Principles of Software Construction: Objects, Design, and Concurrency

Designing classes

Introduction to design patterns

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Administrivia

- Homework 2 due tonight
- Reading due next Tuesday
  - Effective Java: #21, 38, 39, 40, 41, 44
- Homework 3 due Sunday, September 25th

```
  SEND
+ MORE
-------
 MONEY
```

- Human cryptarithm solving by Josh
  - Monday, September 19th 6:30 p.m. (location TBD)

1. “Time for a Change” (2002)

If you pay $2.00 for a gasket that costs $1.10, how much change do you get?

```
public class Change {
    public static void main(String args[]) {
        System.out.println(2.00 - 1.10);
    }
}
```

What does it print?

(a) `0.9`
(b) `0.90`
(c) It varies
(d) None of the above

```
public class Change {
    public static void main(String args[]) {
        System.out.println(2.00 - 1.10);
    }
}
```

What does it print?

(a) `0.9`

(b) `0.90`

(c) It varies

(d) None of the above: `0.8999999999999999`

Decimal values can't be represented exactly by `float` or `double`

Another look

```
public class Change {
    public static void main(String args[]) {
        System.out.println(2.00 - 1.10);
    }
}
```

How do you fix it?

```
// You could fix it this way...
import java.math.BigDecimal;
public class Change {
    public static void main(String args[]) {
        System.out.println(
            new BigDecimal("2.00").subtract(
                new BigDecimal("1.10")));
    }
}
```

Prints 0.90

```
// ...or you could fix it this way
public class Change {
    public static void main(String args[]) {
        System.out.println(200 - 110);
    }
}
```

Prints 90

The moral

- Avoid `float` and `double` where exact answers are required
  - For example, when dealing with money
- Use `BigDecimal`, `int`, or `long` instead

2. “A Change is Gonna Come”

If you pay $2.00 for a gasket that costs $1.10, how much change do you get?

```
import java.math.BigDecimal;

public class Change {
    public static void main(String args[]) {
        BigDecimal payment = new BigDecimal(2.00);
        BigDecimal cost = new BigDecimal(1.10);
        System.out.println(payment.subtract(cost));
    }
}
```

What does it print?

(a) `0.9`
(b) `0.90`
(c) `0.8999999999999999`
(d) None of the above

```
import java.math.BigDecimal;

public class Change {
    public static void main(String args[]) {
        BigDecimal payment = new BigDecimal(2.00);
        BigDecimal cost = new BigDecimal(1.10);
        System.out.println(payment.subtract(cost));
    }
}
```

What does it print?

(a) `0.9`

(b) `0.90`

(c) `0.8999999999999999`

(d) None of the above:

`0.899999999999999911821580299874767661094665527343 75`

We used the wrong `BigDecimal` constructor

Another look

The spec says:

```
public BigDecimal(double val)
```

Translates a double into a BigDecimal which is the exact decimal representation of the double's binary floating-point value.

```
import java.math.BigDecimal;

public class Change {
    public static void main(String args[]) {
        BigDecimal payment = new BigDecimal(2.00);
        BigDecimal cost = new BigDecimal(1.10);
        System.out.println(payment.subtract(cost));
    }
}
```

How do you fix it?

```
import java.math.BigDecimal;

public class Change {
    public static void main(String args[]) {
        BigDecimal payment = new BigDecimal("2.00");
        BigDecimal cost = new BigDecimal("1.10");
        System.out.println(payment.subtract(cost));
    }
}
```

Prints `0.90`

The moral

- Use `new BigDecimal(String)`, not `new BigDecimal(double)`
- `BigDecimal.valueOf(double)` is better, but not perfect
  - Use it for non-constant values.
- For API designers
  - Make it easy to do the commonly correct thing
  - Make it possible to do exotic things

Key concepts from Tuesday…

Using delegation to extend functionality

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

- One solution:

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

Implementation inheritance for code reuse

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

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

Design with inheritance (or not)

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

Behavioral subtyping

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

- e.g., Compiler-enforced rules in Java:
  - Subtypes can add, but not remove methods
  - Concrete class must implement all undefined methods
  - Overriding method must return same type or subtype
  - Overriding method must accept the same parameter types
  - Overriding method may not throw additional exceptions
- Also applies to specified behavior:
  - Same or stronger invariants
  - Same or stronger postconditions for all methods
  - Same or weaker preconditions for all methods

This is called the *Liskov Substitution Principle*.

