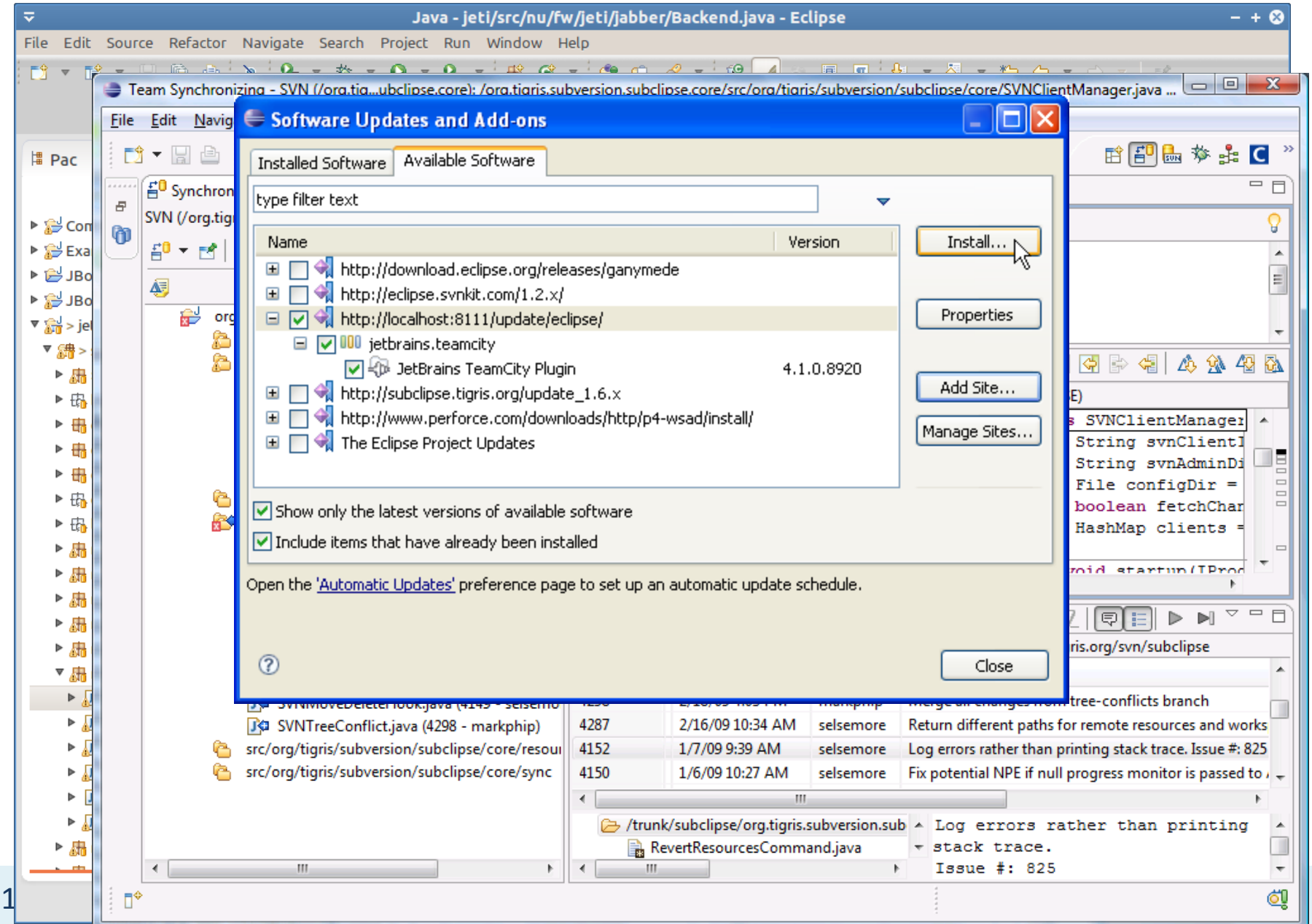
Instructions

Graph Implementations

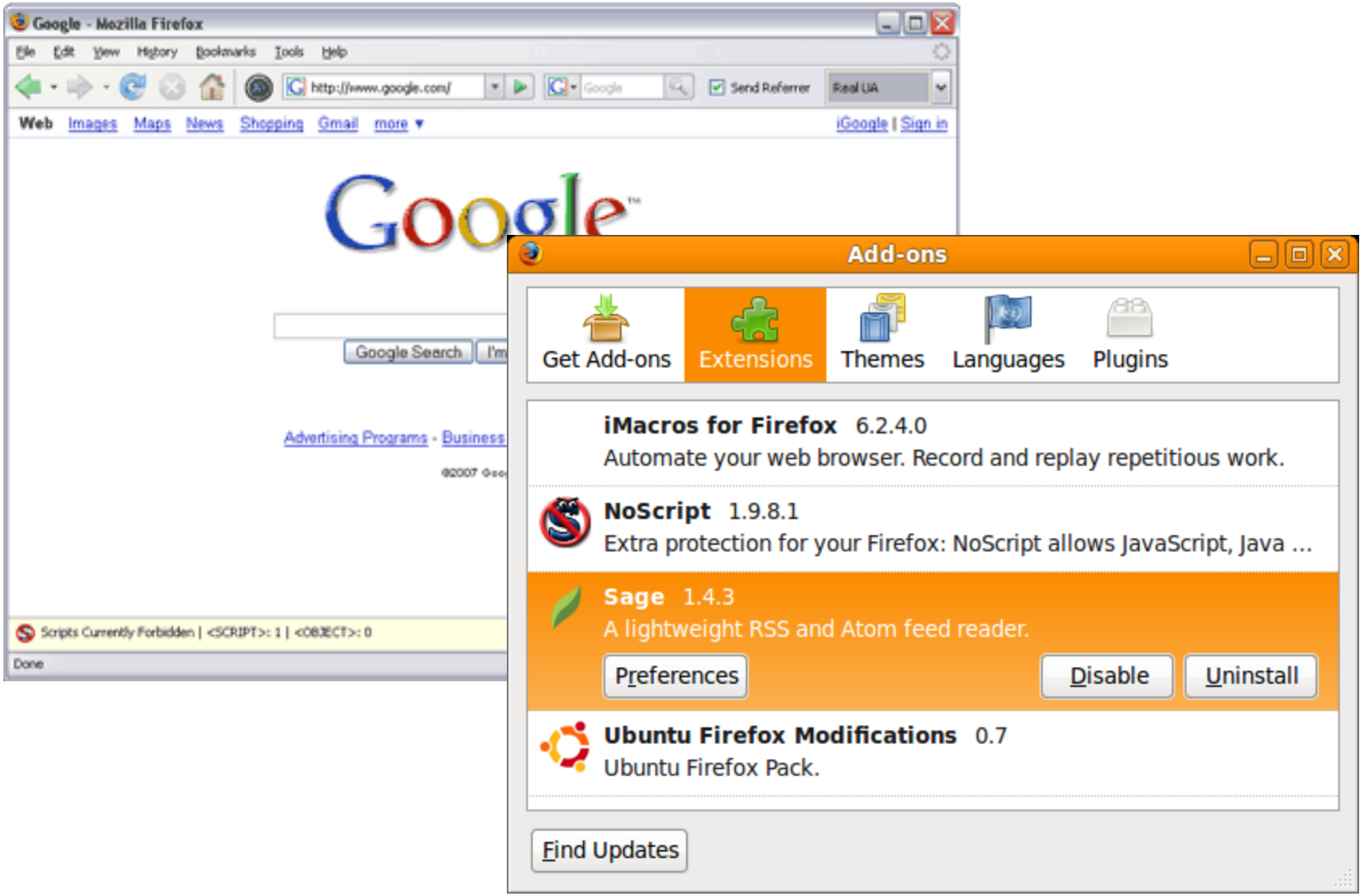
First, write two classes that implement the `edu.cmu.cs.cs214.hw1.staff.Graph` interface, which represents an undirected graph.

- **Adjacency List:** Inside the package `edu.cmu.cs.cs214.hw1.graph`, implement the `AdjacencyListGraph` class. Your implementation must internally represent the graph as an adjacency list. Your class should provide a constructor with a single `int` argument, `maxVertices`. Your implementation must then support a graph containing as many as `maxVertices` vertices. Your implementation may behave arbitrarily

