Konzepte objektorientierter Programmierung
– Lecture 3 –

Prof. Dr. Peter Müller

Software Component Technology

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Core and Basic Language Concepts

- Core Concepts
  - Object Model
  - Interfaces and Encapsulation
  - Classification and Polymorphism
- Basic Language Concepts
  - Description of Objects
  - Inheritance
  - Dynamic Method Binding
  - Contracts
  - Etc.

Subtyping

- **Substitution principle**
  Objects of subtypes can be used wherever objects of supertypes are expected

- **Subtype polymorphism**
  Program parts working with supertype objects work as well with subtype objects

Inheritance versus Subtyping

- **Subtyping** expresses **classification**
- **Inheritance** is a means of **code reuse**
- Inheritance is **usually coupled** with subtyping
  - Terminology: **Subclassing** = Subtyping + Inheritance

Classification in Software Technology

- Syntactic classification
  - Subtype objects have **wider interfaces** than supertype objects
  - Subtype objects can understand at least the messages that supertype objects can understand

- Semantic classification
  - Subtype objects provide **at least the behavior** of supertype objects

Rules for Subtyping

- Subtype objects must **fulfill contracts** of supertypes, but
  - Subtypes can have **stronger invariants**
  - Overriding methods of subtypes can have
    weaker preconditions
    stronger postconditions
    than corresponding supertype methods

- Concept is called **Behavioral Subtyping**
- Consequence of substitution principle

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Inheritance without Subtyping

- Using subclassing without establishing the “is-a” relation is problematic

```
class List {
  …
  void appendFront( Object o ) { … }
  void appendBack( Object o ) { … }
}
```

```
class Stack extends List {
  …
  // appendFront used as push
  void appendBack( Object o ) {
    System.out.println (“Should not
      be used!!”);
  }
}
```

```
void foo ( List l, Object o )
  { l.appendBack( o ); }      //  l could be a Stack object!
```