Behavioral subtyping (Liskov Substitution Principle)

```
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);
    }
}
```

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;
    }

    //@ 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);
    }
}
```

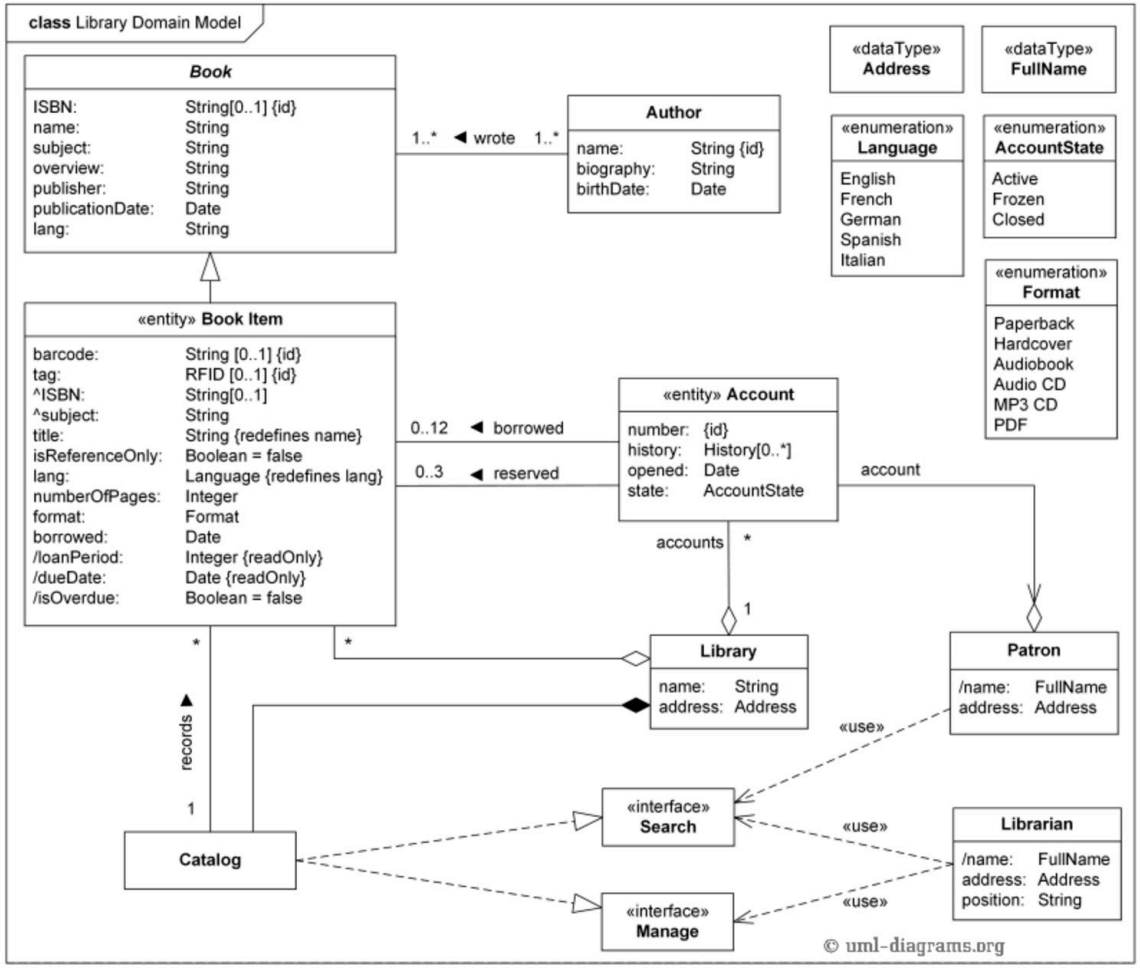
← **Invalidates stronger invariant (w==h) in subclass**

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

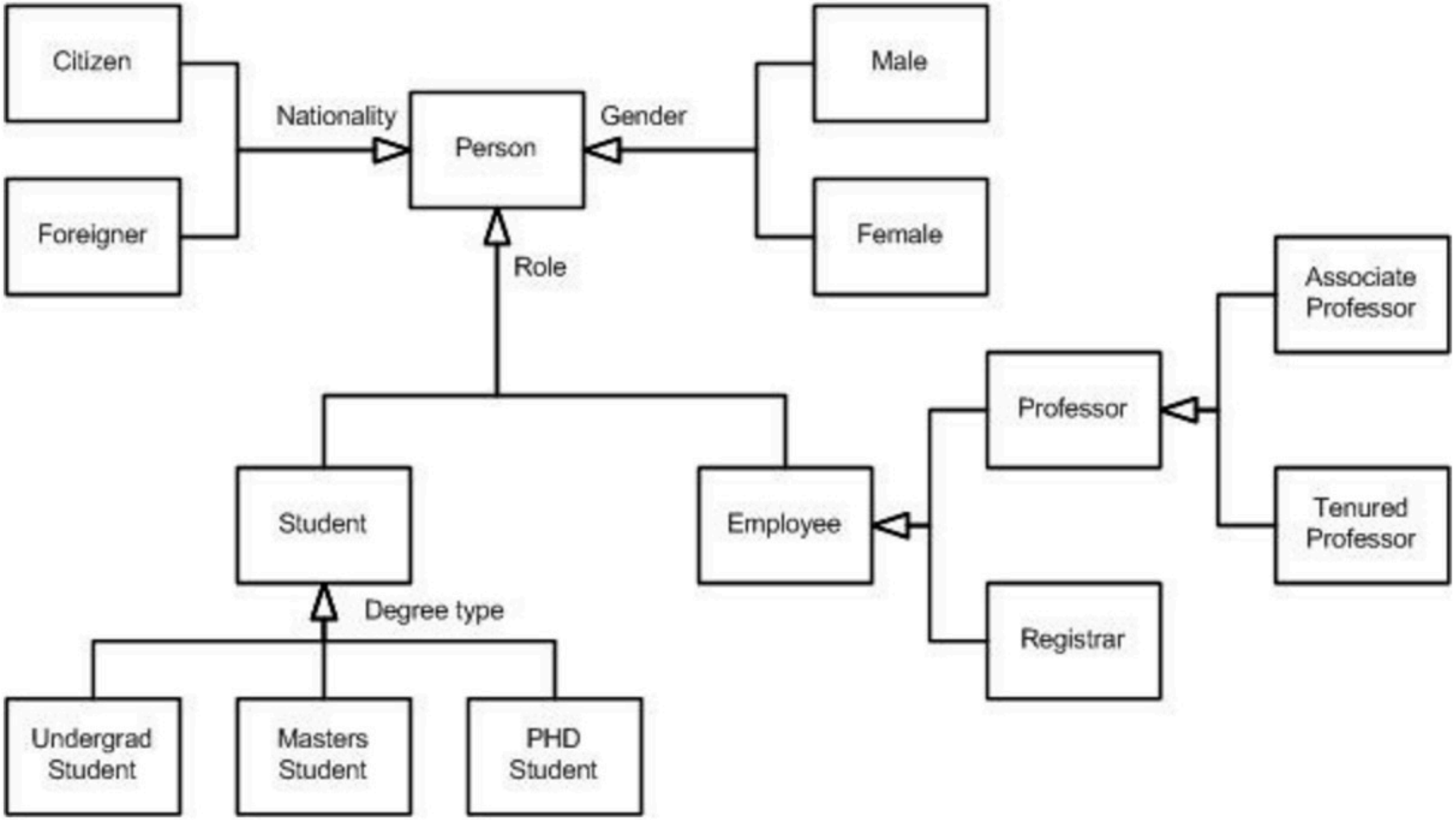
Today: Introduction to Design Patterns

- A Java Puzzler
- Introduction to UML class diagrams