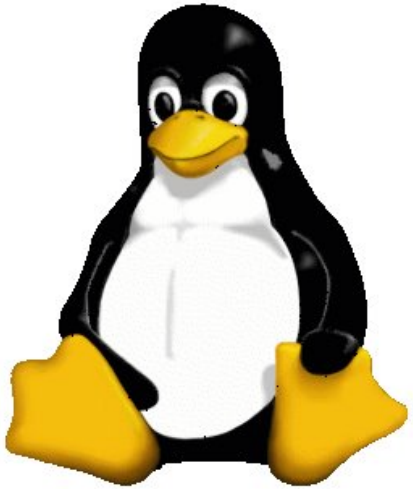
Reuse: Family of development tools



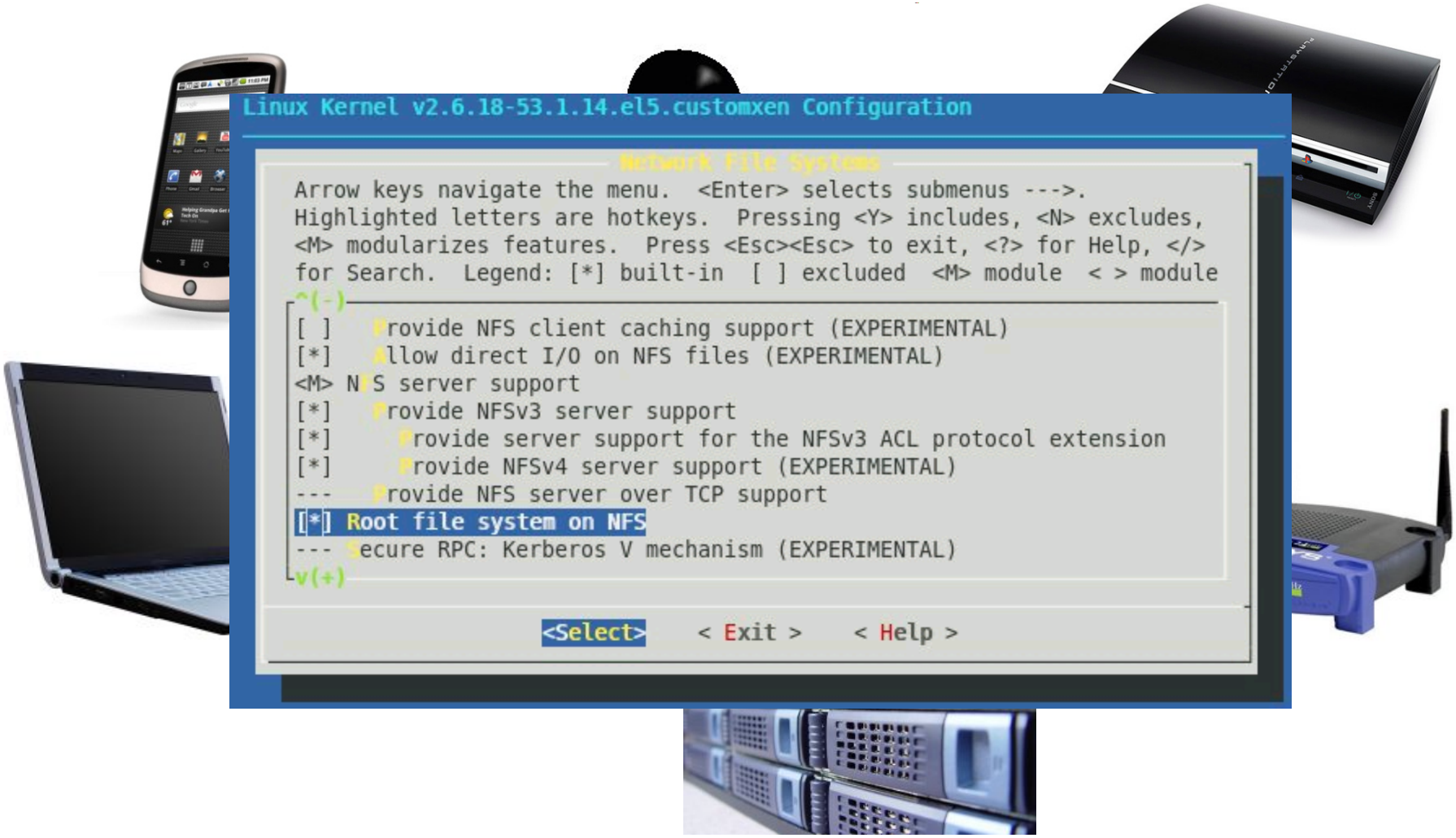
Reuse: Web browser extensions



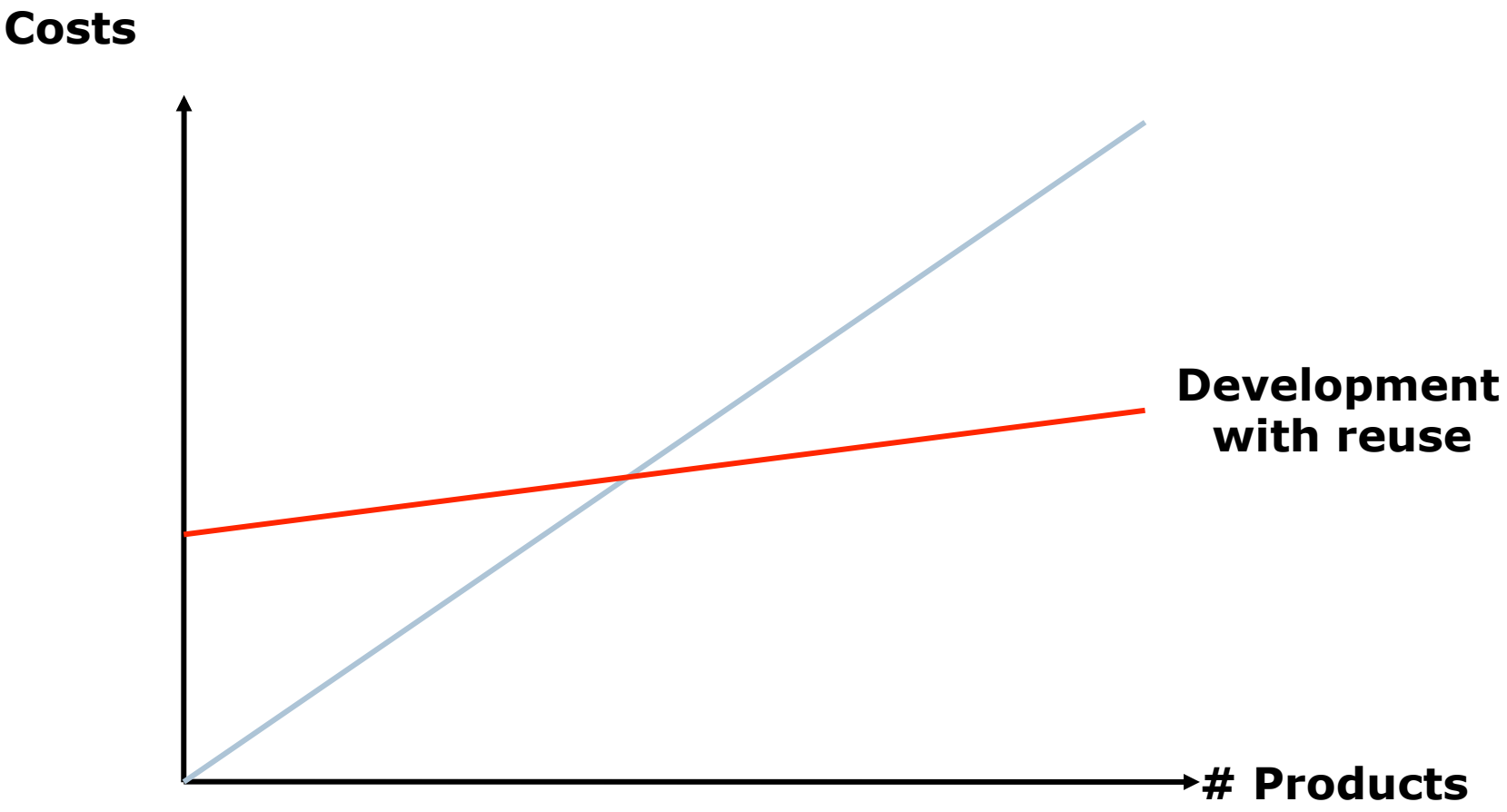
Reuse and variation: Flavors of Linux



Reuse and variation: Flavors of Linux



The promise:



Agenda

- This week:
  - Class-level reuse with inheritance and delegation
- Later in the course:
  - System level reuse with libraries and frameworks
  - Systematic reuse with software product lines

COMPOSITION AND DELEGATION

Recall our earlier sorting example:

```
public class Sorter {
  void sort(int[] list, Comparator cmp) {
    …
    boolean mustswap;
    mustswap = cmp.compare(list[i], list[j]);
    …
  }}

interface Comparator {
  boolean compare(int i, int j);
}

class UpComparator implements Comparator {
  boolean compare(int i, int j) { return i<j; }}

class DownComparator implements Comparator {
  boolean compare(int i, int j) { return i>j; }}
```

Delegation

- *Delegation* is simply when one object relies on another object for some subset of its functionality
  - In the previous example, the `Sorter` is delegating functionality to some `Comparator` implementation

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- *Delegation* is simply when one object relies on another object for some subset of its functionality
  - In the previous example, the `Sorter` is delegating functionality to some `Comparator` implementation
- 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 to create a list that logs its operations to the console…

Using delegation to extend functionality

- One solution:

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

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

Aside: A sequence diagram for the `LoggingList`

Delegation and design

- Small interfaces
- Classes to encapsulate algorithms
  - E.g., the `Comparator`, the Strategy pattern

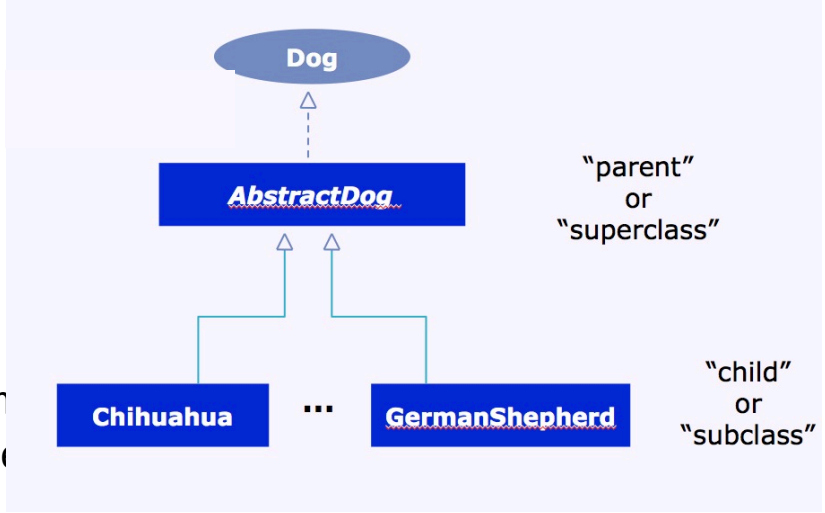
Delegation and design

- Small interfaces with clear contracts
- Classes to encapsulate algorithms, behaviors
  - E.g., the `Comparator`, the Strategy pattern, the `RoutePlanner`, the `RoutePlannerBuilder`, …

CLASS INHERITANCE AND ABSTRACT CLASSES

An introduction to inheritance

- A dog of an example:
  - Dog.java
  - AbstractDog.java
  - Chihuahua.java
  - GermanShepherd.java

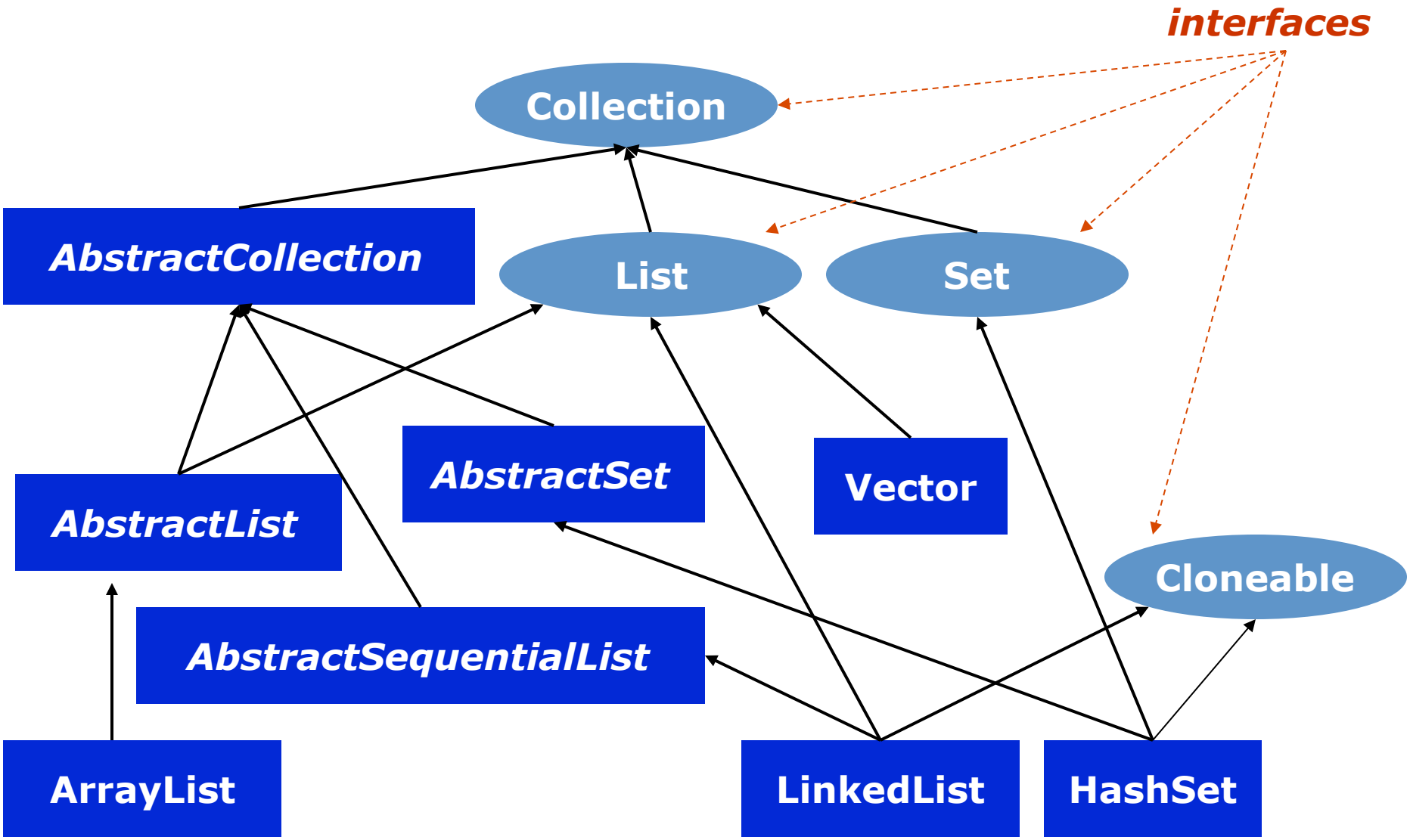


- Typical roles:
  - An interface defines expectations / comm
  - An abstract class is a convenient hybrid b implementation
  - A subclass overrides a method definition to specialize its implementation