Agenda for Today

3. Reusable Components

3.1 Units of Reuse

3.2 Forms of Reuse

3.3 Libraries and APIs

Objectives

- Main concepts of reuse
- Deeper understanding of inheritance

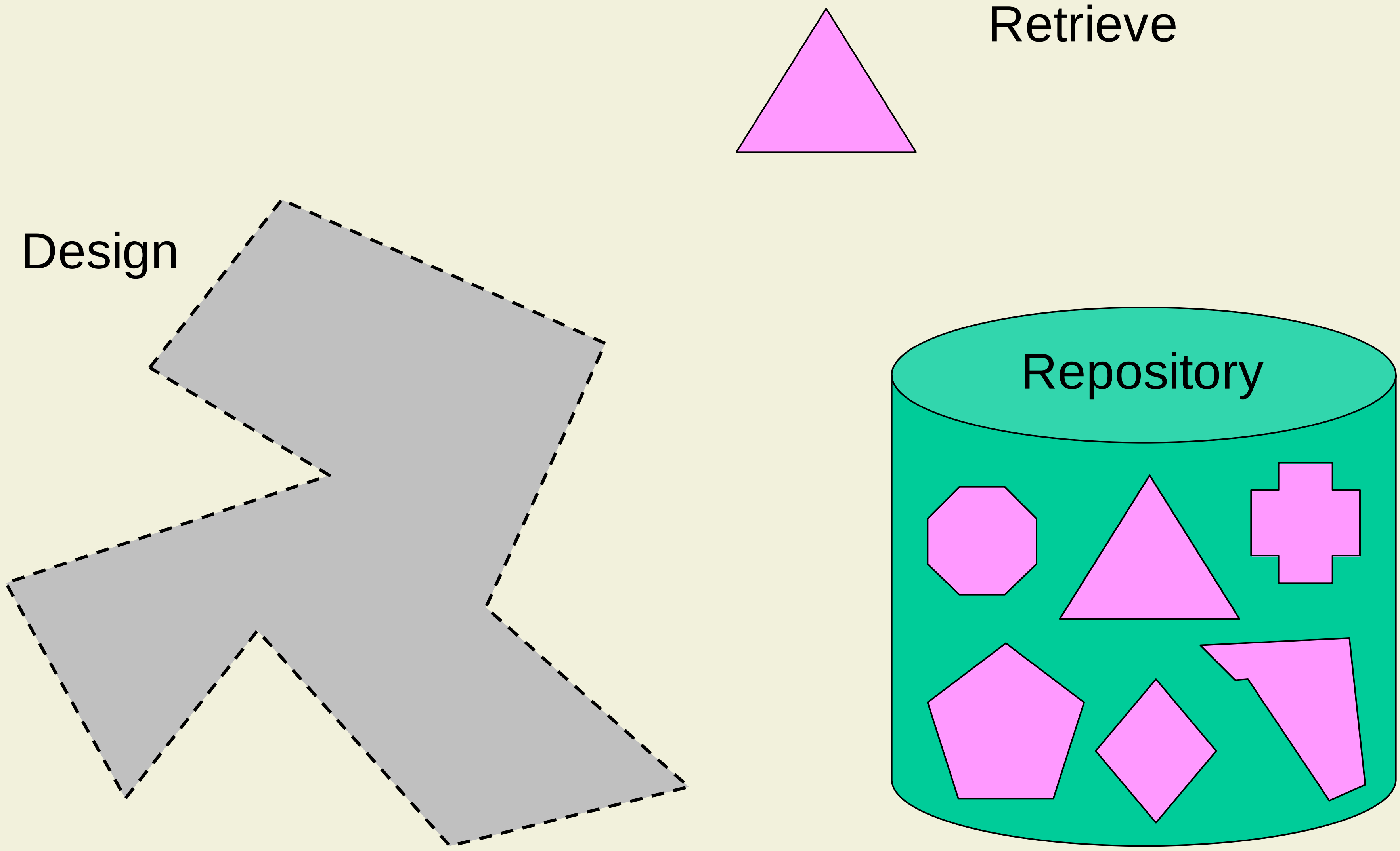
3. Reusable Components

3.1 Units of Reuse

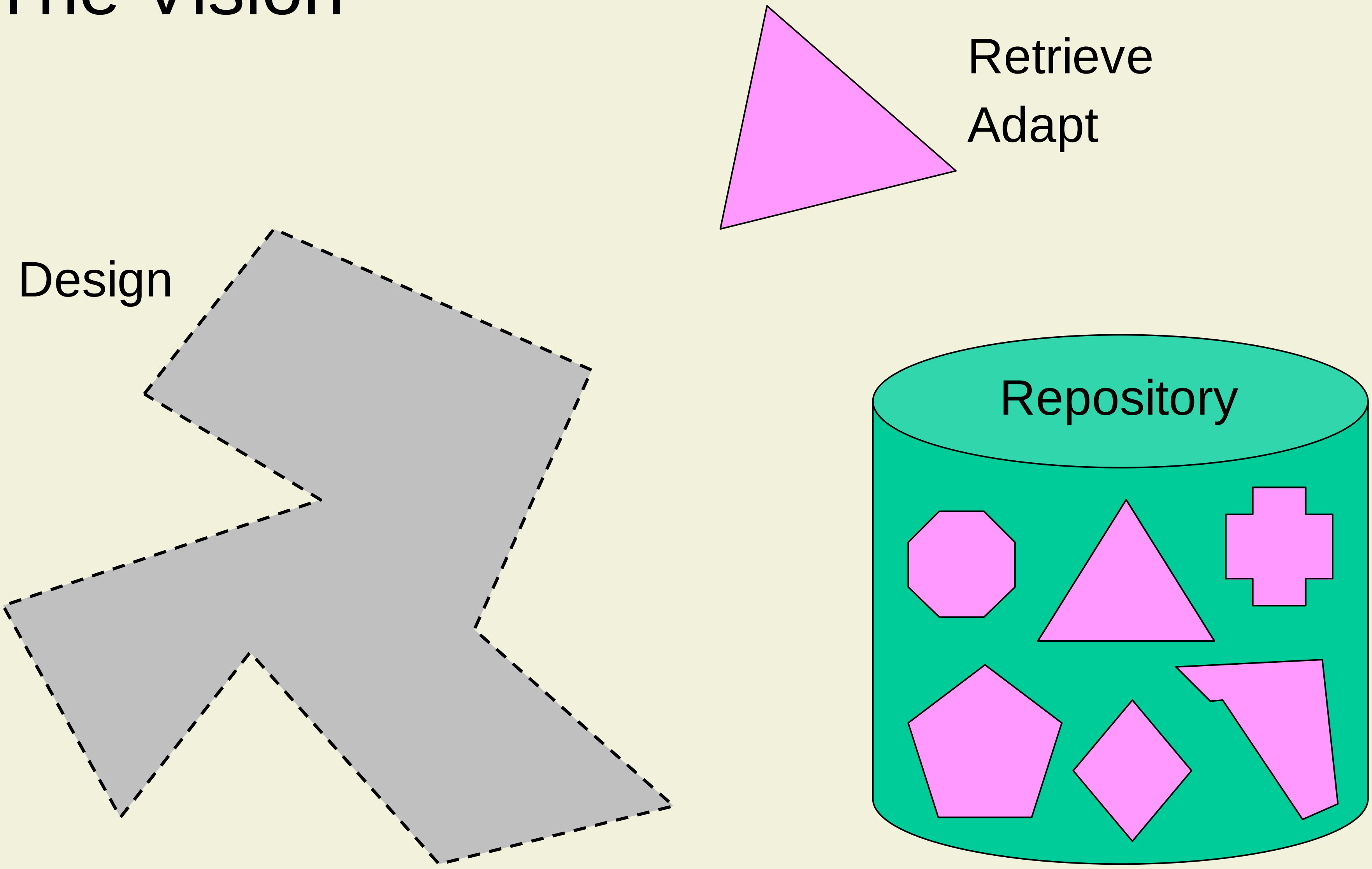
3.2 Forms of Reuse

3.3 Libraries and APIs

The Vision



The Vision

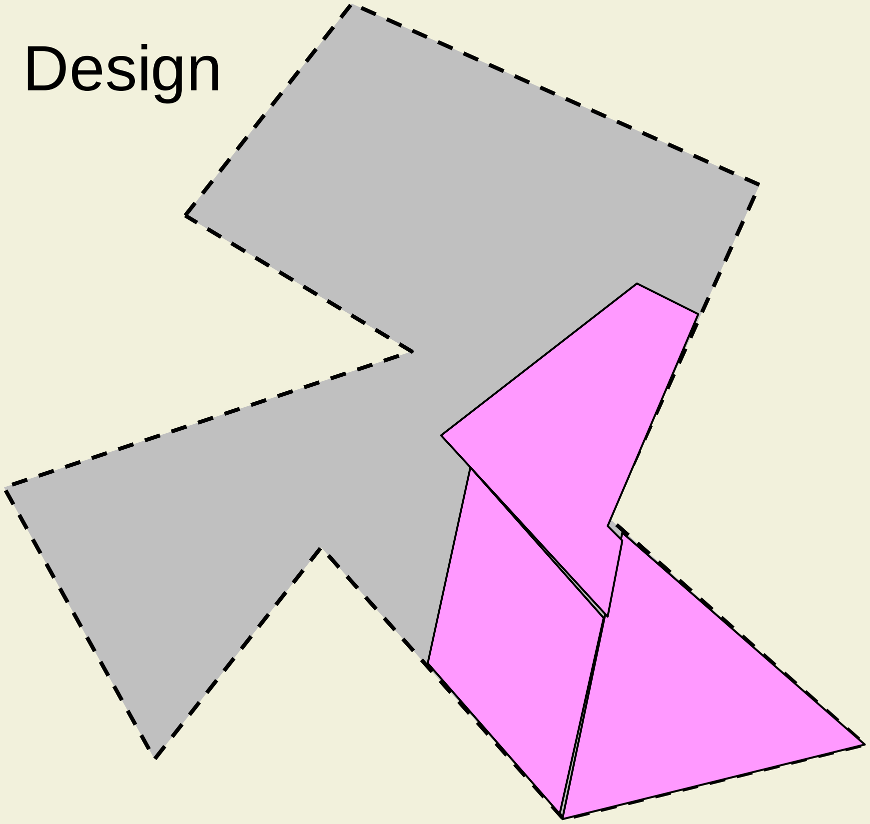


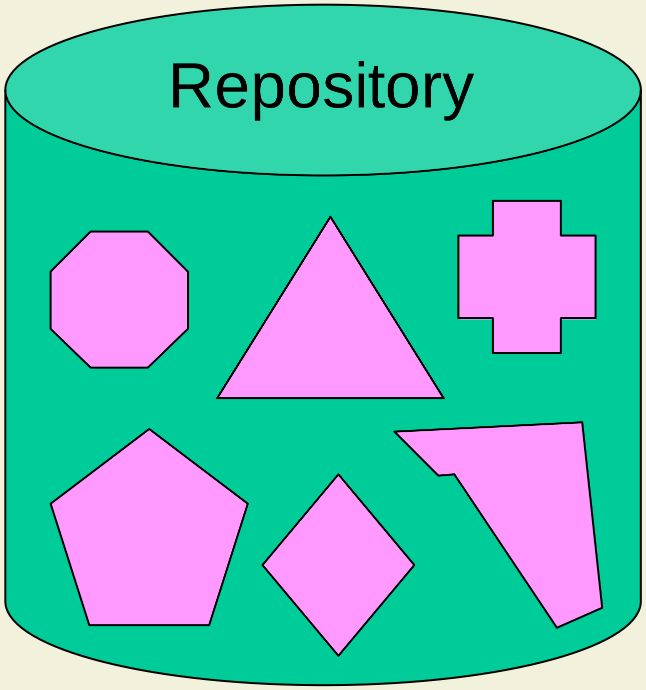
The Vision

Retrieve

Adapt

Reuse





Levels of Reuse

- Program parts
  - Code
  - Examples: String, LinkedList
- Designs
  - Design patterns
  - Examples: Observer pattern, factory pattern
- Software architectures
  - Architectural patterns
  - Examples: Client-server, layered architecture

Components (reuse in the small)

Frameworks (reuse in the large)

Component

- Definition:
  An object-oriented component is a group of one or more cooperating classes and interfaces that implements a common abstraction. Components can be reused without further specialization.

- Examples
  - Simple classes such as String, BigInteger, etc.
  - Groups of classes such as DoublyLinkedList – Node – Iterator
  - But not: The Java Abstract Window Toolkit

Characteristics of Components

- Components can be in source or binary format
- Components have dependencies
  - Superclasses
  - Types of attributes
  - Return and parameter types of methods
- Many programming languages provide modules to group cooperating classes
  - Modules make dependencies explicit
  - High cohesion within one module (common abstraction)

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3. Reusable Components

3.1 Units of Reuse

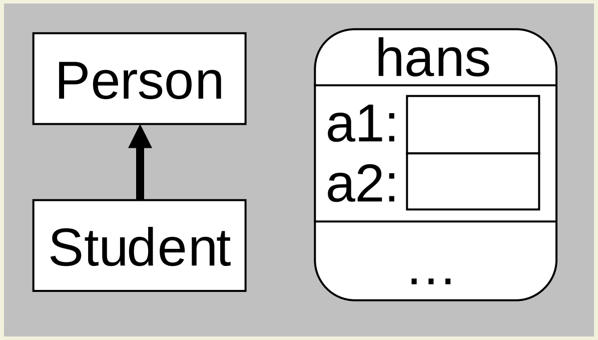
3.2 Forms of Reuse

- **Aggregation and Inheritance**
- A Deeper Look at Inheritance and Subtyping
- The Fragile Baseclass Problem

