Principles of Software Construction: Objects, Design, and Concurrency

Part 1: Design for reuse

Design patterns for reuse

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Administrivia

- Reading due this week:
  - Required: UML and Patterns Chapters 9 and 10
  - Optional: UML and Patterns Chapter 17
  - Optional: Effective Java items 49, 54, and 69
- Homework 3 due Sunday at 11:59 p.m.
- Midterm exam next week
  - Extended time exam, released sometime Wednesday, due Thursday night
  - Review session Tuesday 7:30 – 9:30 p.m.
  - Practice exam coming soon

Key concepts from last Thursday

Delegation vs. inheritance summary

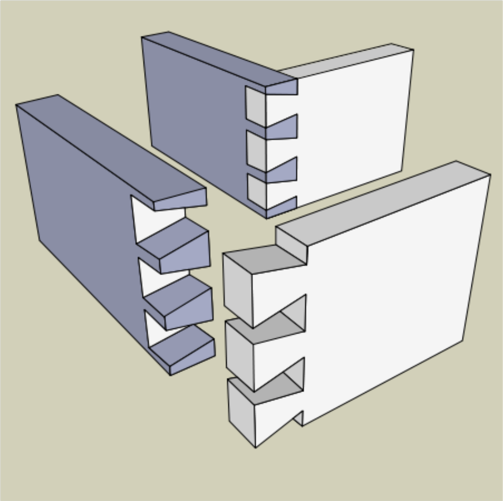
- Inheritance can improve modeling flexibility
- Usually, favor composition/delegation over inheritance
  - Inheritance violates information hiding
  - Delegation supports information hiding
- Design and document for inheritance, or prohibit it
  - Document requirements for overriding any method

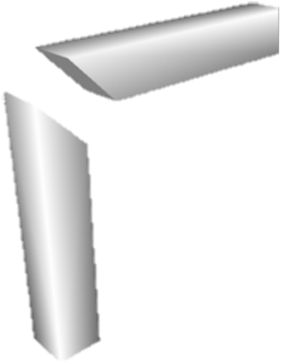
UML you should know

- Interfaces vs. classes
- Fields vs. methods
- Relationships:
  - "extends" (inheritance)
  - "implements" (realization)
  - "has a" (aggregation)
  - non-specific association
- Visibility: + (public) - (private) # (protected)
- Basic best practices…

Design patterns

- Carpentry:
  - "Is a dovetail joint or a miter joint better here?"
- Software Engineering:
  - "Is a strategy pattern or a template method better here?"





Elements of a design pattern

- Name
- Abstract description of problem
- Abstract description of solution
- Analysis of consequences

Strategy pattern

- Problem: Clients need different variants of an algorithm
- Solution: Create an interface for the algorithm, with an implementing class for each variant of the algorithm
- Consequences:
  - Easily extensible for new algorithm implementations
  - Separates algorithm from client context
  - Introduces an extra interface and many classes:
    - Code can be harder to understand
    - Lots of overhead if the strategies are simple

Different patterns can have the same structure

Command pattern:

- Problem: Clients need to execute some (possibly flexible) operation without knowing the details of the operation
- Solution: Create an interface for the operation, with a class (or classes) that actually executes the operation
- Consequences:
  - Separates operation from client context
  - Can specify, queue, and execute commands at different times
  - Introduces an extra interface and classes:
    - Code can be harder to understand
    - Lots of overhead if the commands are simple

Today

- More design patterns for reuse
  - Template method pattern
  - Iterator pattern
  - Decorator pattern
- Design goals and design principles (probably next week)

One design scenario

- A GUI-based document editor works with multiple document formats. Some parts of the algorithm to load a document (e.g., reading a file, rendering to the screen) are the same for all document formats, and other parts of the algorithm vary from format-to-format (e.g. parsing the file input).

Another design scenario

- Several versions of a domain-specific machine learning algorithm are being implemented to use data stored in several different database systems. The basic algorithm for all versions is the same; just the interactions with the database are different from version to version.

The abstract `java.util.AbstractList<E>`

```
abstract T   get(int i);
abstract int size();
boolean      set(int i, E e);         // pseudo-abstract
boolean      add(E e);                // pseudo-abstract
boolean      remove(E e);             // pseudo-abstract
boolean      addAll(Collection<? extends E> c);
boolean      removeAll(Collection<?> c);
boolean      retainAll(Collection<?> c);
boolean      contains(E e);
boolean      containsAll(Collection<?> c);
void         clear();
boolean      isEmpty();
abstract Iterator<E>  iterator();
Object[]     toArray()
<T> T[]      toArray(T[] a);
…
```

Template method pattern

- Problem: An algorithm consists of customizable parts and invariant parts
- Solution: Implement the invariant parts of the algorithm in an abstract class, with abstract (unimplemented) primitive operations representing the customizable parts of the algorithm. Subclasses customize the primitive operations
- Consequences
  - Code reuse for the invariant parts of algorithm
  - Customization is restricted to the primitive operations
  - Inverted (Hollywood-style) control for customization

Template method vs. the strategy pattern

- Template method uses inheritance to vary part of an algorithm
  - Template method implemented in supertype, primitive operations implemented in subtypes
- Strategy pattern uses delegation to vary the entire algorithm
  - Strategy objects are reusable across multiple classes
  - Multiple strategy objects are possible per class

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Traversing a collection

- Since Java 1.0:

```
Vector arguments = …;
for (int i = 0; i < arguments.size(); ++i) {
  System.out.println(arguments.get(i));
}
```

- Java 1.5: enhanced for loop

```
List<String> arguments = …;
for (String s : arguments) {
  System.out.println(s);
}
```

- For-each loop works for every implementation of `Iterable`

```
public interface Iterable<E> {
  public Iterator<E> iterator();
}
```

The Iterator interface

```
public interface java.util.Iterator<E> {
  boolean hasNext();
  E next();
  void remove();  // removes previous returned item
}                 // from the underlying collection
```

- If you need to use an iterator explicitly:

```
List<String> arguments = …;
for (Iterator<String> it = arguments.iterator();
     it.hasNext();  ) {
  String s = it.next();
  System.out.println(s);
}
```

Getting an Iterator

```
public interface Collection<E> extends Iterable<E> {
  boolean     add(E e);
  boolean     addAll(Collection<? extends E> c);
  boolean     remove(Object e);
  boolean     removeAll(Collection<?> c);
  boolean     retainAll(Collection<?> c);
  boolean     contains(Object e);
  boolean     containsAll(Collection<?> c);
  void        clear();
  int         size();
  boolean     isEmpty();
  Iterator<E> iterator();
  Object[]    toArray()
  <T> T[]     toArray(T[] a);
  …
}
```

Defines an interface for creating an Iterator, but allows Collection implementation to decide which Iterator to create.

An Iterator implementation for Pairs

```
public class Pair<E> {
  private final E first, second;
  public Pair(E f, E s) { first = f; second = s; }









}
```

```
Pair<String> pair = new Pair<String>("foo", "bar");
for (String s : pair) { … }
```

An Iterator implementation for Pairs

```
public class Pair<E> implements Iterable<E> {
  private final E first, second;
  public Pair(E f, E s) { first = f; second = s; }
  public Iterator<E> iterator() {
    return new PairIterator();
  }
  private class PairIterator implements Iterator<E> {
    private boolean seenFirst = false, seenSecond = false;
    public  boolean hasNext() { return !seenSecond; }
    public  E next() {
      if (!seenFirst)  { seenFirst  = true; return first;  }
      if (!seenSecond) { seenSecond = true; return second; }
      throw new NoSuchElementException();
    }
    public void remove() {
      throw new UnsupportedOperationException();
    }
  }
}
```

```
Pair<String> pair = new Pair<String>("foo", "bar");
for (String s : pair) { … }
```

Iterator design pattern

- Problem: Clients need uniform strategy to access all elements in a container, independent of the container type
  - Order is unspecified, but access every element once
- Solution: A strategy pattern for iteration
- Consequences:
  - Hides internal implementation of underlying container
  - Easy to change container type
  - Facilitates communication between parts of the program

Using a `java.util.Iterator<E>`: A warning

- The default Collections implementations are mutable…
- …but their `Iterator` implementations assume the collection does not change while the `Iterator` is being used
  - You will get a `ConcurrentModificationException`