Inheritance: a glimpse at the hierarchy

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

Java Collections API (excerpt)



Benefits of inheritance

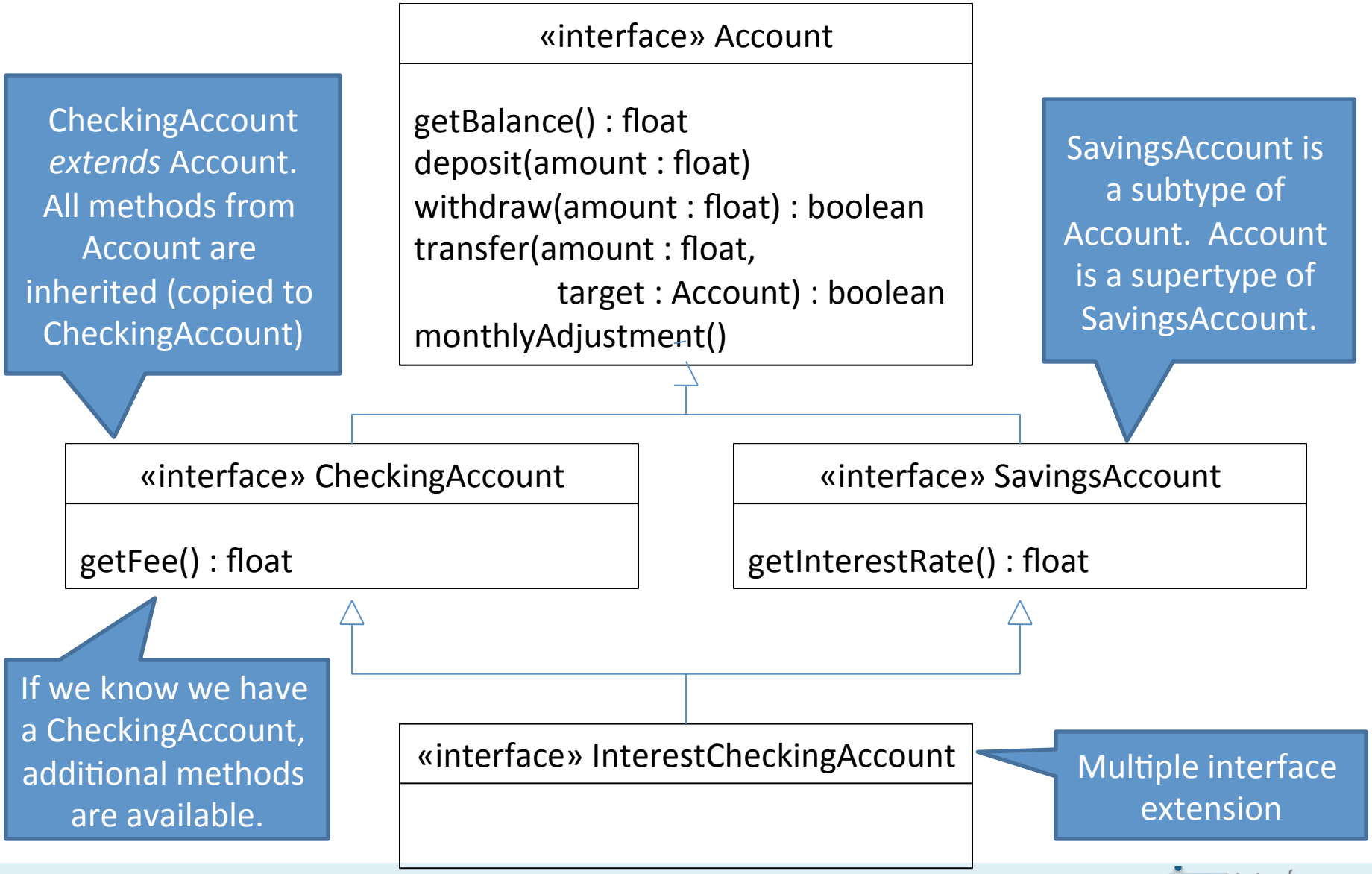
- Reuse of code
- Modeling flexibility
- A Java aside:
  - Each class can directly extend only one parent class
  - A class can implement multiple interfaces

Another example: different kinds of bank accounts

«interface» CheckingAccount
getBalance() : float deposit(amount : float) withdraw(amount : float) : boolean transfer(amount : float, target : Account) : boolean getFee() : float

«interface» SavingsAccount
getBalance() : float deposit(amount : float) withdraw(amount : float) : boolean transfer(amount : float, target : Account) : boolean getInterestRate() : float

A better design: An account type hierarchy



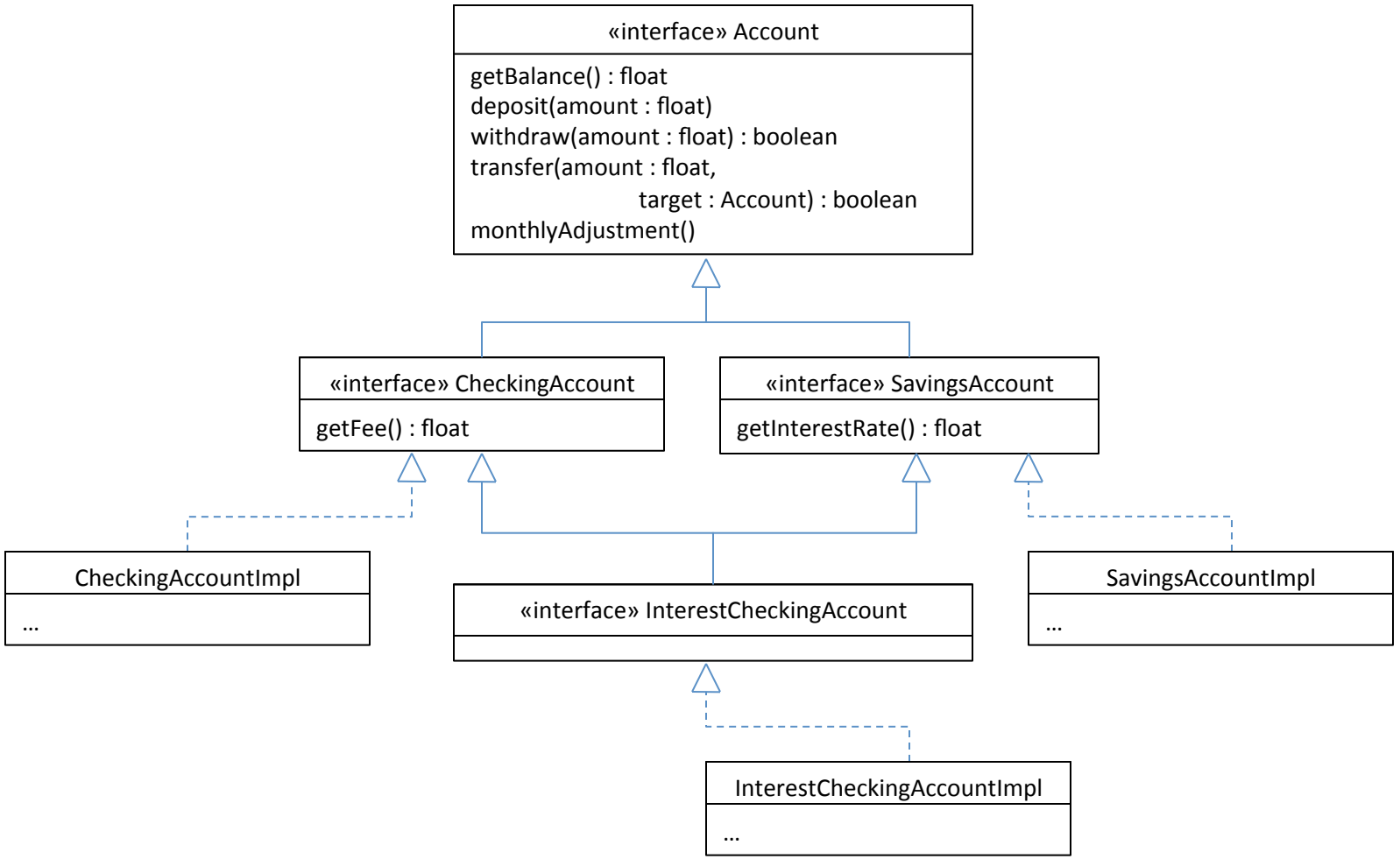
The power of object-oriented interfaces

- Subtype polymorphism
  - Different kinds of objects can be treated uniformly by client code
    - e.g., a list of all accounts
  - Each object behaves according to its type
    - If you add new kind of account, client code does not change
  - Consider this pseudocode:

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

  - See

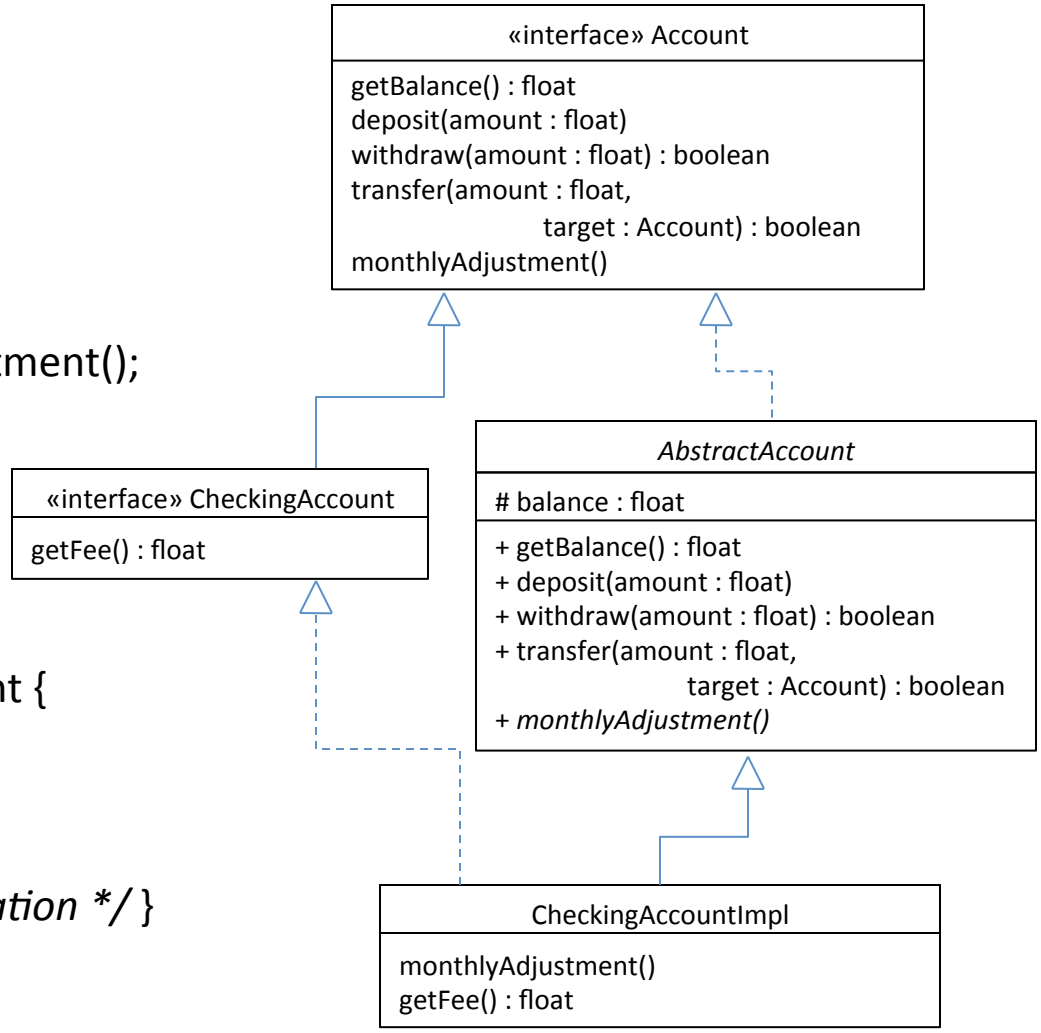
One implementation:



Better: Reuse abstract account code

```
public abstract class AbstractAccount
            implements Account {
    protected float balance = 0.0;
    public float getBalance() {
            return balance;
    }
    abstract public void monthlyAdjustment();
    // other methods…
}

public class CheckingAccountImpl
            extends AbstractAcount
            implements CheckingAccount {
    public void monthlyAdjustment() {
            balance -= getFee();
    }
    public float getFee() { /* fee calculation */ }
}
```



Better: Reuse abstract account code

```
public abstract class AbstractAccount
        implements Account {
    protected float balance = 0.0;
    public float getBalance() {
        return balance;
    }
    abstract public void monthlyAdjustment();
    // other methods ...
}

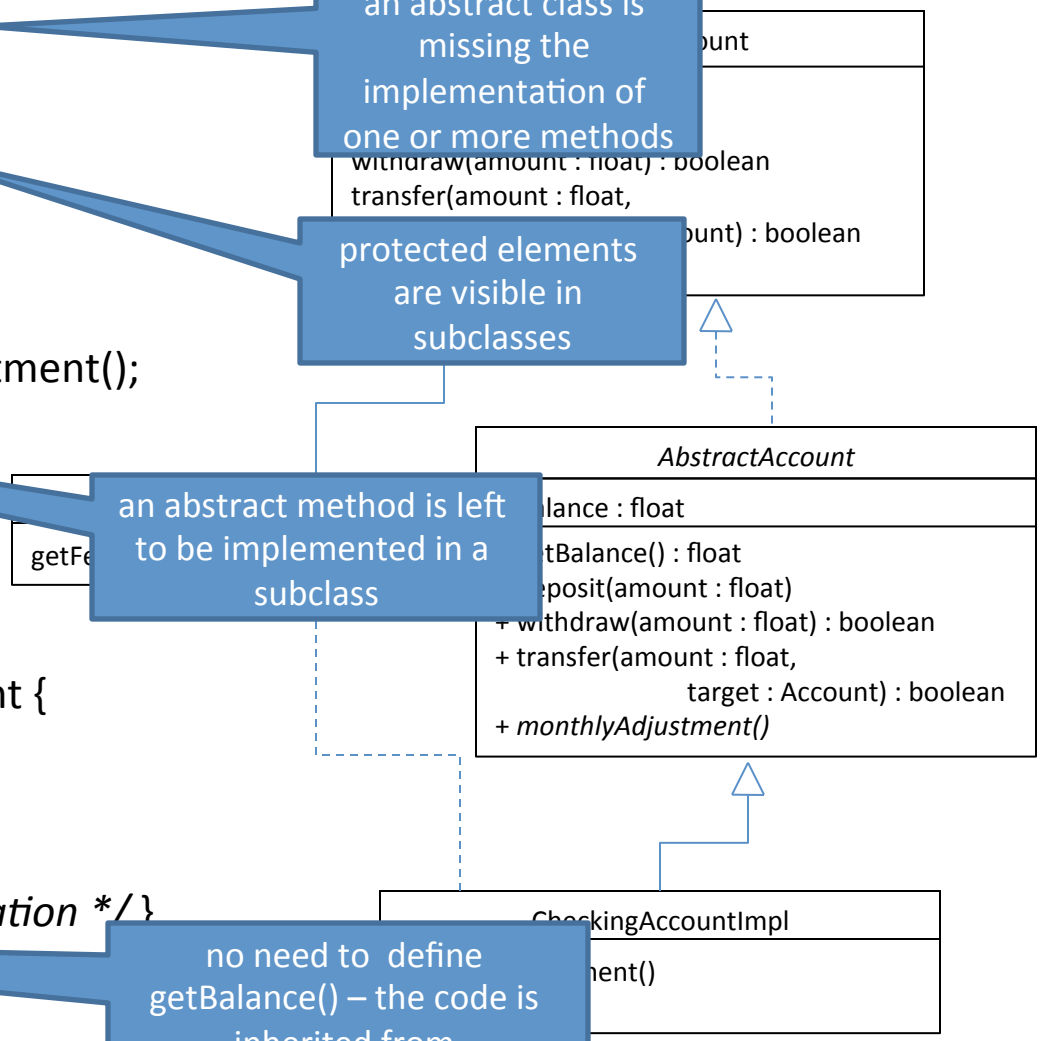
public class CheckingAccountImpl
        extends AbstractAcount
        implements CheckingAccount {
    public void monthlyAdjustment() {
        balance -= getFee();
    }
    public float getFee() { /* fee calculation */ }
}
```

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 and subtyping

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

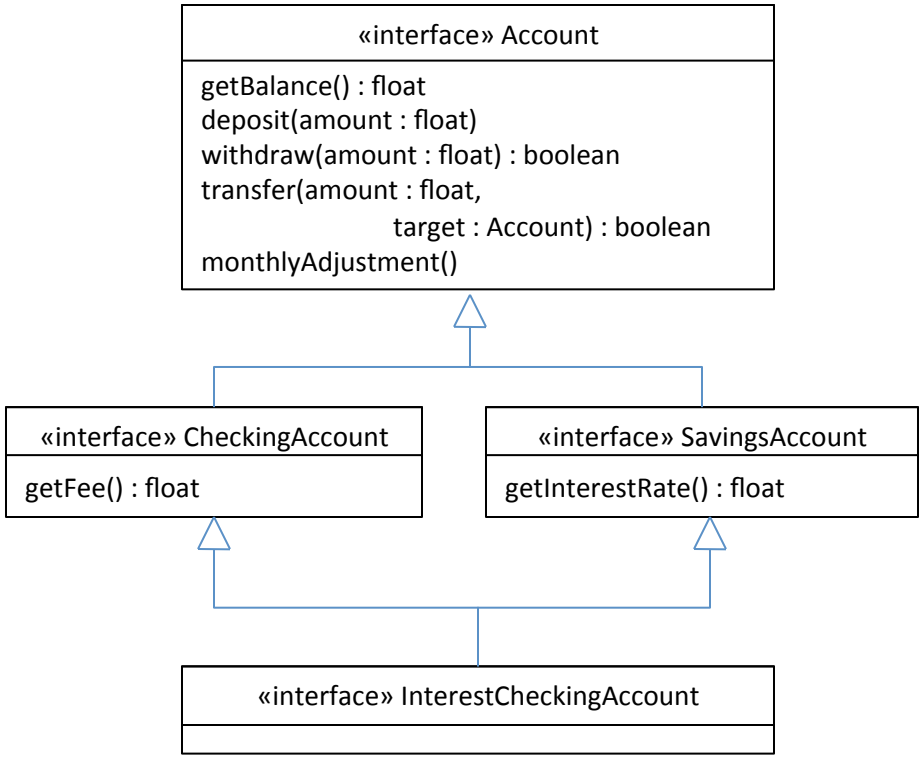
```
class A extends B
```

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

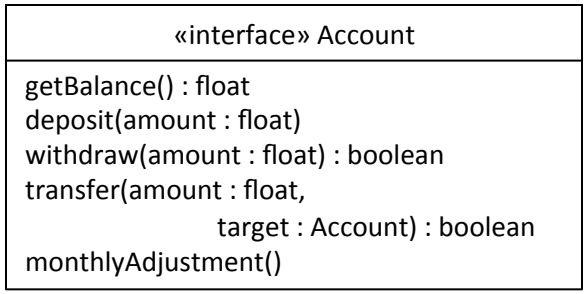
```
class A implements I
class A extends B
```

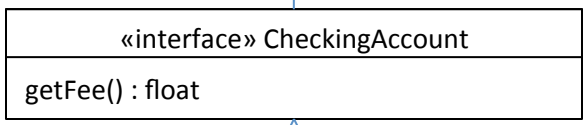
Challenge: Is inheritance necessary?

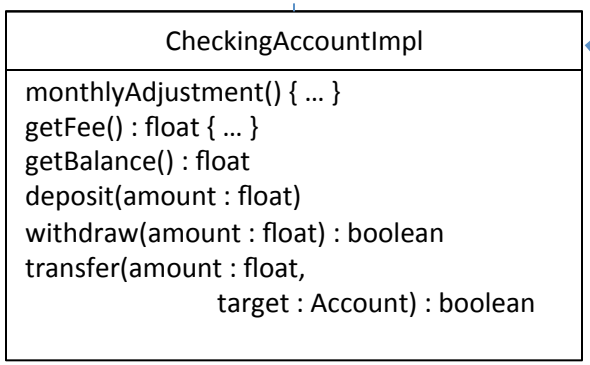
- Can we get good code reuse without inheritance?

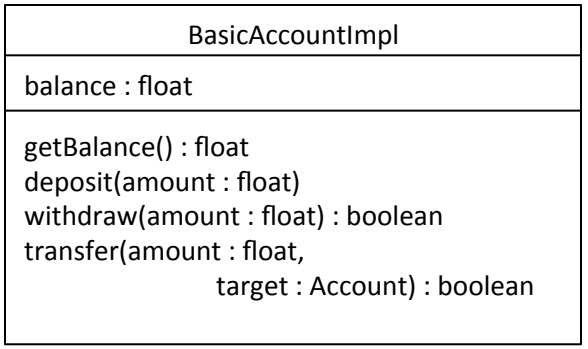


Yes! (Reuse via composition and delegation)










```
public class CheckingAccountImpl
        implements CheckingAccount {
    BasicAccountImpl basicAcct = new(…);
    public float getBalance() {
        return basicAcct.getBalance();
    }
    // …
```

CheckingAccountImpl is composed of a BasicAccountImpl

Principles of Software Construction: Objects, Design, and Concurrency
(Part 1: Designing Classes)

Design for Reuse (class level)

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Administrivia

- Homework 2 due tonight
- Homework 3 released tomorrow, due next Thursday

Key concepts from Tuesday

Key concepts from Tuesday

- Motivations for reuse
- Delegation vs. inheritance
  - The power of polymorphism…
  - Inheritance and information hiding…

Today's agenda

- Java-specific details for inheritance-based reuse
- Design patterns for class-level code reuse
  - Template Method
  - Decorator
- Behavioral subtyping: Liskov's Substitution Principle
  - The `java.lang.Object` behavioral contracts