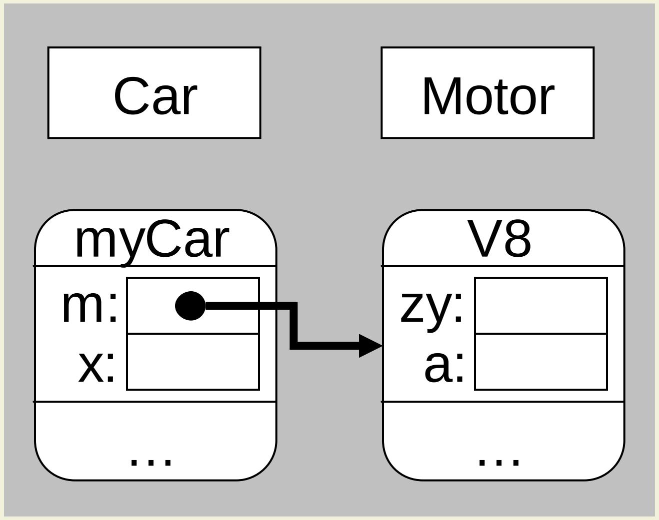
3.3 Libraries and APIs

Main Forms of Reuse “in the Small”

- Inheritance
  - Subclassing establishes **“is-a” relation**
  - Enables subtype **polymorphism**
  - Only **one object** at runtime



- Aggregation
  - Establishes **“has-a” relation**
  - **No subtyping** in general
  - **Two objects** at runtime



Inheritance or Aggregation?

- Frequent design issue:
  Reuse a class by inheritance or by aggregation?

- Rule of thumb: Model the real world
  - A student *is a* person – use inheritance
  - A car *has a* motor – use aggregation
  - However, the real world is not always that simple!
- Aggregation is often useful
  - To avoid subtyping
  - To simulate multiple inheritance (e.g., in Java)

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Example: Implementation of SymbolTable

- Stores pairs of name / value
- Provides methods add and lookup
- Reuse library class Dictionary

```
class Dictionary {
  Pair[ ] elems;
  int next;

  Dictionary( )                                  { … }
  void put( Object key, Object value )   { … }
  Object atKey( Object key )                { … }
}
```

```
class Pair {
  Object first, second;
  Pair( Object f, Object s )  { … }
}
```

Alternative 1: Inheritance

```
class SymbolTable extends Dictionary {

  void add( String key, String value ) {
    put( key, value );
  }

  String lookup( String key ) {
    return ( String ) atKey( key );
  }

}
```

- Attributes and constructor are inherited
- Inherited methods work still
- New methods for naming conventions and type conversion

Alternative 2: Aggregation

```
class SymbolTable {
  Dictionary rep;

  SymbolTable( ) {
    rep = new Dictionary( );
  }
  void add( String key, String value ) {
    rep.put( key, value );
  }
  String lookup( String key ) {
    return ( String ) rep.atKey( key );
  }
}
```

- Attribute and constructor needed
- Methods implemented by delegation

Comparison

- Both alternatives are proper OO-implementations
  - SymbolTable is behavioral subtype of Dictionary
- Inheritance leads to shorter implementation
  - Quicker to develop
- Aggregation permits exchange of implementation
  - Not possible with subclassing
- Aggregation approach has smaller interface
  - Dictionary methods can be used in inheritance approach
- Maintainability
  - Aggregation: Longer, but smaller interface

3. Reusable Components

3.1 Units of Reuse

3.2 Forms of Reuse

- Aggregation and Inheritance
- **A Deeper Look at Inheritance and Subtyping**
- The Fragile Baseclass Problem

3.3 Libraries and APIs

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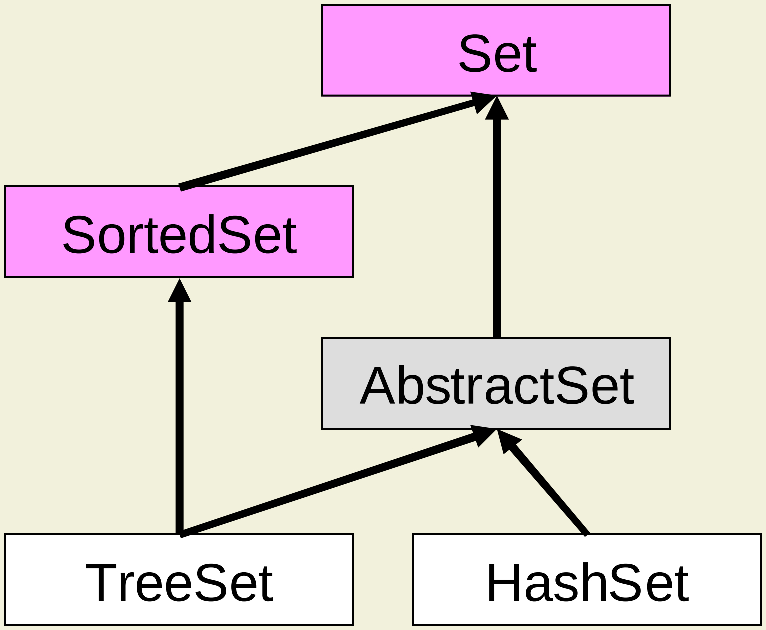
Classification of Components

- Reusable components are classified
  - To structure libraries
  - To use inheritance
  - To support polymorphism
- Classification is often not trivial in practice
- Example: Sets and bounded sets