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- …but their `Iterator` implementations assume the collection does not change while the `Iterator` is being used
  - You will get a `ConcurrentModificationException`
  - If you simply want to remove an item:

```
List<String> arguments = …;
for (Iterator<String> it = arguments.iterator();
     it.hasNext();  ) {
  String s = it.next();
  if (s.equals("Charlie"))
    arguments.remove("Charlie"); // runtime error
}
```

Using a `java.util.Iterator<E>`: A warning

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- …but their `Iterator` implementations assume the collection does not change while the `Iterator` is being used
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```
 List<String> arguments = …;
for (Iterator<String> it = arguments.iterator();
     it.hasNext();  ) {
  String s = it.next();
  if (s.equals("Charlie"))
    it.remove();
}
```

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Limitations of inheritance

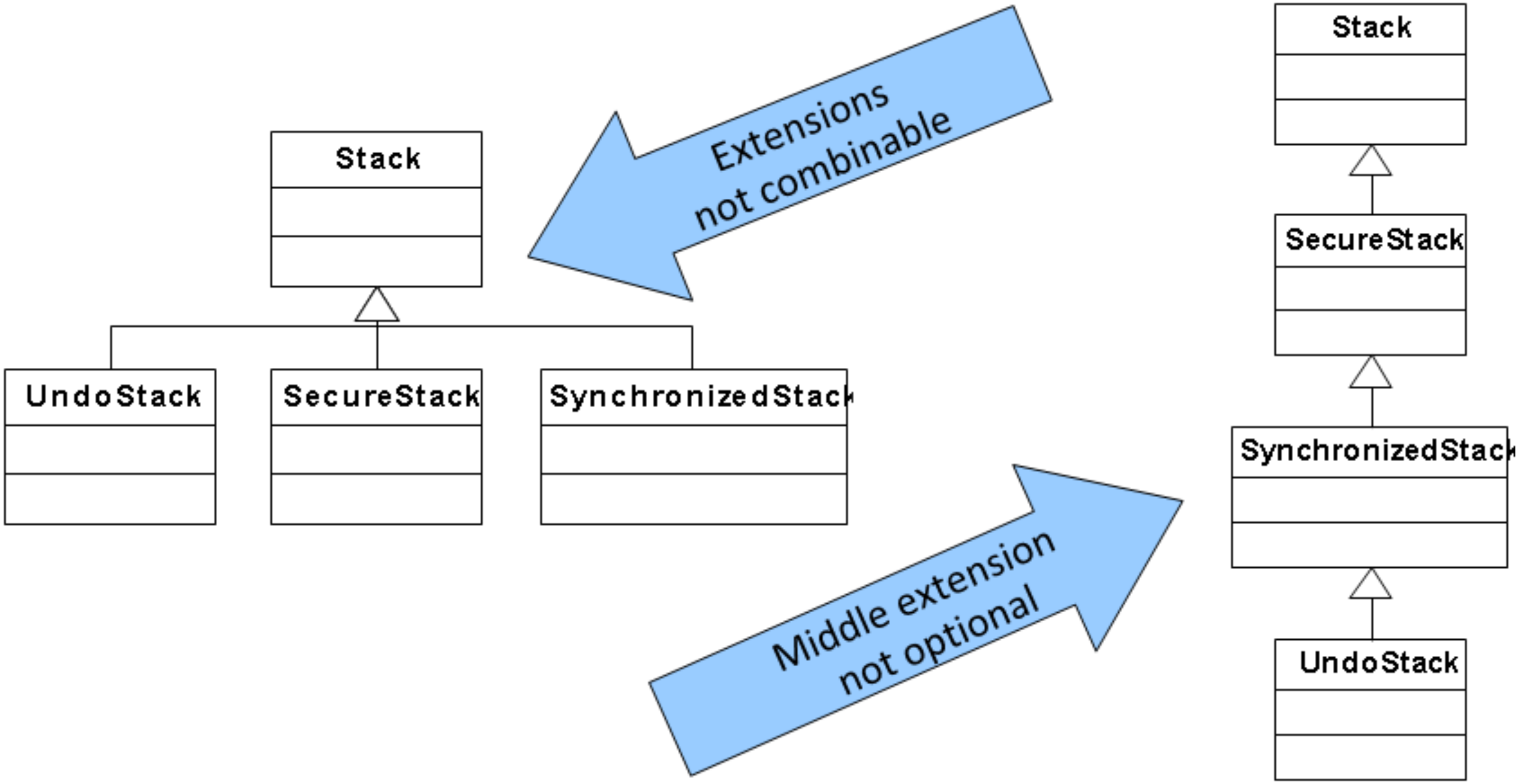
- Suppose you want various extensions of a `Stack` data structure…
  - `UndoStack`: A stack that lets you undo previous push or pop operations
  - `SecureStack`: A stack that requires a password
  - `SynchronizedStack`: A stack that serializes concurrent accesses

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`: A stack that requires a password
  - `SynchronizedStack`: A stack that serializes concurrent accesses
  - `SecureUndoStack`: A stack that requires a password, and also lets you undo previous operations
  - `SynchronizedUndoStack`: A stack that serializes concurrent accesses, and also lets you undo previous operations
  - `SecureSynchronizedStack`: …
  - `SecureSynchronizedUndoStack`: …

Goal: arbitrarily composable extensions

Limitations of inheritance



Workarounds?

- Multiple inheritance?
- Combining inheritance hierarchies?

The decorator design pattern

- Problem: You need arbitrary or dynamically composable extensions to individual objects.
- Solution: Implement a common interface as the object you are extending, add functionality, but delegate primary responsibility to an underlying object.
- Consequences:
  - More flexible than static inheritance
  - Customizable, cohesive extensions
  - Breaks object identity, self-references

Decorators use both subtyping and delegation

```
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);
  }
  …
```

An `AbstractStackDecorator` forwarding class

```
public abstract class AbstractStackDecorator
           implements Stack {
  private final Stack stack;
  public AbstractStackDecorator(Stack stack) {
      this.stack = stack;
  }
  public void push(Item e) {
      stack.push(e);
  }
  public Item pop() {
      return stack.pop();
  }
  …
}
```

Concrete decorator classes

```
public class UndoStack extends AbstractStackDecorator
      implements Stack {
  private final UndoLog log = new UndoLog();
  public UndoStack(Stack stack) { super(stack); }
  public void push(Item e) {
      log.append(UndoLog.PUSH, e);
      super.push(e);
  }
  …
}
```

Using the decorator classes

- To construct a plain stack:

```
Stack stack = new ArrayStack();
```

- To construct an undo stack:

Using the decorator classes

- To construct a plain stack:

```
Stack stack = new ArrayStack();
```

- To construct an undo stack:

```
UndoStack stack = new UndoStack(new ArrayStack());
```

Using the decorator classes

- To construct a plain stack:

```
Stack stack = new ArrayStack();
```

- To construct an undo stack:

```
UndoStack stack = new UndoStack(new ArrayStack());
```

- To construct a secure synchronized undo stack:

Using the decorator classes

- To construct a plain stack:

```
Stack s = new ArrayStack();
```

- To construct an undo stack:

```
UndoStack s = new UndoStack(new ArrayStack());
```

- To construct a secure synchronized undo stack:

```
SecureStack s = new SecureStack(new SynchronizedStack(
                       new UndoStack(new ArrayStack())));
```

Decorators from `java.util.Collections`

- Turn a mutable collection into an immutable collection:

```
static List<T>   unmodifiableList(List<T>   lst);
static Set<T>    unmodifiableSet( Set<T>    set);
static Map<K,V> unmodifiableMap( Map<K,V> map);
```

- 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 UnsupportedOperationExceptio
       public boolean remove(Object o) { throw new UnsupportedOperatio
       public boolean containsAll(Collection<?> coll) {  return c.conta
       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

- Decorator composes features at run time
  - Inheritance composes features at compile time
- Decorator consists of multiple collaborating objects
  - Inheritance produces a single, clearly-typed object
- Can mix and match multiple decorations
  - Multiple inheritance is conceptually difficult

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Metrics of software quality, i.e., *design goals*

Functional correctness	Adherence of implementation to the specifications
Robustness	Ability to handle anomalous events
Flexibility	Ability to accommodate changes in specifications
Reusability	Ability to be reused in another application
Efficiency	Satisfaction of speed and storage requirements
Scalability	Ability to serve as the basis of a larger version of the application
Security	Level of consideration of application security

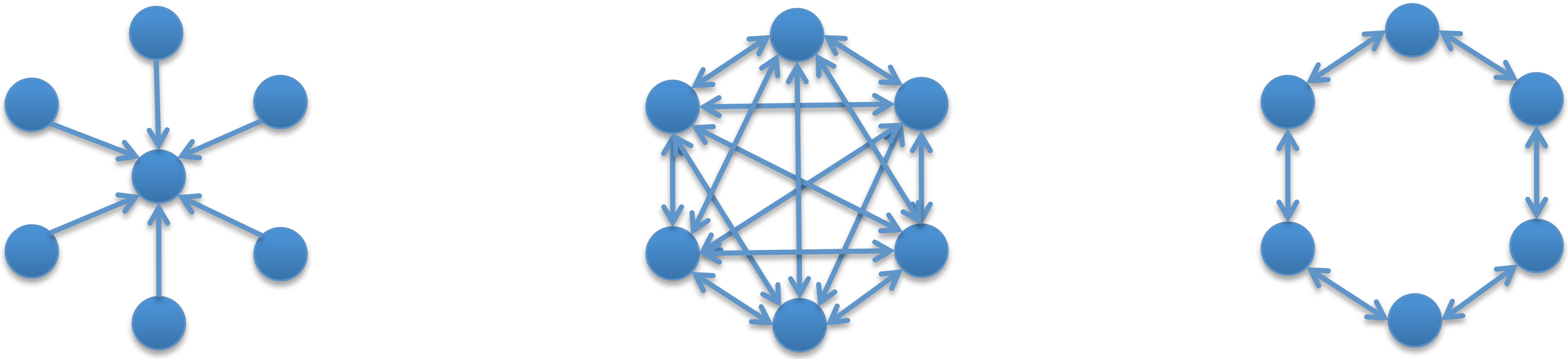