Java details: extended reuse with super

```
public abstract class AbstractAccount implements Account {
   protected float balance = 0.0;
   public boolean withdraw(float amount) {
       // withdraws money from account (code not shown)
   }
}

public class ExpensiveCheckingAccountImpl
      extends AbstractAcount implements CheckingAccount {
   public boolean withdraw(float 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 AbstractAcount implements CheckingAccount {

   private float fee;

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

   public CheckingAccountImpl(float initialBalance) {
      this(initialBalance, 5.00);
   }
   /* 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.,
```
float 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;
float fee = checkingAcct.getFee();
```
  - Will get a `ClassCastException` if types are incompatible
- Advice: avoid downcasting types
  - Never(?) downcast within superclass to a subclass

Note: `instanceof`

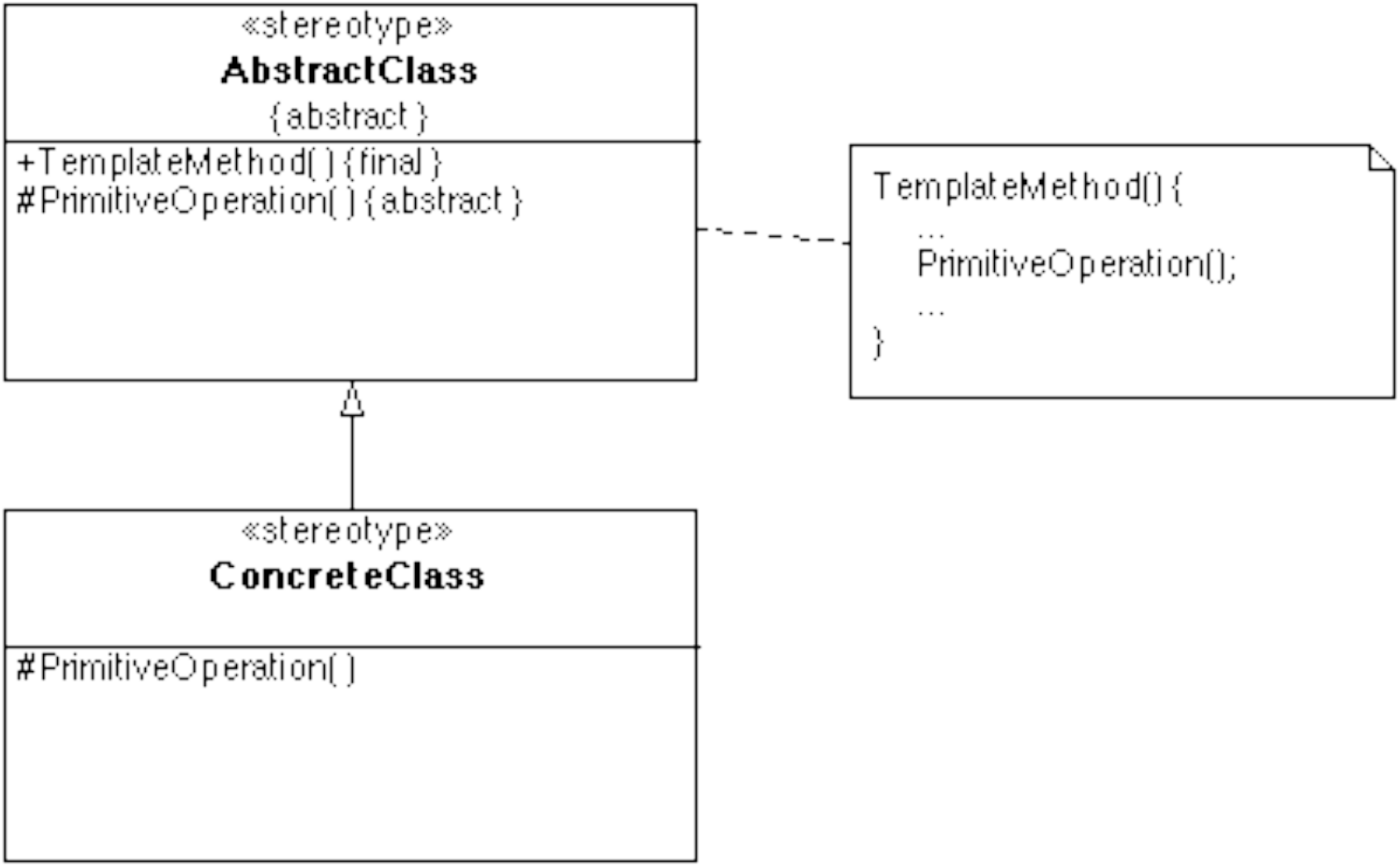
- Operator that tests whether an object is of a given class

```
public void doSomething(Account acct) {
    float adj = 0.0;
    if (acct instanceof CheckingAccount) {
        checkingAcct = (CheckingAccount) acct;
         adj = checkingAcct.getFee();
    } else if (acct instanceof SavingsAccount) {
        savingsAcct = (SavingsAccount) acct;
         adj = savingsAcct.getInterest();
    }
    …
}
```

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

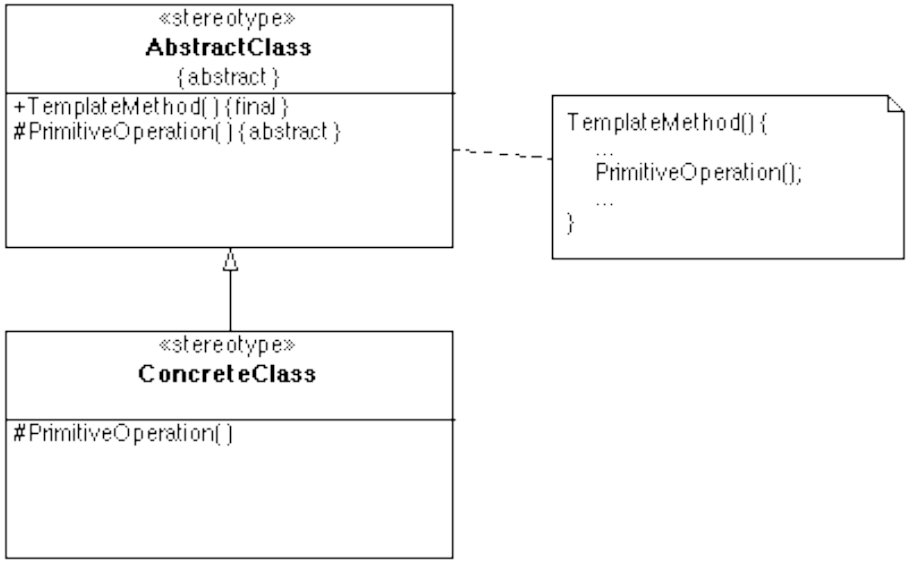
THE TEMPLATE-METHOD DESIGN PATTERN

The *Template Method* design pattern



The *Template Method* design pattern

- Applicability
  - When an algorithm consists of varying and invariant parts that must be customized
  - When common behavior in subclasses should be factored and localized to avoid code duplication
  - To control subclass extensions to specific operations
- Consequences
  - Code reuse
  - Inverted “Hollywood” control: don’t call us, we’ll call you
  - Ensures the invariant parts of the algorithm are not changed by subclasses



Note: instanceof

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

```
public void doSomething(Account acct) {
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        savingsAcct = (SavingsAccount) acct;
         adj = savingsAcct.getInterest();
    }
    …
}
```

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

Avoiding `instanceof` with the Template Method pattern

```
public interface Account {
    …
    public float getMonthlyAdjustment();
}

public class CheckingAccount implements Account {
    …
    public float getMonthlyAdjustment() {
        return getFee();
    }
}

public class SavingsAccount implements Account {
    …
    public float getMonthlyAdjustment() {
        return getInterest();
    }
}
```

Avoiding `instanceof` with the Template Method pattern

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    savingsAcct = (SavingsAccount) acct;
    adj = savingsAcct.getInterest();
  }
  …
}
```

Instead:

```
public void doSomething(Account acct) {
  float adj = acct.getMonthlyAdjustment();
  …
}
```

Template Method vs. the Strategy Pattern

- Both support variations in larger common context
- Template method uses inheritance + an abstract method
- Strategy uses interface and polymorphism (object composition)
  - Strategy objects are reusable across multiple classes
  - Multiple strategy objects are possible per class

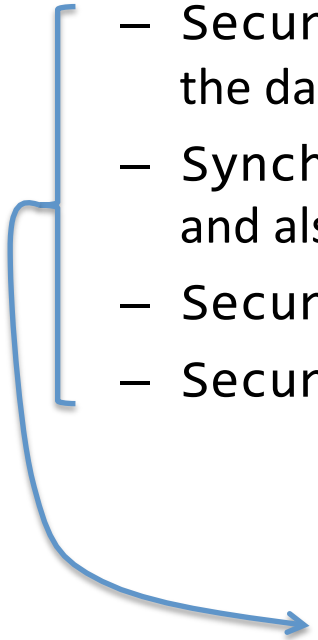
THE DECORATOR DESIGN PATTERN

Limitations of inheritance

- Suppose you want various extensions of a `Stack` data structure…
  - `UndoStack`: A stack that lets you undo previous push or pop operations
  - `SecureStack` or `LockedStack`: A stack that requires a password to let you access the data
  - `SynchronizedStack`: A stack that serializes concurrent accesses