Attempt 1: BoundedSet extends Set

```
class Set {
  …



  void insert( Object o ) { … }
}
```

```
class BoundedSet extends Set {
  int size, maxSize;



  void insert( Object o ) {
    if (size<maxSize) super.insert(o);
  }
}
```

Attempt 1: BoundedSet extends Set

- BoundedSet refines insert method
- Precondition of insert is strengthened
- Clients using Set might fail when using a BoundedSet

➔ **BoundedSet is no (behavioral) subtype of Set**

```
class Set {
  …
  // requires true
  // ensures isElem( o )
  void insert( Object o ) { … }
}
```

```
class BoundedSet extends Set {
  int size, maxSize;
  // requires size < maxSize
  // ensures isElem( o )
  void insert( Object o ) {
    if (size<maxSize) super.insert(o);
  }
}
```

Attempt 2: Set extends BoundedSet

```
class BoundedSet {
  int size, maxSize;

  …
  // requires size < maxSize
  // ensures isElem( o )
  void insert( Object o )
  { if (size < maxSize) { code } }
}
```

```
class Set extends BoundedSet {
  // requires true
  // ensures isElem( o )
  void insert( Object o ) { code }
}
```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Attempt 2: Set extends BoundedSet

- Set must respect BoundedSet's invariant
- Code duplication is necessary
- Hack: Assign very high number to maxSize
  - Set is more general
  - Might cause other problems (e.g., array implementation)
  - Loss of mathematical properties

➔ **Set is no (behavioral) subtype of BoundedSet**

```
class BoundedSet {
  int size, maxSize;
  // invariant size <= maxSize
  …
  // requires size < maxSize
  // ensures isElem( o )
  void insert( Object o )
  { if (size < maxSize) { code } }
}
```

```
class Set extends BoundedSet {
  // requires size < maxSize
  // ensures isElem( o )
  void insert( Object o ) { code }
}
```

Discussion

- The presented classes for Set and BoundedSet are not subtypes
  - Syntactic requirements are met
  - Semantic requirements are not met
  - No effective reuse in attempt 2
- Large parts of the implementation are identical
  - This code should be reused
  - Aggregation is another form of reuse

Solution 1: Aggregation

- BoundedSet **uses** Set
- Method calls are **delegated** to Set
- Code duplication is avoided
  - But code for delegation is needed, even if methods work identically for Set and BoundedSet
- **No subtype relation**
  - No polymorphism

```
class Set {
  …
  void  insert( Object o )    { … }
  int   size( )               { … }
}
```

```
class BoundedSet {
  Set rep;
  int maxSize;

  void insert( Object o ) {
    if (rep.size( ) < maxSize)
      rep.insert( o );
  }
  int size( ) { return rep.size( ); }
}
```


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A Variant of the Problem

- Aggregation seems okay for Set and BoundedSet
- Similar examples require subtyping
- Polygons and Rectanges
  - Polygon: Unbounded set of vertices
  - Rectangle: Bounded set of (exactly four) vertices
  - A rectangle is a polygon!

```
class Polygon {
  Vertex[ ] vertices;
  …
  void addVertex( Vertex v ) { … }
}
```

```
class Rectangle extends Polygon {
  // vertices contains 4 vertices
  …
  void addVertex( Vertex v ) {
    // do nothing
  }
}
```

Solution 2: Returning Appropriate Objects

```
class Polygon {
  Vertex[ ] vertices;
  …


  Polygon addVertex( Vertex v ) {
    … // add v to vertices
    return this;
  }
}
```

```
class Rectangle extends Polygon {
  // vertices contains 4 vertices
  …


  Polygon addVertex( Vertex v ) {
    return new Pentagon(
      vertices[ 0 ], vertices[ 1 ],
      vertices[ 2 ], vertices[ 3 ], v );
  }
}
```

Solution 2: Returning Appropriate Objects

```
class Polygon {
  Vertex[ ] vertices;
  …
  // requires true
  // ensures result.hasVertex( v )
  Polygon addVertex( Vertex v ) {
    … // add v to vertices
    return this;
  }
}
```

```
class Rectangle extends Polygon {
  // vertices contains 4 vertices
  …
  // requires true
  // ensures result.hasVertex( v )
  Polygon addVertex( Vertex v ) {
    return new Pentagon(
      vertices[ 0 ], vertices[ 1 ],
      vertices[ 2 ], vertices[ 3 ], v );
  }
}
```

Solution 2: Returning Appropriate Objects

```
class Polygon {
  Vertex[ ] vertices;
  …
  // requires true
  // ensures result.hasVertex( v )
  Polygon addVertex( Vertex v ) {
    … // add v to vertices
    return this;
  }
}
```

```
class Rectangle extends Polygon {
  // vertices contains 4 vertices
  …
  // requires true
  // ensures result.hasVertex( v )
  Polygon addVertex( Vertex v ) {
    return new Pentagon(
      vertices[ 0 ], vertices[ 1 ],
      vertices[ 2 ], vertices[ 3 ], v );
  }
}
```

```
void foo ( Polygon[ ] p, Vertex v ) {
  for( int i=0; i < p.length; i++ ) { p[ i ].addVertex( v ).display( ); }
}
```

BoundedSet Revisited

```
class Set {
  …



  Set insert( Object o ) {
    … // insert new element
    return this;
  }
}
```

```
class BoundedSet extends Set {
  int size, maxSize;



  Set insert( Object o ) {
    if (size < maxSize)
      return super.insert(o);
    else {
      Set res = new Set( );
      res.insertAll( this );
      res.insert( o );
      return res;
    }
  }
}
```