Source: Braude, Bernstein, Software Engineering. Wiley 2011

Design principles: heuristics to achieve design goals

- Low coupling
- Low representational gap
- High cohesion

A design principle for reuse: *low coupling*

- Each component should depend on as few other components as possible



- Benefits of low coupling:
  - Enhances understandability
  - Reduces cost of change
  - Eases reuse

Law of Demeter

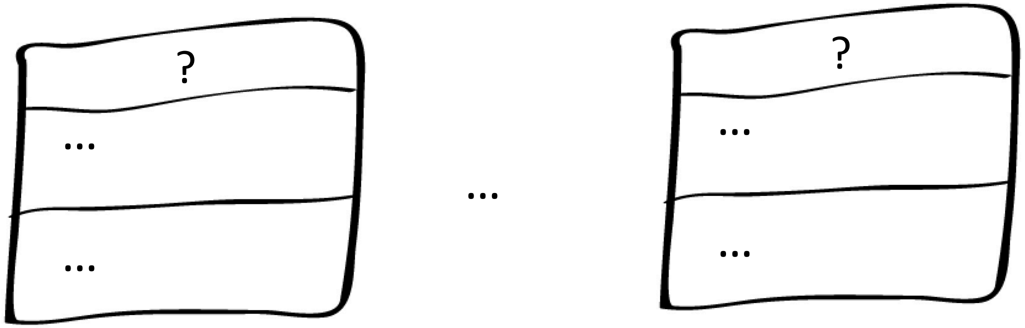
- "Only talk to your immediate friends"

~~foo.bar().baz().quz(42)~~

Representational gap

- Real-world concepts:

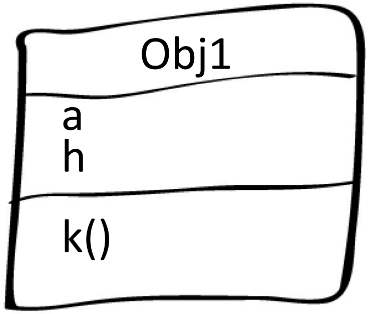
- Software concepts:



Representational gap

- Real-world concepts:

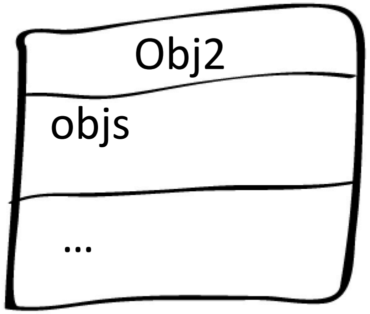
- Software concepts:



Obj1

a
h

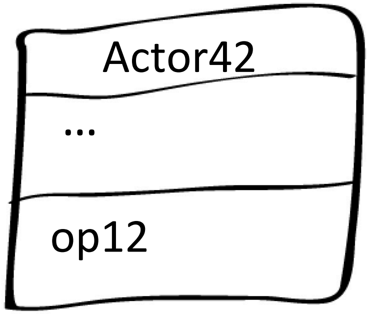
k()



Obj2

objs

…



Actor42

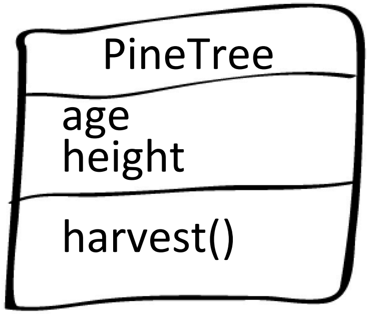
…

op12

Representational gap

- Real-world concepts:

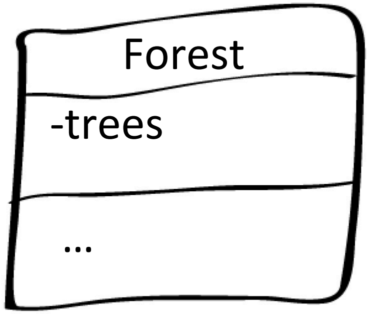
- Software concepts:



PineTree

age
height

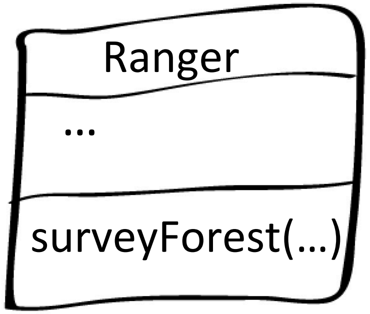
harvest()



Forest

-trees

…



Ranger

…

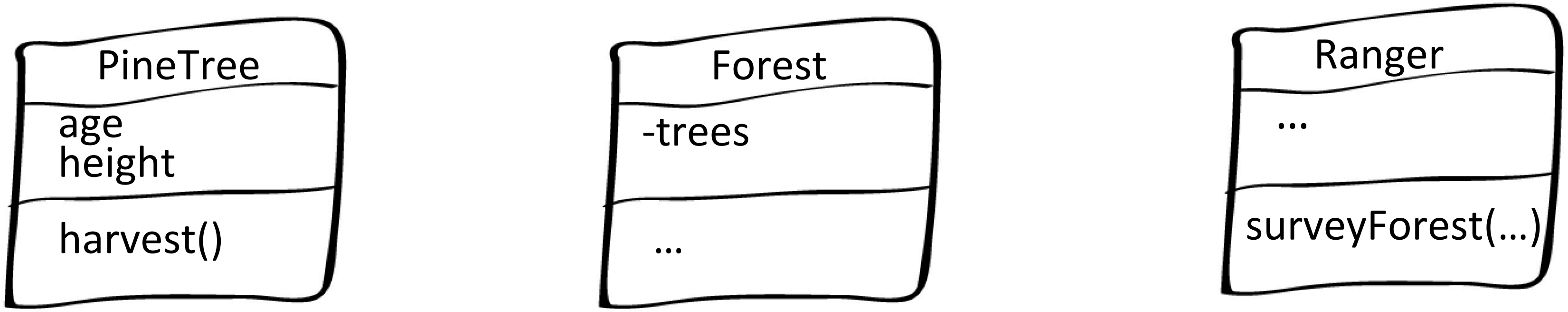
surveyForest(…)

Benefits of low representational gap

- Facilitates understanding of design and implementation
- Facilitates traceability from problem to solution
- Facilitates evolution

A related design principle: high cohesion