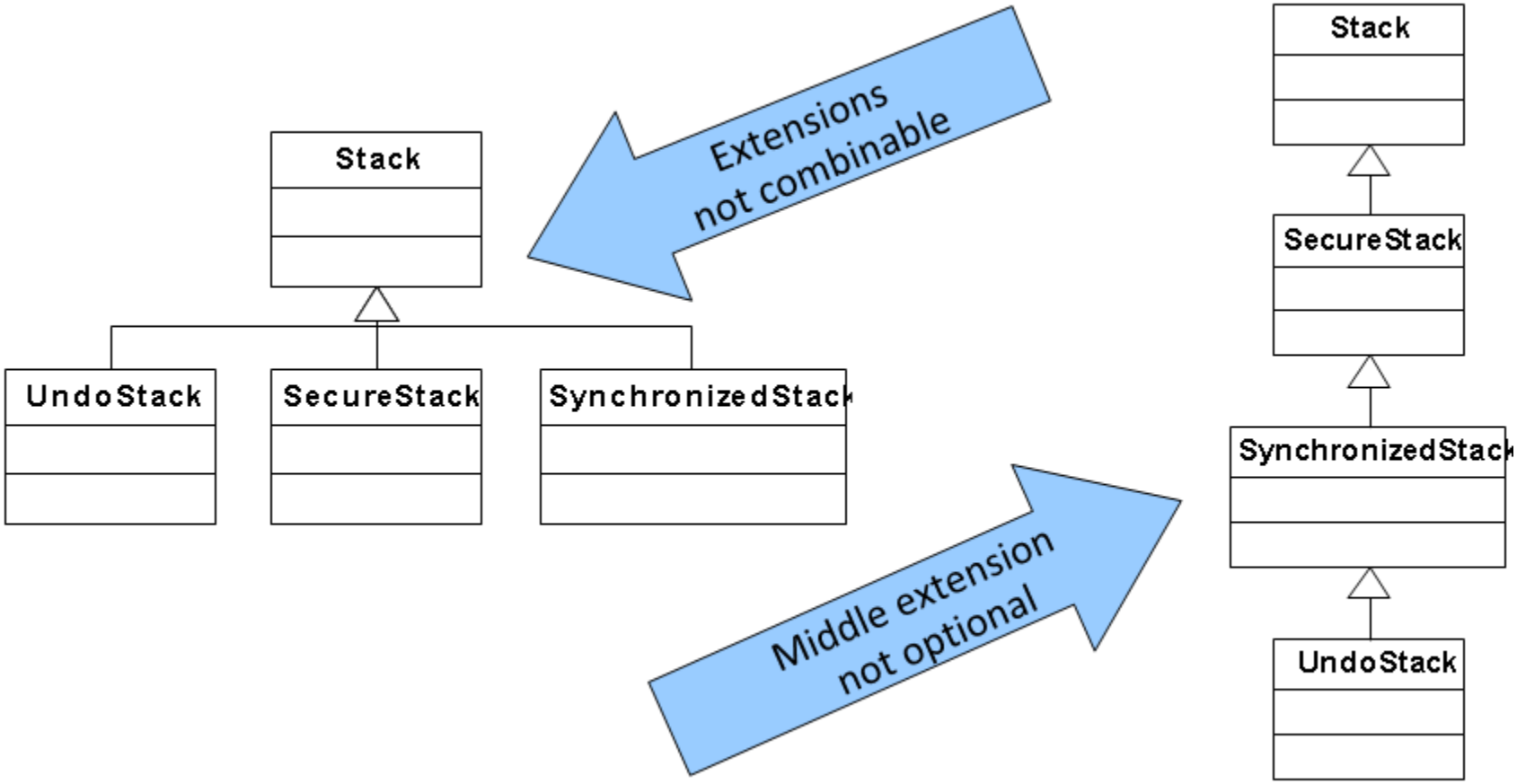
Limitations of inheritance

- Suppose you want various extensions of a `Stack` data structure…
  - `UndoStack`: A stack that lets you undo previous push or pop operations
  - `SecureStack` or `LockedStack`: A stack that requires a password to let you access the data
  - `SynchronizedStack`: A stack that serializes concurrent accesses
  - `SecureUndoStack`: A stack that requires a password to let you access the data, and also lets you undo previous operations
  - `SynchronizedUndoStack`: A stack that serializes concerrent accesses, and also lets you undo previous operations
  - `SecureSynchronizedStack`: …
  - `SecureSynchroniedUndoStack`: …



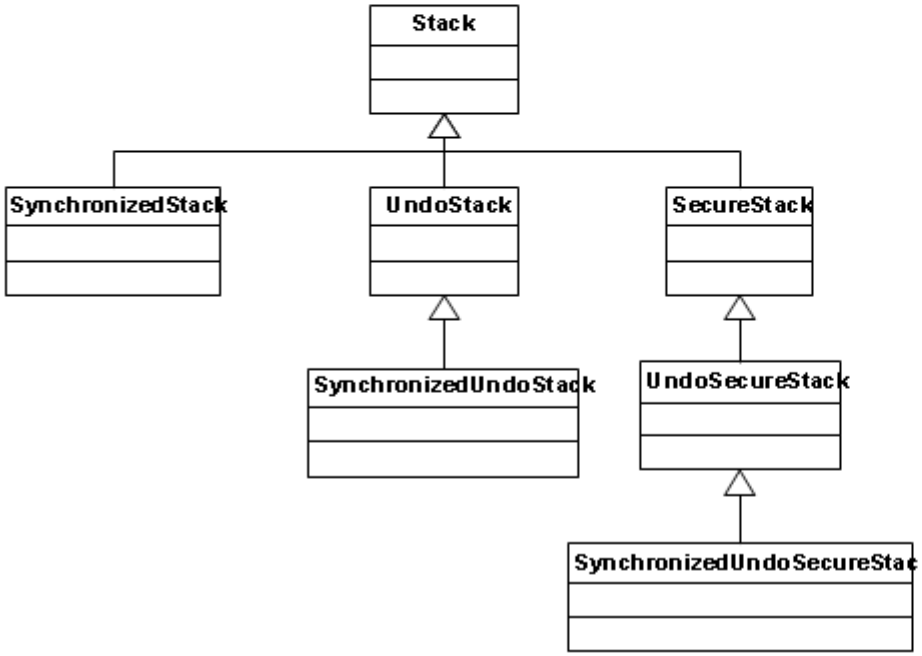
Goal: arbitrarily composable extensions

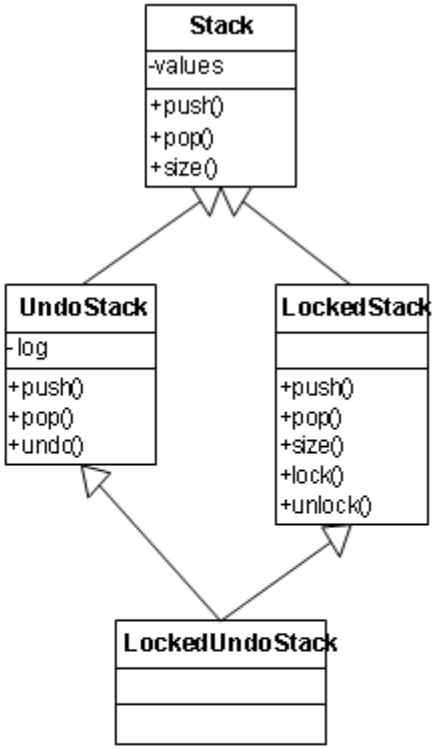
Limitations of inheritance



Workarounds?

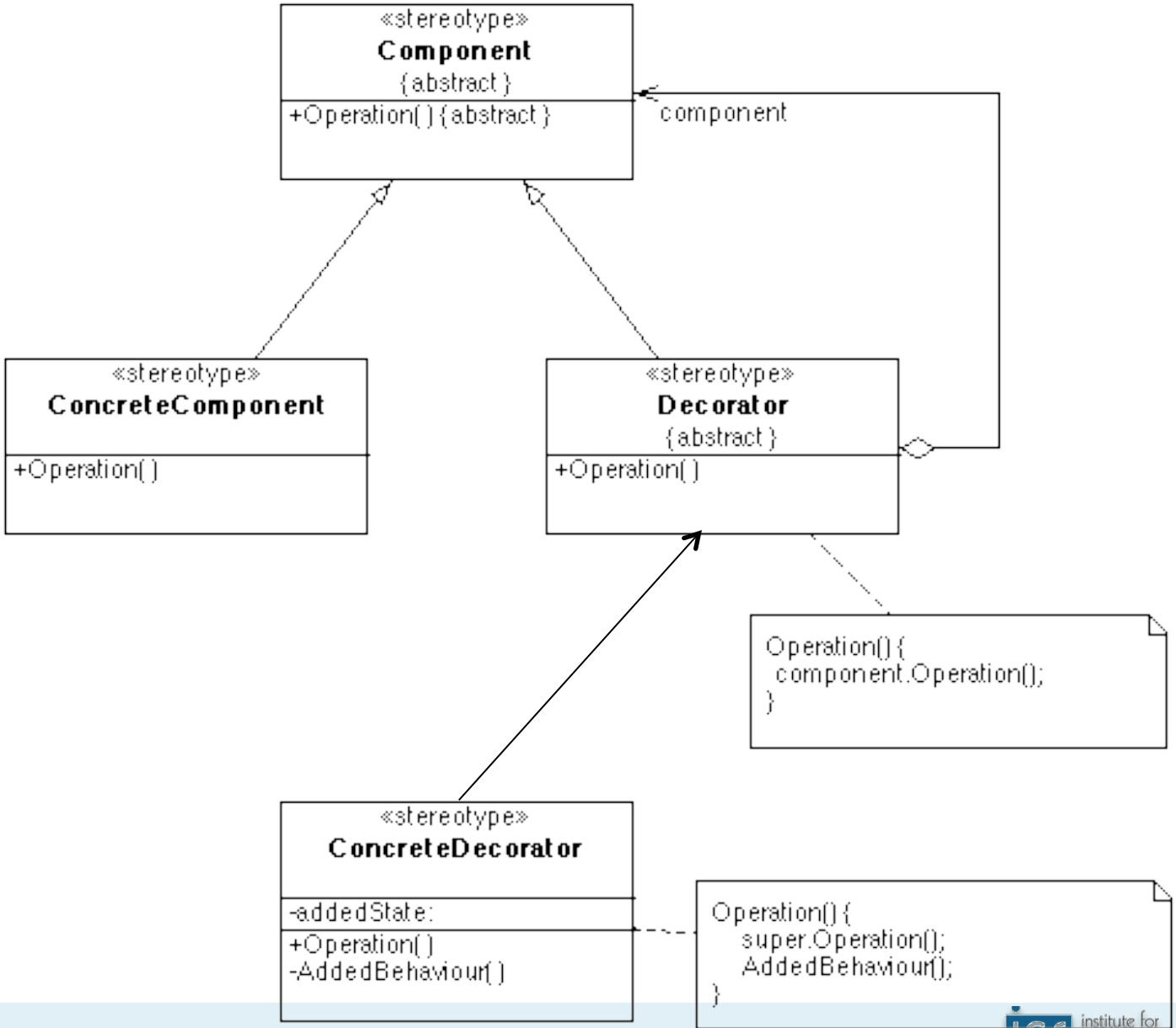
- Combining inheritance hierarchies
  - Combinatorical explosion
  - Massive code replication





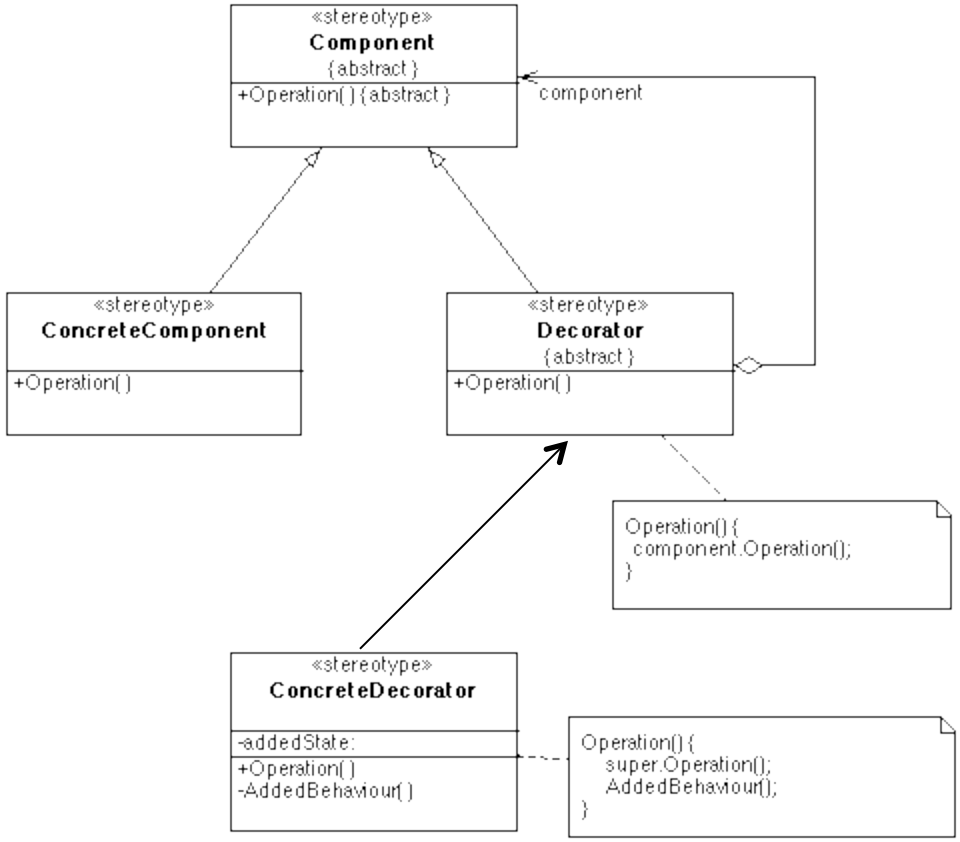
- Multiple inheritance
  - Diamond problem