BoundedSet Revisited

```
class Set {
  …
  // requires true
  // ensures result.isElem( o )
  Set insert( Object o ) {
    … // insert new element
    return this;
  }
}
```

```
class BoundedSet extends Set {
  int size, maxSize;
  // requires true
  // ensures result.isElem( o )
  Set insert( Object o ) {
    if (size < maxSize)
      return super.insert(o);
    else {
      Set res = new Set( );
      res.insertAll( this );
      res.insert( o );
      return res;
    }
  }
}
```

Discussion

- BoundedSet.insert may return Set or BoundedSet object
  - No covariant result types

Set:
  Set insert(Object o)

BoundedSet:
  Set insert(Object o)

- No problem for polymorphic client code

```
Set union( Set from ) {
  Set to = this;
  forall e ∈ from { to = to.insert( e ); }
  return to;
}
```

- Error-prone for clients of BoundedSet
  - Result types must be invariant in Java

```
BoundedSet bs = …;
bs = ( BoundedSet )
              bs.insert( "Risky" );
```

Solution 3: Descendant Hiding in Eiffel

- Eiffel supports CAT-calls
  - Changed Availability or Type
- Subclasses can
  - Hide methods
  - Have covariant parameter types
- Possible technical solutions
  - Dynamic checks
  - No polymorphic CAT-calls
- Problems
  - Not compliant with classical subtyping theory
  - Solves Rectangle problem, but not BoundedSet problem

```
class Rectangle
            extends Polygon {
  …
 HIDE void addVertex
              ( Vertex v );
}
```

3. Reusable Components

3.1 Units of Reuse

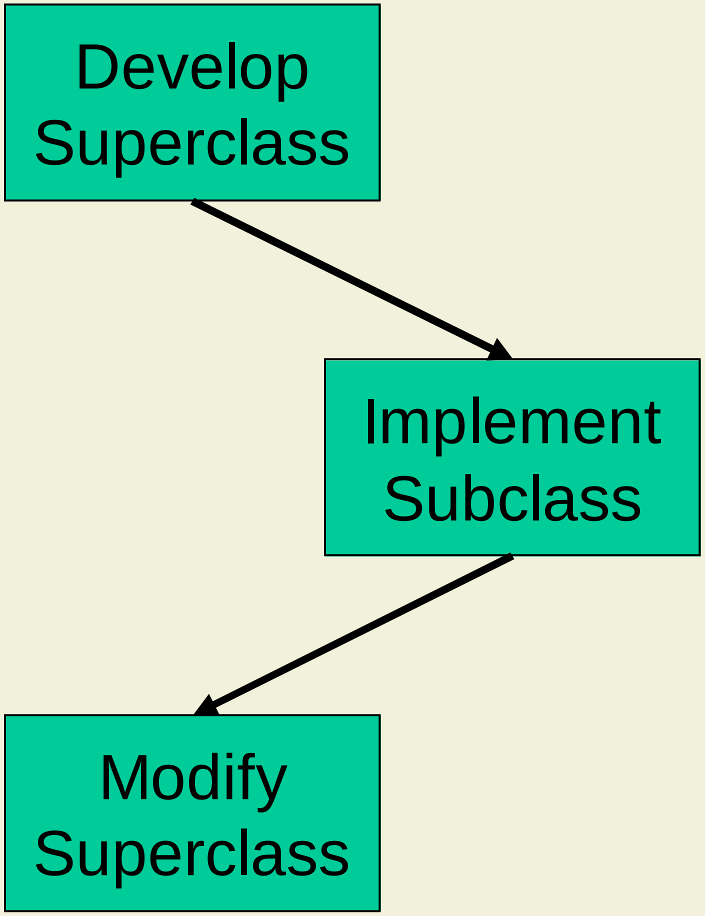
3.2 Forms of Reuse

- Aggregation and Inheritance
- A Deeper Look at Inheritance and Subtyping
- **The Fragile Baseclass Problem**

3.3 Libraries and APIs

Fragile Baseclass Scenario

- Software, including reusable components, is not static
  - Maintenance
  - Bugfixing
  - Reengineering
- Subclasses can be affected by changes to superclasses
- How should we apply inheritance to make our code robust against revisions of superclasses?



Example 1: Selective Overriding

```
class Bag {
  …
  int getSize( ) {
    … // count elements
  }

  void insert( Object o )
    { … }

  void insertAll( Object[ ] arr )    {
    for( int i=0; i < arr.length; i++ )
      insert( arr[ i ] );
  }
}
```

```
class CountingBag extends Bag {
  int size;

  int getSize( )
    { return size; }
  void insert( Object o )
    { super.insert( o ); size++; }
}
```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Example 1: Selective Overriding

```
class Bag {
  …
  int getSize( ) {
    … // count elements
  }

  void insert( Object o )
    { … }

  void insertAll( Object[ ] arr )    {
    for( int i=0; i < arr.length; i++ )
      insert( arr[ i ] );
  }
}
```

```
class CountingBag extends Bag {
  int size;

  int getSize( )
    { return size; }
  void insert( Object o )
    { super.insert( o ); size++; }
}
```

```
Object[ ]  oa = …  // 5 elements
CountingBag cb =
                new CountingBag( );
cb.insertAll( oa );
System.out.println( cb.getSize( ) );
```