- Each component should have a small set of closely-related responsibilities
- Benefits:
  - Facilitates understandability
  - Facilitates reuse
  - Eases maintenance



PineTree
age
height
harvest()

Forest
-trees
…

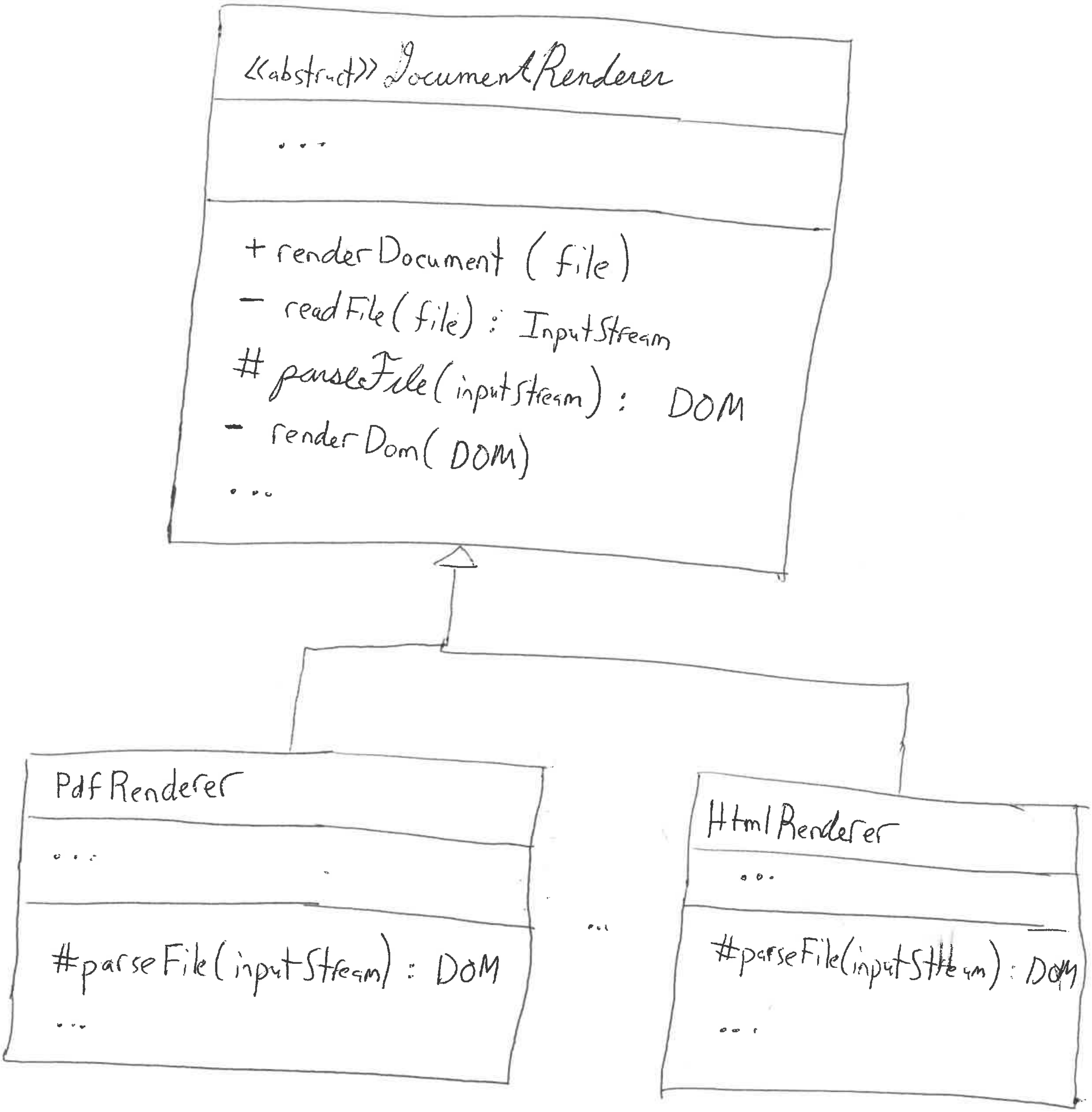
Ranger
…
surveyForest(…)

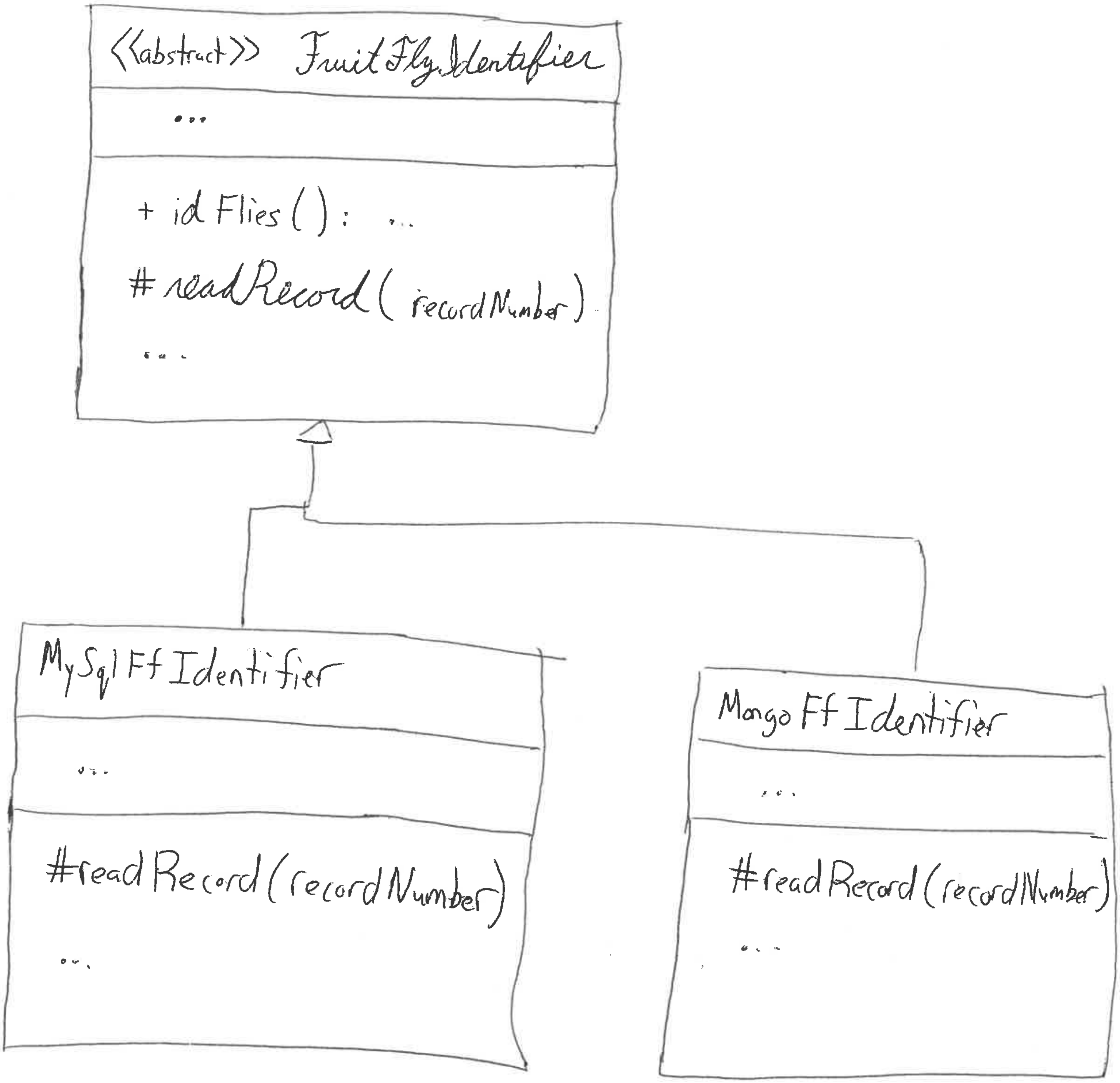
Coupling vs. cohesion

- All code in one component?
  - Low cohesion, low coupling
- Every statement / method in a separate component?
  - High cohesion, high coupling

Summary

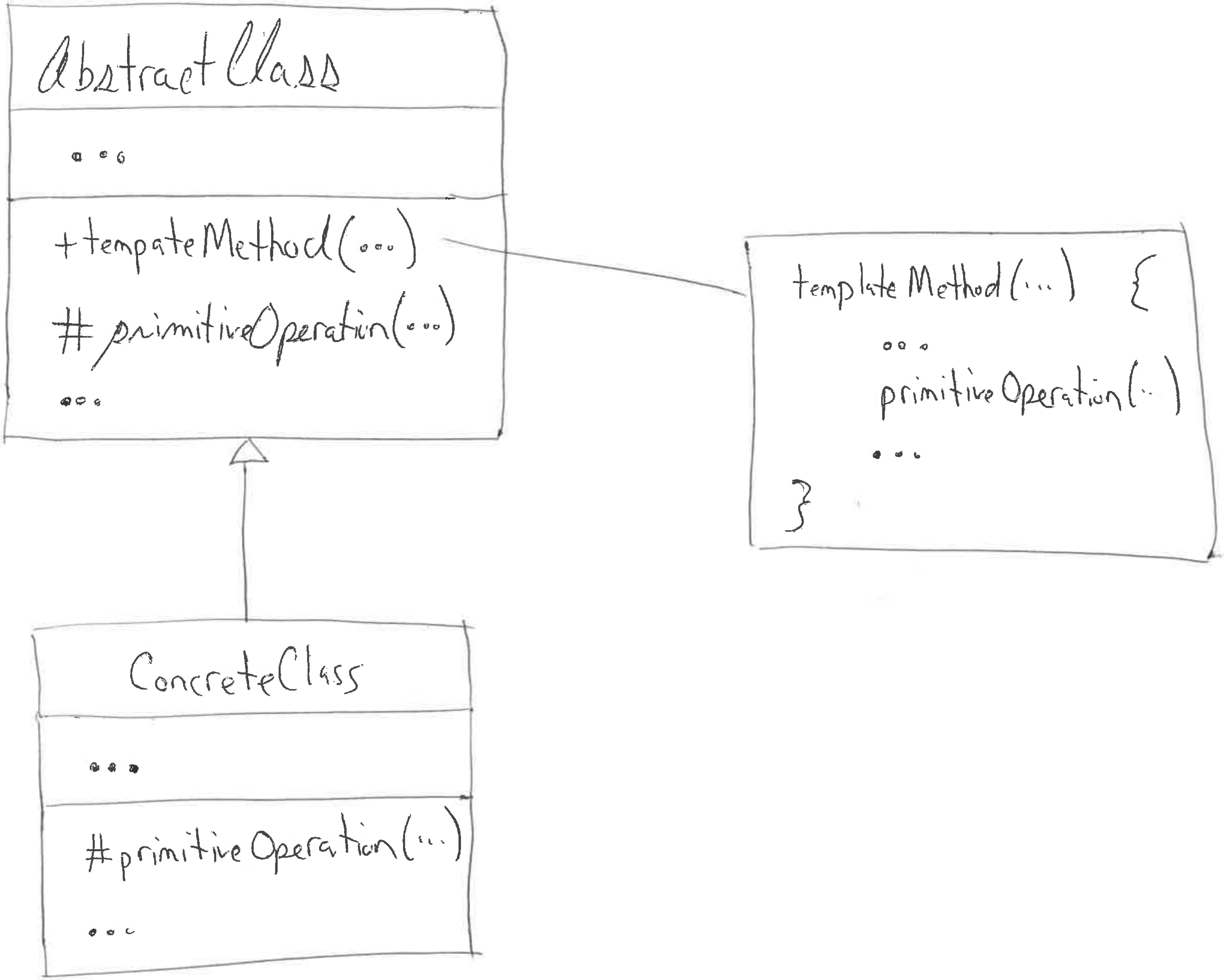
- Five design patterns to facilitate reuse…
- Design principles are useful heuristics
  - Reduce coupling to increase understandability, reuse
  - Lower representational gap to increase understandability, maintainability
  - Increase cohesion to increase understandability


«abstract» DocumentRenderer
...
+ renderDocument (file)
- readFile(file) : InputStream
# parseFile(inputStream) : DOM
- renderDom(DOM)
...
PdfRenderer
...
#parseFile(inputStream) : DOM
...
...
HtmlRenderer
...
#parseFile(inputStream) : DOM
...

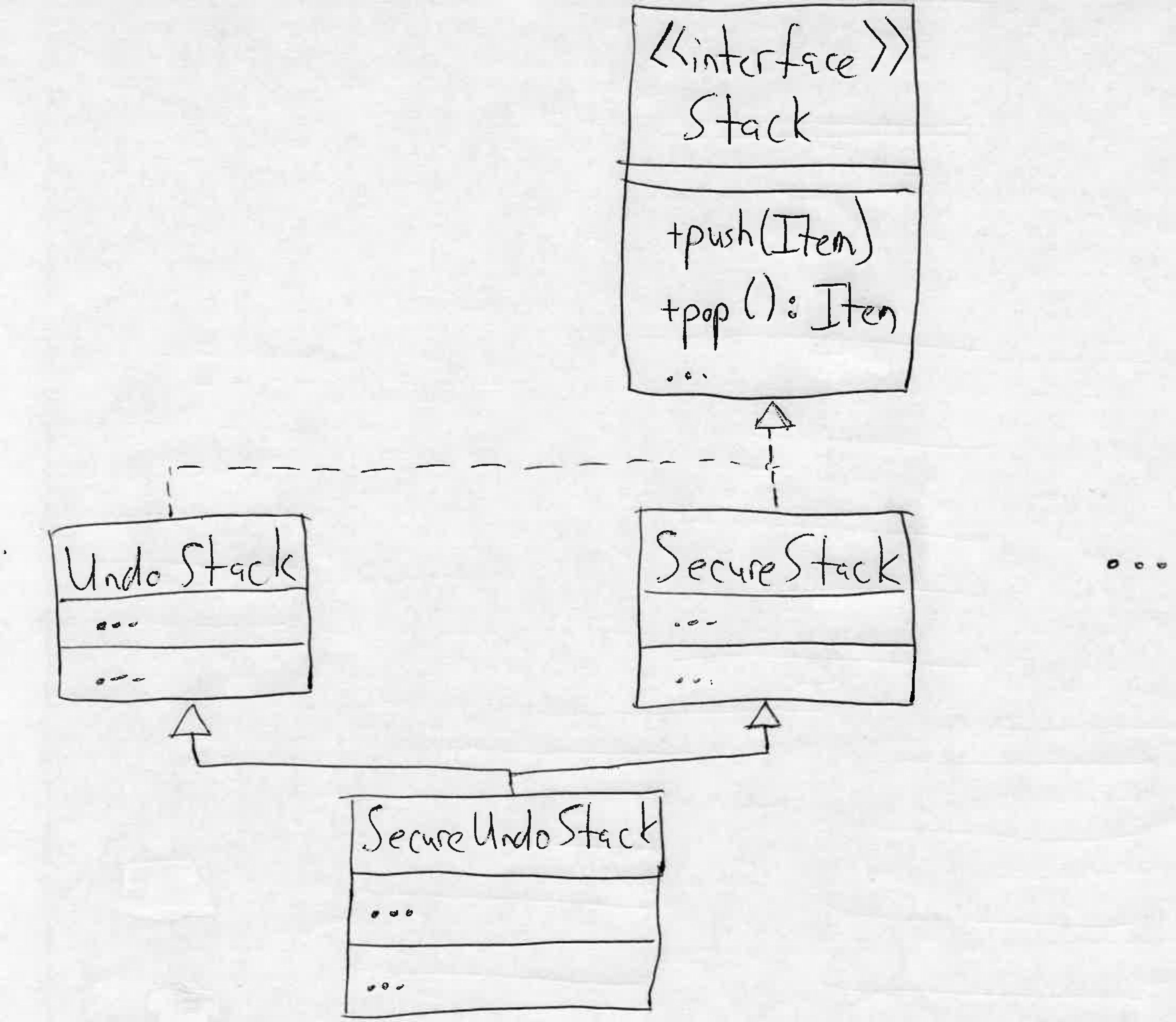


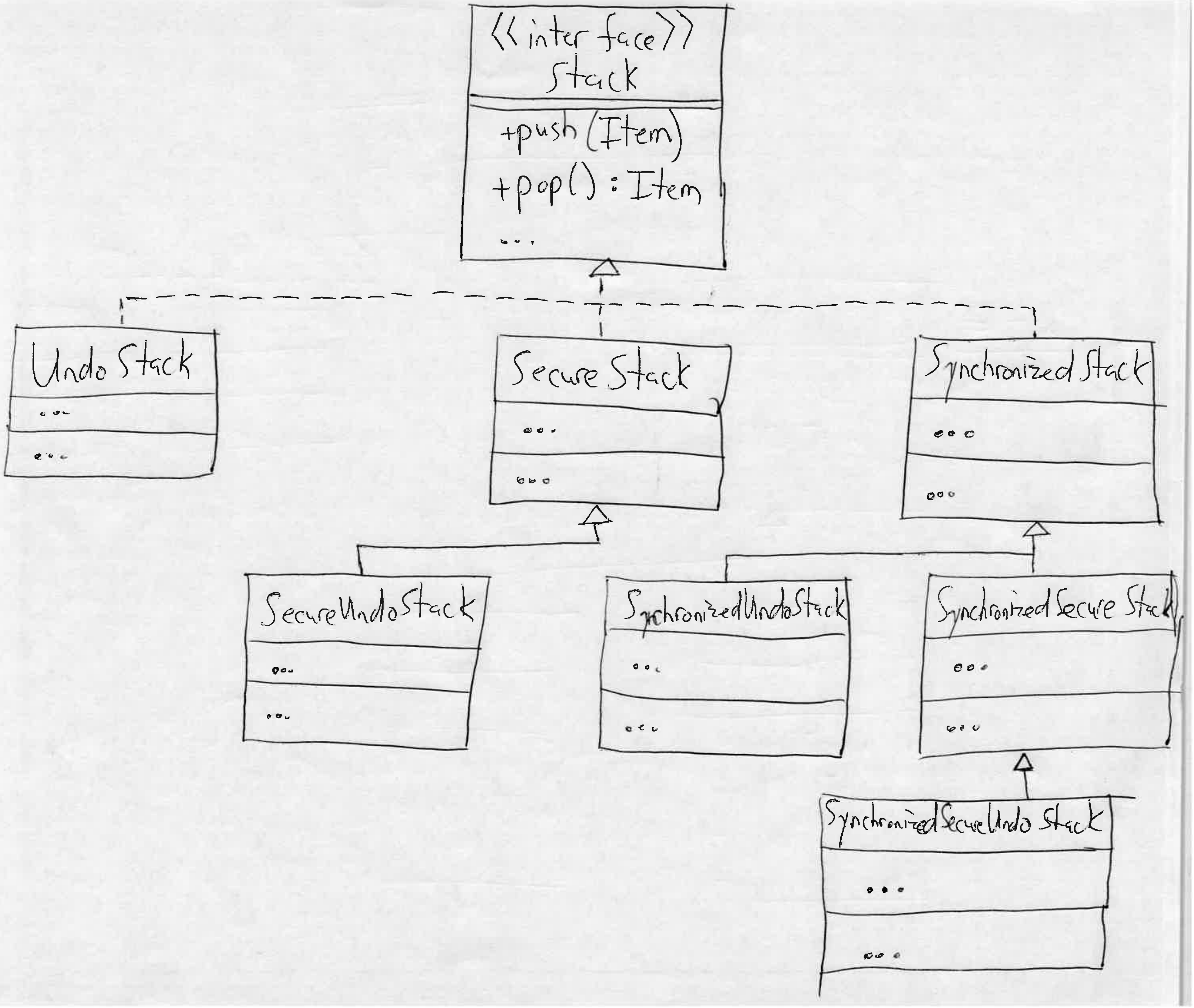
<<abstract>> FruitFlyIdentifier
...
+ idFlies( ): ...
#readRecord(recordNumber)
...
MySqlFfIdentifier
...
#readRecord(recordNumber)
...
MongoFfIdentifier
...
#readRecord(recordNumber)
...