The *Decorator* design pattern

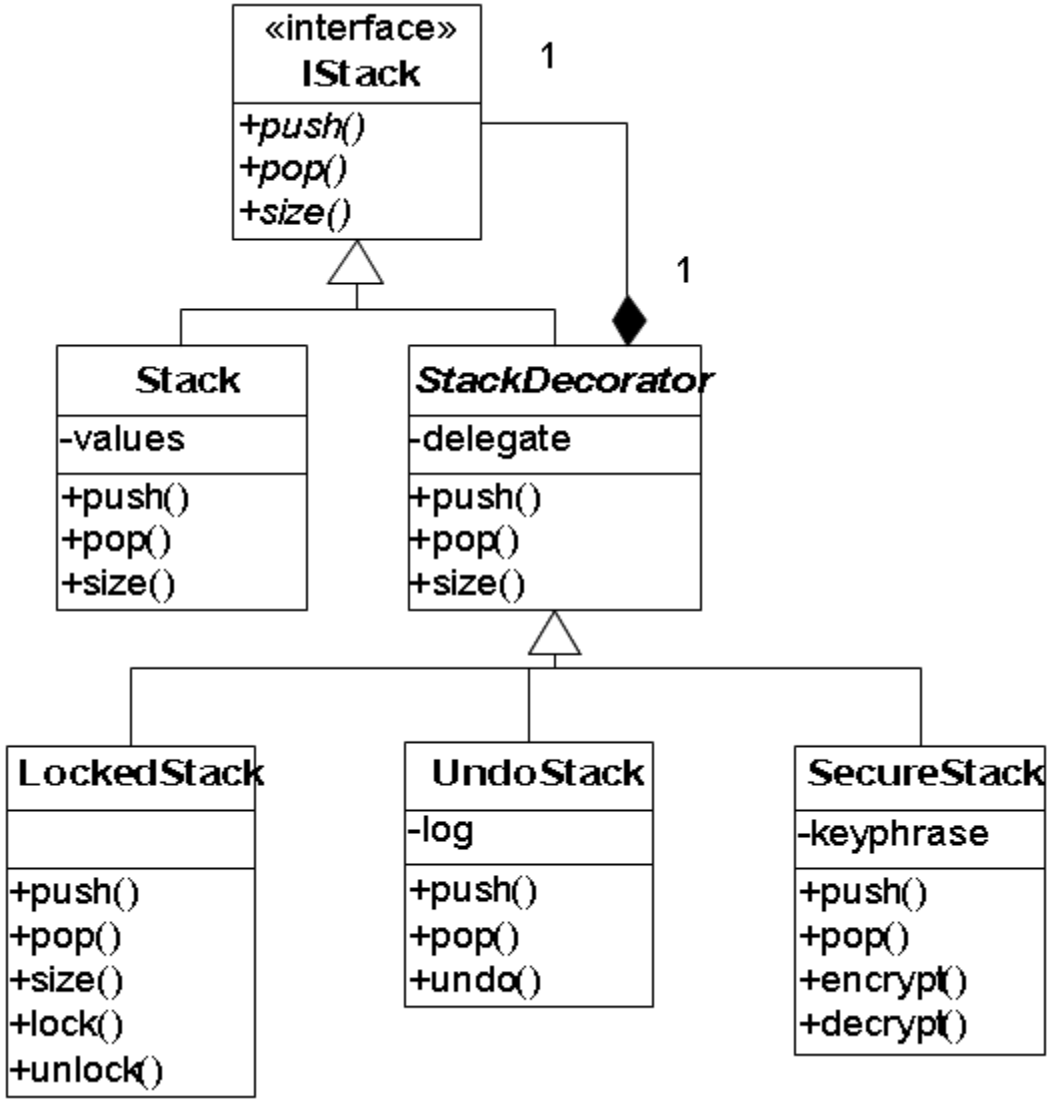


The *Decorator* design pattern

- Applicability
  - To add responsibilities to individual objects dynamically and transparently
  - For responsibilities that can be withdrawn
  - When extension by subclassing is impractical
- Consequences
  - More flexible than static inheritance
  - Avoids monolithic classes
  - Breaks object identity
  - Lots of little objects



Using the Decorator for our Stack example



Decorators from `java.util.Collections`

- Helper methods in java.util.Collections:
  - static List<T> unmodifiableList(List<T> lst);
  - static Set<T> unmodifiableSet(Set<T> set);
  - static Map<K,V> unmodifiableMap(Map<K,V> map);
- Turn a mutable list into an immutable list
  - All mutation operations on resulting list throw UnsupportedOperationException
- Similar for synchronization:
  - static List<T> synchronizedList(List<T> lst);
  - static Set<T> synchronizedSet(Set<T> set);
  - static Map<K,V> synchronizedMap(Map<K,V> map);

The UnmodifiableCollection (simplified excerpt)

```
public static <T> Collection<T> unmodifiableCollection(Collection<T> c)
       return new UnmodifiableCollection<>(c);
}
class UnmodifiableCollection<E> implements Collection<E>, Serializable
       final Collection<E> c;
       UnmodifiableCollection(Collection<> c) {this.c = c; }
       public int size() {return c.size();}
       public boolean isEmpty() {return c.isEmpty();}
       public boolean contains(Object o) {return c.contains(o);}
       public Object[] toArray() {return c.toArray();}
       public <T> T[] toArray(T[] a) {return c.toArray(a);}
       public String toString() {return c.toString();}
       public boolean add(E e) {throw new UnsupportedOperationException
       public boolean remove(Object o) { throw new UnsupportedOperation
              public boolean containsAll(Collection<?> coll) {  return
       public boolean addAll(Collection<? extends E> coll) { throw new
       public boolean removeAll(Collection<?> coll) { throw new Unsuppo
       public boolean retainAll(Collection<?> coll) { throw new Unsuppo
       public void clear() {  throw new UnsupportedOperationException()
   }
```

The Decorator pattern vs. inheritance

- Composition at runtime vs compile-time
- Inheritance can add methods
- Decorator allows mix and match of extensions
- Can apply decorators multiple times
- Multiple inheritance has conceptual problems
- Inheritance produces single object, decorator consists of multiple collaborating objects
  - Multiple clients: Danger of inconsistent references, possibility of different perspectives

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:
  - Subtype (subclass, subinterface, object implementing interface) can add, but not remove methods
  - Overriding method must return same type or subtype
  - Overriding method must accept the same parameter types
  - Overriding method may not throw additional exceptions
  - Concrete class must implement all undefined interface methods and abstract methods

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.
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- e.g., Compiler-enforced rules in Java:
  - Subtype (subclass, subinterface, object implementing interface) can add, but not remove methods
  - Overriding method must return same type or subtype
  - Overriding method must accept the same parameter types
  - Overriding method may not throw additional exceptions
  - Concrete class must implement all undefined interface methods and abstract methods
- Also applies to behavior: A subclass must fulfill all contracts its superclass does:
  - 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 in a nutshell

- If `Cowboy.draw()` overrides `Circle.draw()` somebody gets hurt!

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 break 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 Princple)

```
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? (Yes.)

Behavioral subtyping (Liskov Substitution Principle)

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

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

        //methods
}
```

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

Is this Square a behavioral subtype of Rectangle?

Behavioral subtyping (Liskov Substitution Principle)

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

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

        //methods
}
```

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

Is this Square a behavioral subtype of Rectangle? (Yes.)

Behavioral subtyping (Liskov Substitution Principle)

```
class Rectangle {
        //@ invariant h>0 && w>0;
        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;
        }
}
```

```
class Square extends Rectangle {
        //@ invariant h>0 && w>0;
        //@ invariant h==w;
        Square(int w) {
            super(w, w);
        }
}
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Is this Square a behavioral subtype of Rectangle?

Behavioral subtyping (Liskov Substitution Principle)

```
class Rectangle {
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        int h, w;

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            this.h=h; this.w=w;
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            w=w*factor;
            h=h*factor;
        }
}
```

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

Is this Square a behavioral subtype of Rectangle? (Yes.)

Behavioral subtyping (Liskov Substitution Principle)

```
class Rectangle {
        //@ invariant h>0 && w>0;
        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;
        }
        //@ requires neww > 0;
        void setWidth(int neww) {
            w=neww;
        }
}
```

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

Is this Square a behavioral subtype of Rectangle?

Behavioral subtyping (Liskov Substitution Principle)

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

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

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

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

```
class Square extends Rectangle {
        //@ 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**

Maybe? (If so, it's not a square…)

JAVA.LANG.OBJECT BEHAVIORAL CONTRACTS

The `java.lang.Object`

- All Java objects inherit from `java.lang.Object`
- Commonly-used/overridden public methods:

```
String      toString()
boolean     equals(Object obj)
int         hashCode()
Object      clone()
```

Overriding java.lang.Object's .equals

- The default Object.equals:

```
public class Object {
    public boolean equals(Object obj) {
        return this == obj;
    }
}
```

- An aside: Do you like:

```
public class CheckingAccountImpl
        implements CheckingAccount {
    @Override
    public boolean equals(Object obj) {
        return false;
    }
}
```

The `.equals(Object obj)` contract

- An equivalence relation
  - Reflexive: ∀`x` `x.equals(x)`
  - Symmetric: ∀`x,y` `x.equals(y)` if and only if `y.equals(x)`
  - Transitive: ∀`x,y,z` `x.equals(y)` and `y.equals(z)` implies `x.equals(z)`
- Consistent
  - Invoking `x.equals(y)` repeatedly returns the same value unless `x` or `y` is modified
- `x.equals(null)` is always false
- `.equals()` always terminates and is side-effect free

The `.hashCode()` contract

- Consistent
  - Invoking `x.hashCode()` repeatedly returns same value unless x is modified
- `x.equals(y)` implies `x.hashCode() == y.hashCode()`
  - The reverse implication is not necessarily true:
    - `x.hashCode() == y.hashCode()` does not imply `x.equals(y)`
- Advice: Override `.equals()` if and only if you override `.hashCode()`

The `.clone()` contract

- Returns a *deep copy* of an object
- Generally (but not required!):
  - `x.clone() != x`
  - `x.clone().equals(x)`

Conforming to behavioral contracts

- Complete to support object equality checks:

```
public class Person {
    private String firstName;
    private String lastName;
    public Person(String name) {
        this.firstName = name.split(" ")[0];
        this.lastName = name.split(" ")[1];
    }

}
```

A lesson in equality

```
public class Point {
  private final int x;
  private final int y;
  public Point(int x, int y) {
    this.x = x;
    this.y = y;
  }
}
```

Recall: The `java.lang.Object`

- All Java objects inherit from `java.lang.Object`
- Commonly-used/overridden public methods:
  - `String toString()`
  - `boolean equals(Object obj)`
  - `int hashCode()`
  - `Object clone()`

Complete to support equality-checking for the `Point` class.

A tempting but incorrect solution

```
public class Point {
  private final int x;
  private final int y;
  public Point(int x, int y) {
    this.x = x;
    this.y = y;
  }
}
```

```
public boolean equals(Point p) {
  return x == p.x && y == p.y;
}
```

Types must match

Recall: The `java.lang.Object`

- All Java objects inherit from `java.lang.Object`
- Commonly-used/overridden public methods:
  - `String toString()`
  - `boolean equals(Object obj)`
  - `int hashCode()`
  - `Object clone()`

`boolean equals(Point p)` does not override `boolean equals(Object obj)`

A correct solution