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Example 1: Selective Overriding

```
class Bag {
  …
  int getSize( ) {
    … // count elements
  }

  void insert( Object o )
    { … }

  void insertAll( Object[ ] arr )    {
    … // insert elements of arr
        // directly (not using insert)
  }
}
```

```
class CountingBag extends Bag {
  int size;

  int getSize( )
    { return size; }
  void insert( Object o )
    { super.insert( o ); size++; }
}
```

Example 1: Discussion

```
class Bag {
  …
  int getSize( ) {
    … // count elements
  }

  // requires true
  // ensures ∀i. 0 <= i < arr.length:
  //                   isElem( arr[ i ] )
  void insertAll( Object[ ] arr )    {
    for( int i=0; i < arr.length; i++ )
      insert( arr[ i ] );
  }
}
```

```
class CountingBag extends Bag {
  int size;
  // invariant size==super.getSize( )
  …
  void insert( Object o )
    { super.insert( o ); size++; }
}
```


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Example 1: Discussion

```
c
    Using inheritance,
    rely on interface
    documentation, not
    on implementation
 }

 // requires true
 // ensures ∀i. 0 <= i < arr.length:
 //                 isElem( arr[ i ] )
 void insertAll( Object[ ] arr )    {
  for( int i=0; i < arr.length; i++ )
    insert( arr[ i ] );
 }
}
```

```
class CountingBag extends Bag {
 int size;
 // invariant size==super.getSize( )
 …
 void insert( Object o )
  { super.insert( o ); size++; }
}
```

Example 1: Discussion

Using inheritance, rely on interface documentation, not on implementation

```
c
  ...
  }

  // requires true
  // ensures ∀i. 0 <= i < arr.length:
  //             isElem( arr[ i ] )
  void insertAll( Object[ ] arr )    {
    for( int i=0; i < arr.length; i++ )
      insert( arr[ i ] );
  }
}
```

```
class CountingBag extends Bag {
  int size;
  // invariant size==super.getSize( )
  …
  void insert( Object o )
   { super.insert( o ); size++; }

  void insertAll( Object[ ] arr ) {
    for( int i=0; i < arr.length; i++ )
      insert( arr[ i ] );
  }
}
```

Override all methods that could break invariants

Example 2: Unjustified Assumptions

```
class Math {

  float squareRt( float f ) {
    return √ f;
  }

  float fourthRt( float f ) {
   return √√ f;
  }
}
```

```
class MyMath extends Math {

  float squareRt( float f ) {
    return –√f;
  }
}
```

Example 2: Unjustified Assumptions

```
class Math {

  float squareRt( float f ) {
    return √ f;
  }

  float fourthRt( float f ) {
   return  squareRt( squareRt( f ) );
  }
}
```

```
class MyMath extends Math {

  float squareRt( float f ) {
    return –√f;
  }
}
```

```
MyMath m = new MyMath( );
System.out.println
                    ( m.fourthRt( 16 ) );
```

Example 2: Unjustified Assumptions

```
class Math {
  // requires f >= 0
  // ensures result ^ 2 = f
  float squareRt( float f ) {
    return √ f;
  }
  // requires f >= 0
  // ensures result ^ 4 = f
  float fourthRt( float f ) {
   return  squareRt( squareRt( f ) );
  }
}
```

```
class MyMath extends Math {
  // requires f >= 0
  // ensures result ^ 2 = f
  float squareRt( float f ) {
    return –√f;
  }
}
```

```
MyMath m = new MyMath( );
System.out.println
                ( m.fourthRt( 16 ) );
```

Revising or writing a class, rely on interface documentation, not on implementation

Example 3: Mutual Recursion

```
class C {
  int x;

  void inc1( ) {
    x = x + 1;
  }

  void inc2( ) {
    x = x + 1;
  }
}
```

```
class CS extends C {

  void inc2( ) {
    inc1( );
  }
}
```

```
CS cs = new CS( );
cs.x = 5;
cs.inc2( );
System.out.println( cs.x );
```

Example 3: Mutual Recursion

```
class C {
  int x;



  void inc1( ) {
    inc2( );
  }



  void inc2( ) {
    x = x + 1;
  }
}
```

```
class CS extends C {



  void inc2( ) {
    inc1( );
  }
}
```

Example 3: Mutual Recursion

```
class C {
  int x;
  // requires true
  // ensures x = old( x ) + 1
  void inc1( ) {
    inc2( );
  }
  // requires true
  // ensures x = old( x ) + 1
  void inc2( ) {
    x = x + 1;
  }
}
```

```
class CS extends C {
  // requires true
  // ensures x = old( x ) + 1
  void inc2( ) {
    inc1( );
  }
}
```

Example 3: Mutual Recursion

```
class C {
  int x;
  // requires true
  // ensures x = old( x ) + 1
  void inc1( ) {
    inc2( );
  }
  // requires true
  // ensures x = old( x ) + 1
  void inc2( ) {
    x = x + 1;
  }
}
```

```
class CS extends C {
  // requires true
  // ensures x = old( x ) + 1
  void inc2( ) {
    inc1( );
  }
}
```

Be careful when introducing additional invocations on **this.**

Avoid inheriting from classes that are expected to be changed (often)