```
public boolean addAll(Collection<? extends E> c) {
    boolean modified = false;
    for(E e : c) {
        if(add(e)) {
            modified = true;
        }
    }
    return modified;
}
```



```
templateMethod(...)   {
      ...
      primitiveOperation(..)
      ...
}
```


<<interface>>
Stack
+push(Item)
+pop(): Item
...
UndoStack
...
...
SecureStack
...
...
...
SecureUndoStack
...
...



<<interface>>
Stack
+push(Item)
+pop() : Item
...
UndoStack
...
...
SecureStack
...
...
SynchronizedStack
...
...
SecureUndoStack
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SynchronizedUndoStack
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SynchronizedSecureStack
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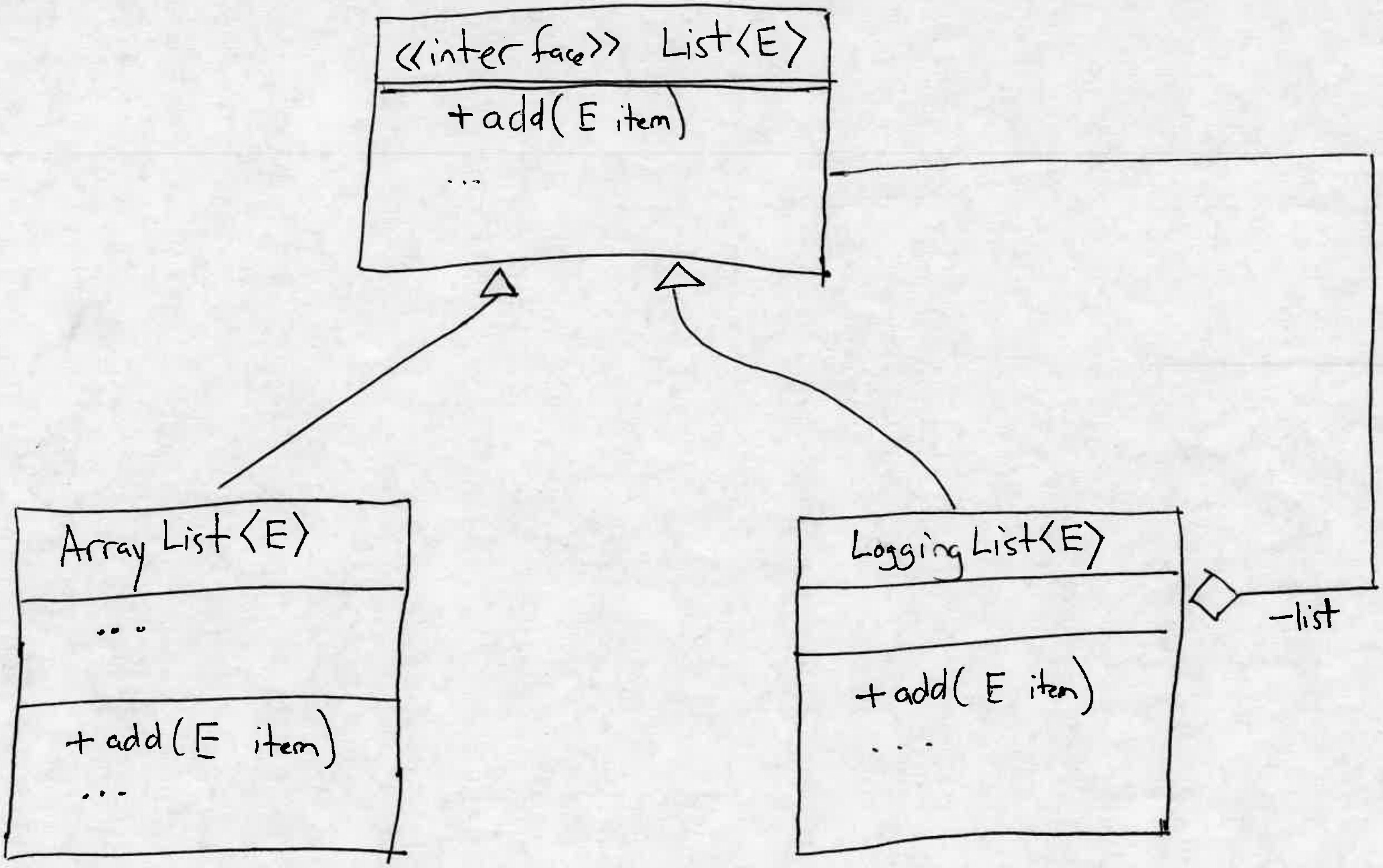
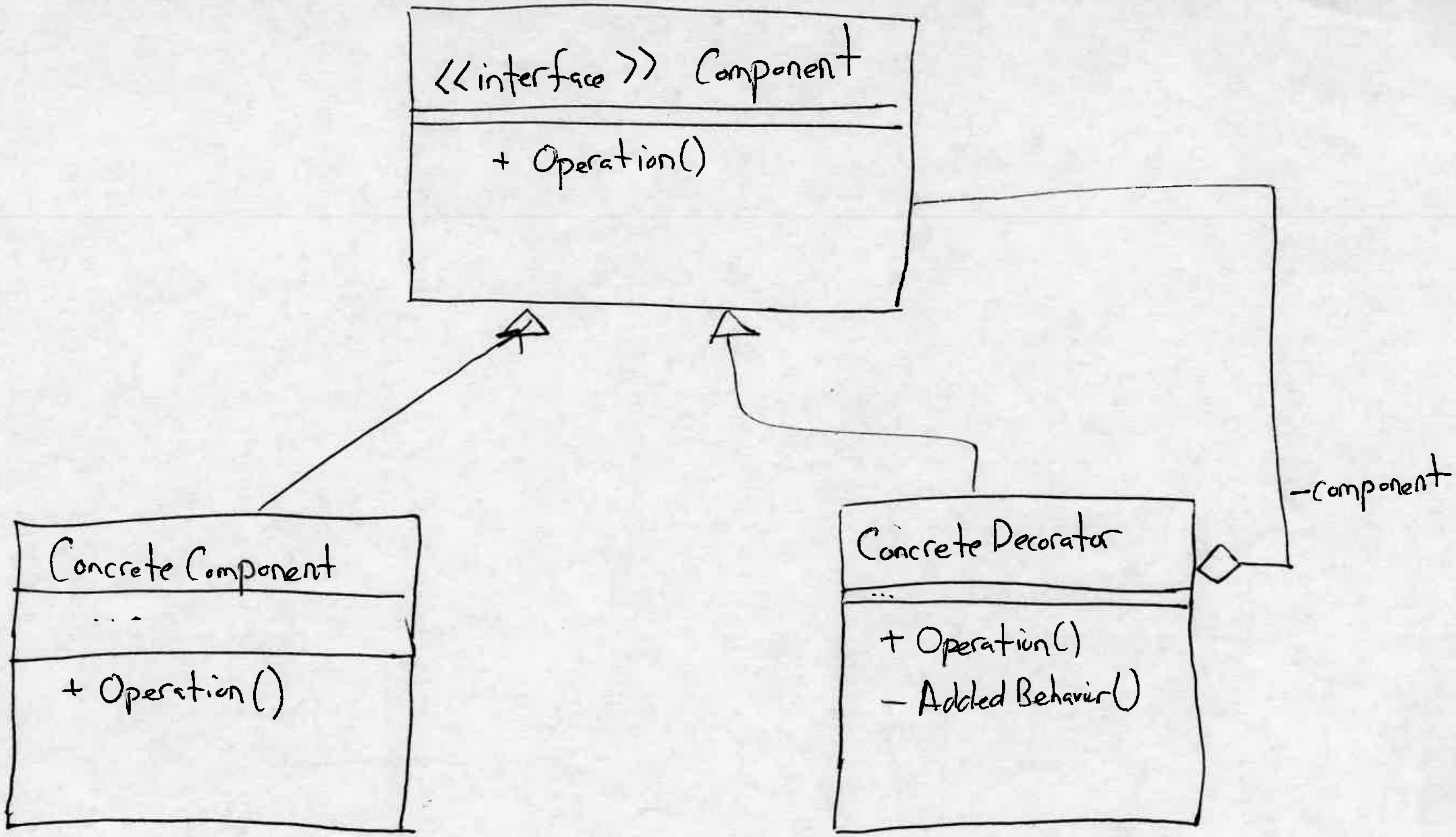
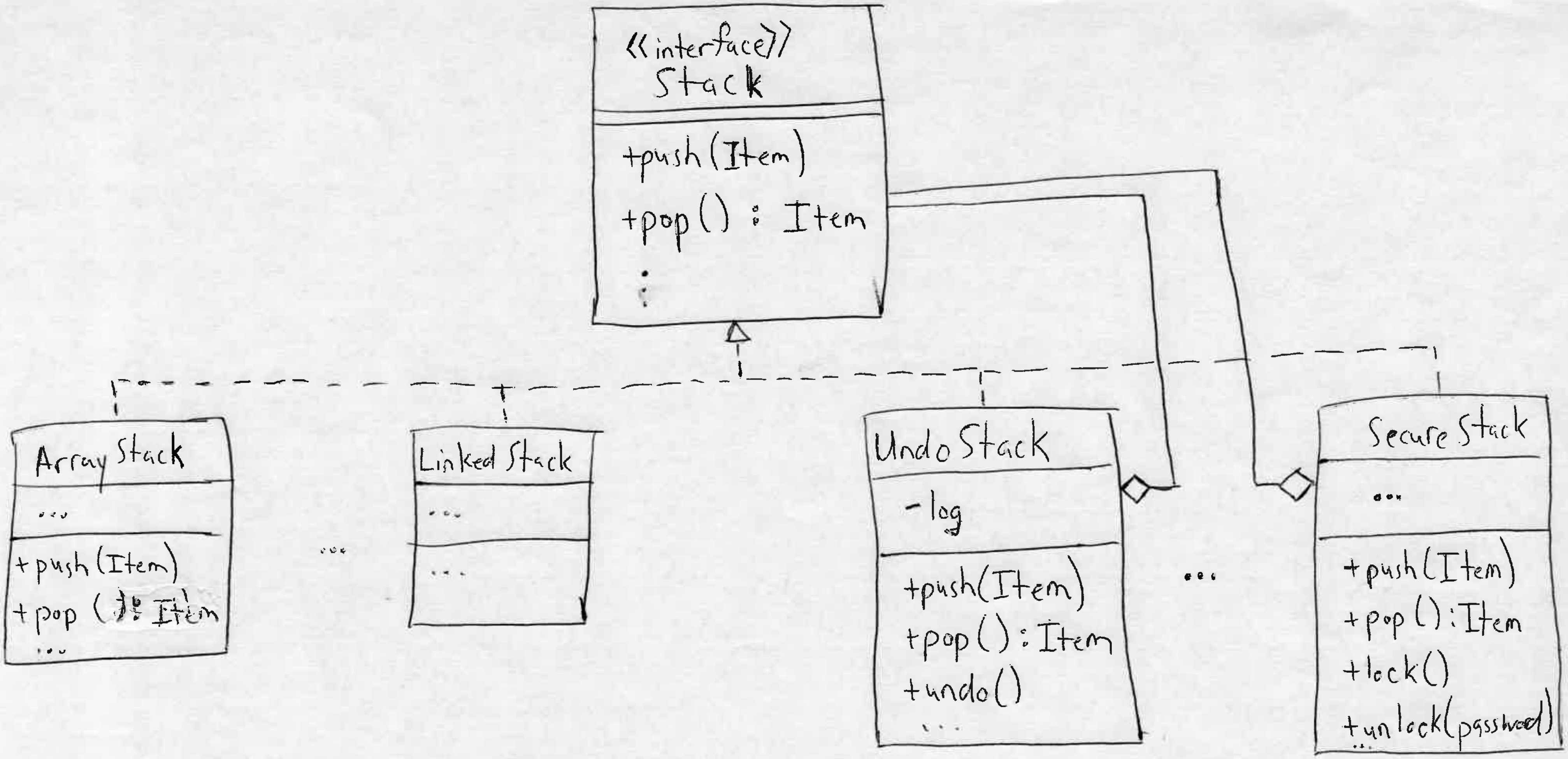
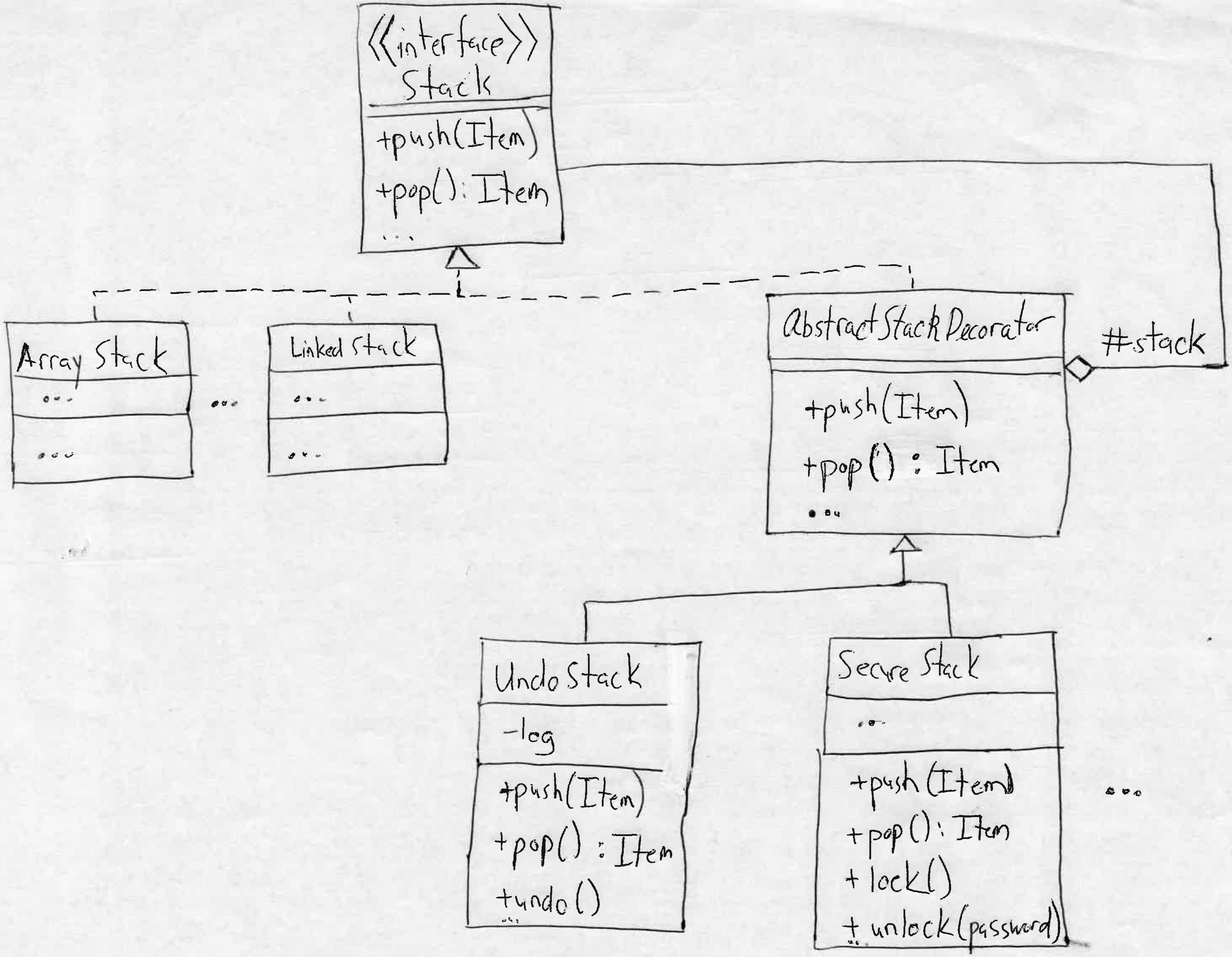
...
SynchronizedSecureUndoStack
...
...

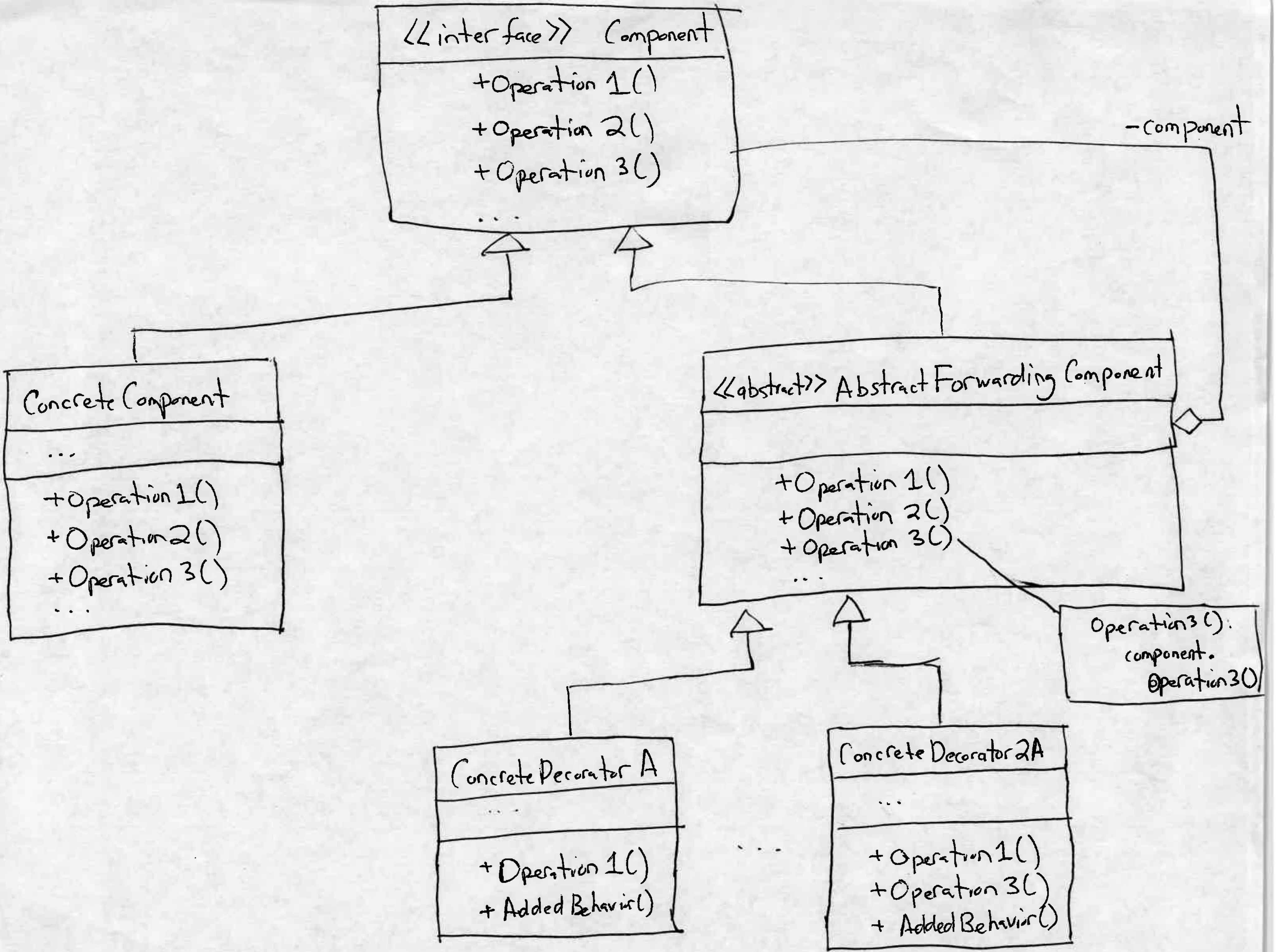


<<interface>> List<E>
+add(E item)
...
ArrayList<E>
...
+add(E item)
...
LoggingList<E>
+add(E item)
...
-list


<<interface>> Component
+ Operation()
Concrete Component
...
+ Operation()
Concrete Decorator
...
+ Operation()
– Added Behavior()
–component


«interface»
Stack
+push(Item)
+pop() : Item
⋮
ArrayStack
...
+push(Item)
+pop (): Item
...
...
LinkedStack
...
...
UndoStack
-log
+push(Item)
+pop(): Item
+undo()
...
...
SecureStack
...
+push(Item)
+pop():Item
+lock()
+unlock(password)
...


«interface»
Stack
+push(Item)
+pop(): Item
...
ArrayStack
...
...
...
LinkedStack
...
...
AbstractStackDecorator
+push(Item)
+pop() : Item
...
#stack
UndoStack
-log
+push(Item)
+pop() : Item
+undo()
...
SecureStack
...
+push(Item)
+pop(): Item
+lock()
+unlock(password)
...
...



<<interface>> Component
+Operation 1()
+Operation 2()
+Operation 3()
...
-component
Concrete Component
...
+Operation1()
+Operation2()
+Operation 3()
...
<<abstract>> Abstract Forwarding Component
+Operation 1()
+Operation 2()
+Operation 3()
...
Operation3():
component.
Operation3()
Concrete Decorator A
...
+Operation 1()
+ Added Behavior()
...
Concrete Decorator 2A
...
+Operation 1()
+Operation 3()
+ Added Behavior()