```
public class Point {
  private final int x;
  private final int y;
  public Point(int x, int y) {
    this.x = x;
    this.y = y;
  }

  public boolean equals(Object obj) {
    if (!(obj instanceof Point)
      return false;
    Point p = (Point) obj;
    return x == p.x && y == p.y;
  }

  public int hashCode() {
    return 31*x + y;
  }
}
```

The `.equals(Object obj)` contract

- An equivalence relation
  - Reflexive: ∀x `x.equals(x)`
  - Symmetric: ∀x,y `x.equals(y)` if and only if `y.equals(x)`
  - Transitive: ∀x,y,z `x.equals(y)` and `y.equals(z)` implies `x.equals(z)`
- Consistent
  - Invoking `x.equals(y)` repeatedly returns the same value unless `x` or `y` is modified
- `x.equals(null)` is always false

15-214 Garrod 8

A new challenge

```
public class Point {
  private final int x;
  private final int y;
  public Point(int x, int y) {
    this.x = x;
    this.y = y;
  }

  public boolean equals(Object obj) {
    if (!(obj instanceof Point)
      return false;
    Point p = (Point) obj;
    return x == p.x && y == p.y;
}
```

```
public class ColorPoint
      extends Point {
  private final Color color;

  public ColorPoint(int x,
                    int y,
                    Color color) {
    super(x, y);
    this.color = color;
  }
}
```

Implement `.equals` for the `ColorPoint` class.
You may assume `Color` correctly implements `.equals`

A tempting solution

```
public class Point {
  private final int x;
  private final int y;
  public Point(int x, int y) {
    this.x = x;
    this.y = y;
  }

  public boolean equals(Object obj
    if (!(obj instanceof Point)
      return false;
    Point p = (Point) obj;
    return x == p.x && y == p.y;
}
```

```
public class ColorPoint
      extends Point {
  private final Color color;

  public ColorPoint(int x,
                    int y,
                    Color color) {
    super(x, y);
    this.color = color;
  }

  public boolean equals(Object obj) {
    if (!(obj instanceof ColorPoint))
       return false;
    ColorPoint cp = (ColorPoint) obj;
    return super.equals(cp) &&
           color.equals(cp.color);
}
```

A tempting solution

```
public class Point {
  private final int x;
  private final int y;
  public Point(int x, int y) {
    this.x = x;
    this.y = y;
  }

  public boolean equals(Object obj
    if (!(obj instanceof Point)
      return false;
    Point p = (Point) obj;
    return x == p.x && y == p.y;
}
```

```
public class ColorPoint
      extends Point {
  private final Color color;

  public ColorPoint(int x,
                    int y,
                    Color color) {
    super(x, y);
    this.color = color;
  }

  public boolean equals(Object obj) {
    if (!(obj instanceof ColorPoint))
       return false;
    ColorPoint cp = (ColorPoint) obj;
    return super.equals(cp) &&
           color.equals(cp.color);
}
```

A problem: p.equals(cp) but !cp.equals(p):

```
Point p = new Point(2, 42);
ColorPoint cp = new ColorPoint(2, 42, Color.BLUE);
```

More problems

```
public class Point {
  private final int x;
  private final int y;
  public Point(int x, int y) {
    this.x = x;
    this.y = y;
  }

  public boolean equals(Object obj
    if (!(obj instanceof Point)
      return false;
    Point p = (Point) obj;
    return x == p.x && y == p.y;
}
```

```
public class ColorPoint
      extends Point {
  private final Color color;

  public ColorPoint(int x,
                    int y,
                    Color color) {
    super(x, y);
    this.color = color;
  }

  public boolean equals(Object obj) {
    if (!(obj instanceof Point))
       return false;
    if (!(obj instanceof ColorPoint))
       return super.equals(obj);
    ColorPoint cp = (ColorPoint) obj;
    return super.equals(cp) &&
           color.equals(cp.color);
}
```

Consider:

```
Point p = new Point(2, 42);
ColorPoint cp1 = new ColorPoint(2, 42, Color.BLUE);
ColorPoint cp2 = new ColorPoint(2, 42, Color.MAUVE);
```

An abstract solution

```
public abstract class Point {
  private final int x;
  private final int y;
  public Point(int x, int y) {
    this.x = x;
    this.y = y;
  }

  public boolean equals(Object obj
    if (!(obj instanceof Point)
      return false;
    Point p = (Point) obj;
    return x == p.x && y == p.y;
}
```

```
public class ColorPoint
      extends Point {
  private final Color color;

  public ColorPoint(int x,
                    int y,
                    Color color) {
    super(x, y);
    this.color = color;
  }

  public boolean equals(Object obj) {
    if (!(obj instanceof ColorPoint))
       return false;
    ColorPoint cp = (ColorPoint) obj;
    return super.equals(cp) &&
           color.equals(cp.color);
}
```

```
public class PointImpl extends Point {
  public PointImpl(int x, int y) { super(x,y); }
  public boolean equals(Object obj) {
    if (!(obj instanceof PointImpl))
      return false;
    return super.equals(obj);
  }
```

The lesson

- Conforming to behavioral contracts can be difficult
- Advice:
  - Don't allow equality between distinct types
  - Be careful when inheriting from a concrete class

"Overriding the `equals` *method seems simple, but there are many ways to get it wrong and the consequences can be dire."* -- Josh Bloch

The lesson

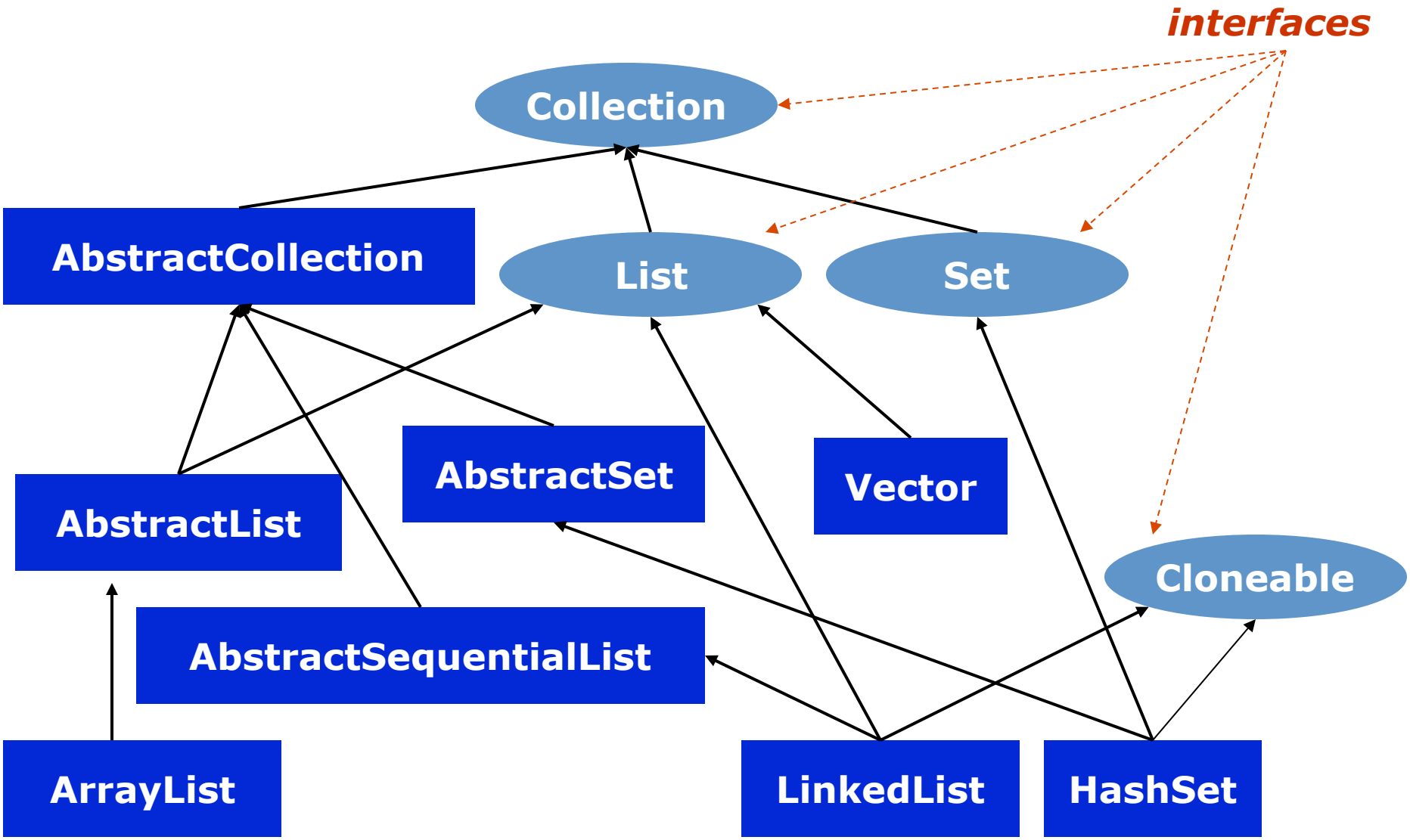
- Conforming to behavioral contracts can be difficult
- Advice:
  - Don't allow equality between distinct types
  - Be careful when inheriting from a concrete class
- Symmetry kills:

```
public class EvilButTrue {
  public boolean equals(Object obj) {
      return obj != null;
  }
  public int hashCode() {
      return 0;
  }
}
```

"Overriding the `equals` *method seems simple, but there are many ways to get it wrong and the consequences can be dire."* -- Josh Bloch

PARAMETRIC POLYMORPHISM (GENERICS)

Recall the Java Collection API (excerpt)



Consider the `java.util.Stack`

```
public class Stack {
      public void push(Object obj) { … }
      public Object pop() { …}
}
```

- Some possible client code?:

```
Stack stack = new Stack();
String s = “Hello!”;
stack.push(s);
String t = stack.pop();
```

Consider the `java.util.Stack`

```
public class Stack {
      public void push(Object obj) { … }
      public Object pop() { …}
}
```

- Some possible client code:

```
Stack stack = new Stack();
String s = “Hello!”;
stack.push(s);
String t = (String) stack.pop();
```

To fix the type error with a downcast (urgs!)

Parametric polymorphism via Java Generics

- *Parametric polymorphism* is the ability to define a type generically to allow static type-checking without fully specifying types
- The `java.util.Stack` instead
  - A stack of some type *T*:

```
public class Stack<T> {
    public void push(T obj) { … }
    public T pop() { … }
}
```

- Improves typechecking, simplifies(?) client code:

```
Stack<String> stack = new Stack<String>();
String s = “Hello!”;
stack.push(s);
String t = stack.pop();
```

Many Java Generics details

- Can have multiple type parameters
  - e.g., `Map<Integer,String>`
- Wildcards
  - e.g., `ArrayList<?>` or `ArrayList<? extends Animal>`
- Subtyping
  - `ArrayList<String>` is a subtype of `List<String>`
  - `ArrayList<String>` is not a subtype of `ArrayList<Object>`
- Cannot create Generic arrays

```
List<String>[] foo = new List<String>[42];  // won't compile
```

- Type erasure
  - Generic type info is compile-time only
    - Cannot use `instanceof` to check generic type
      - But shouldn't use instanceof anyway

Summary: Designing Reusable Classes

- Reuse implementations with clear contracts (information hiding)
- Provide variation points in classes for reuse
  - Strategy Pattern + Composition
  - Overriding / Template Method Pattern + Inheritance
  - Decorator Pattern <- Adding behavior through delegation
  - Type parameters (generics)