Example 4: Additional Methods

```
class DiskMgr {




  void cleanUp( ) {
    … // remove temporary files
  }
}
```

```
class MyMgr extends DiskMgr {
  void delete( ) {
    … // erase whole hard disk
  }
}
```

```
MyMgr mm = new MyMgr( );
…
mm.cleanUp( );
```

Example 4: Additional Methods

```
class DiskMgr {

  void delete( ) {
    … // remove temporary files
  }

  void cleanUp( ) {
    delete( );
  }
}
```

```
class MyMgr extends DiskMgr {
  void delete( ) {
    … // erase whole hard disk
  }
}
```

```
MyMgr mm = new MyMgr( );
…
mm.cleanUp( );
```

Example 4: Additional Methods

```
class DiskMgr {

  void delete( ) {
    … // remove temporary files
  }

  void cleanUp( ) {
    delete( );
  }
}
```

```
class MyMgr extends DiskMgr {
  void delete( ) {
    … // erase whole hard disk
  }
```

```
MyMgr mm = new MyMgr( );
…
mm.cleanUp( );
```

Be careful when introducing additional dynamically-bound methods.

Avoid inheriting from classes that are expected to be changed (often)

Rely on common properties of all subclass methods only.

Example 4: Solutions

- Java
  - Private, static, and final methods are bound statically
  - **private** and **static** work
  - **final** leads to runtime error

```
class DiskMgr {
  void delete( ) {
    … // remove temporary files
  }

  void cleanUp( ) {
    delete( );
  }
}
```

```
class MyMgr extends DiskMgr {
  void delete( ) {
    … // erase whole hard disk
  }
}
```

Example 4: Solutions

- Java
  - Private, static, and final methods are bound statically
  - **private** and **static** work
  - **final** leads to runtime error

```
class DiskMgr {
  virtual void delete( ) {
    … // remove temporary files
  }

  void cleanUp( ) {
    delete( );
  }
}
```

```
class MyMgr extends DiskMgr {
  void delete( ) {
    … // erase whole hard disk
  }
}
```

Example 4: Solutions

- Java
  - Private, static, and final methods are bound statically
  - **private** and **static** work
  - **final** leads to runtime error

```
class DiskMgr {
  private void delete( ) {
    … // remove temporary files
  }

  void cleanUp( ) {
    delete( );
  }
}
```

```
class MyMgr extends DiskMgr {
  void delete( ) {
    … // erase whole hard disk
  }
}
```

Example 4: Solutions

- Java
  - Private, static, and final methods are bound statically
  - **private** and **static** work
  - **final** leads to runtime error
- C#
  - Only **virtual** methods are dynamically bound

```
class DiskMgr {
  void delete( ) {
    … // remove temporary files
  }

  void cleanUp( ) {
    delete( );
  }
}
```

```
class MyMgr extends DiskMgr {
  void delete( ) {
    … // erase whole hard disk
  }
}
```

Example 4: Solutions

- Java
  - Private, static, and final methods are bound statically
  - **private** and **static** work
  - **final** leads to runtime error
- C#
  - Only **virtual** methods are dynamically bound
  - Only methods tagged **override** override inherited virtual methods
  - Otherwise (tag **new**) the superclass method is hidden
  - Compiler warning for MyMgr

```
class DiskMgr {
  final void delete( ) {
    … // remove temporary files
  }

  void cleanUp( ) {
    delete( );
  }
}
```

```
class MyMgr extends DiskMgr {
  void delete( ) {
    … // erase whole hard disk
  }
}
```

Summary: Rules for Proper Subclassing

- Use subclassing only if there is an **“is-a” relation**
  - Syntactic and **behavioral** subtypes
- Do not rely on implementation details
  - Use **precise documentation**, **contracts** where possible
- Make sure that overriding **adapts all methods** that should be specialized
- Rely only on **common behavior of all implementations** of a dynamically-bound method
- Do not use subclassing if superclass implementation is expected to change often
- Apply proper version control

3. Reusable Components

3.1 Units of Reuse

3.2 Forms of Reuse

3.3 Libraries and APIs

Libraries and APIs

- Definition of *Library*:
  A collection of components to be used in many different programs
  - Often delivered with software development environments
  - The components in a library may be general purpose or designed for some specific function
- Examples
  - java.util (Set, HashSet, Stack, Iterator, etc.)
  - EiffelBase Support cluster (PRIMES, RANDOM, etc.)
- Special cases of libraries
  - Standard libraries of the programming language
  - Application Program Interfaces (APIs)

Standard Libraries

- Components that are tightly coupled with language
  - Object as root of the subtype hierarchy
  - String as type for string constants
  - Throwable for typing **throws** and **catch** statements
- Standard libraries are part of the language
  - Usually components cannot be implemented in the language (not just a matter of reuse)
  - Syntax and semantics of language cannot be described without standard libraries
- Examples
  - java.lang (Object, Throwable, String, Thread, etc.)
  - EiffelBase Kernel (ARRAY, STRING, REAL, etc.)

Application Program Interfaces (APIs)

- Definition of *API*:
  The interface by which an application program accesses operating system and other services. An API provides a level of abstraction between the application and the kernel (or other privileged utilities).
- Examples
  - java.awt (Component, Window, Event, etc.)
  - .NET Framework Class Library System.IO (File, TextReader, etc.)
  - EiffelBase Dynamic External Shared Call cluster (DLL_32, etc.)