- Introduction to design patterns
  - Strategy pattern
- Specific design patterns for change and reuse:
  - Template method pattern
  - Iterator pattern
  - Decorator pattern (next Tuesday)

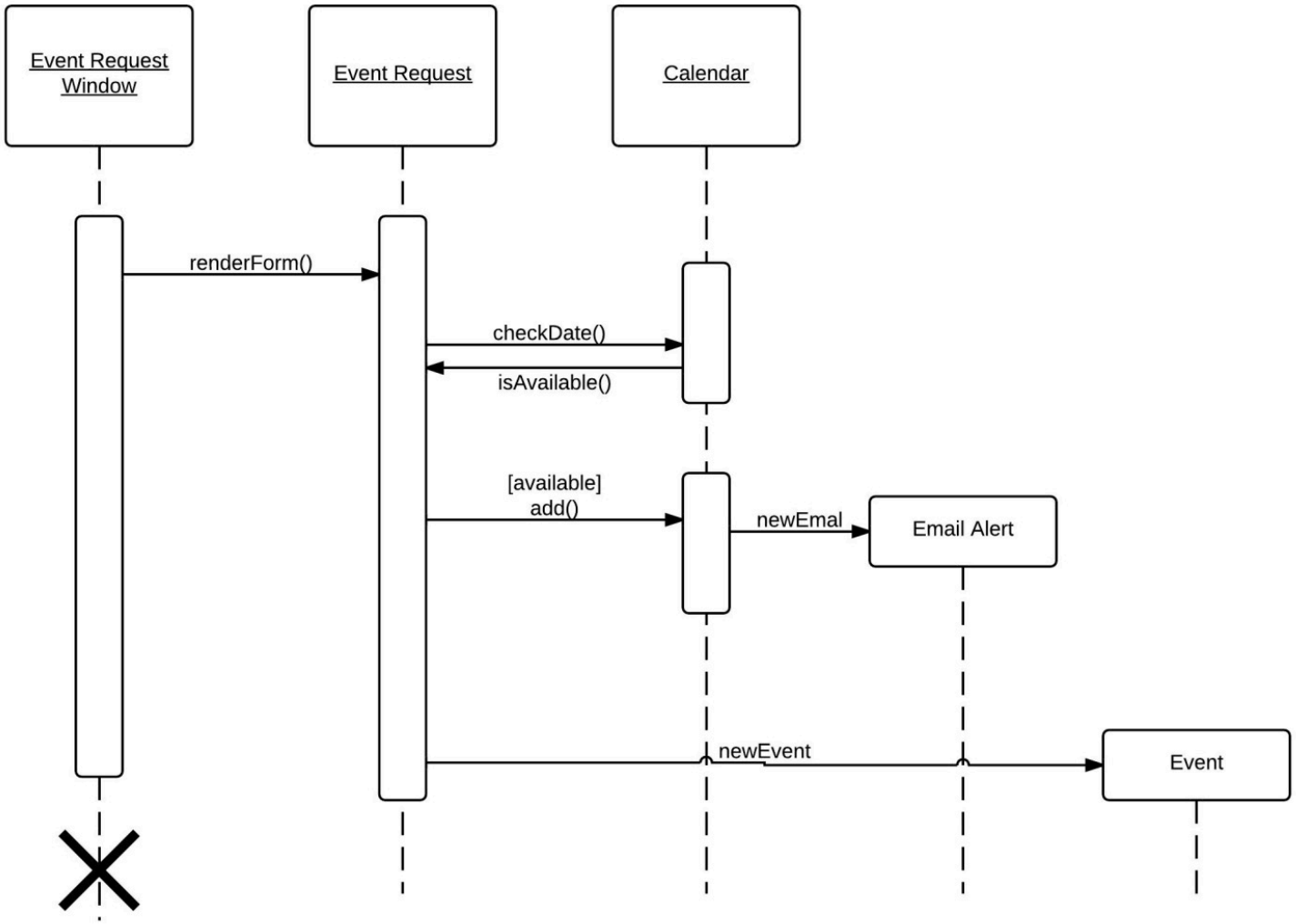
UML: Unified Modeling Language



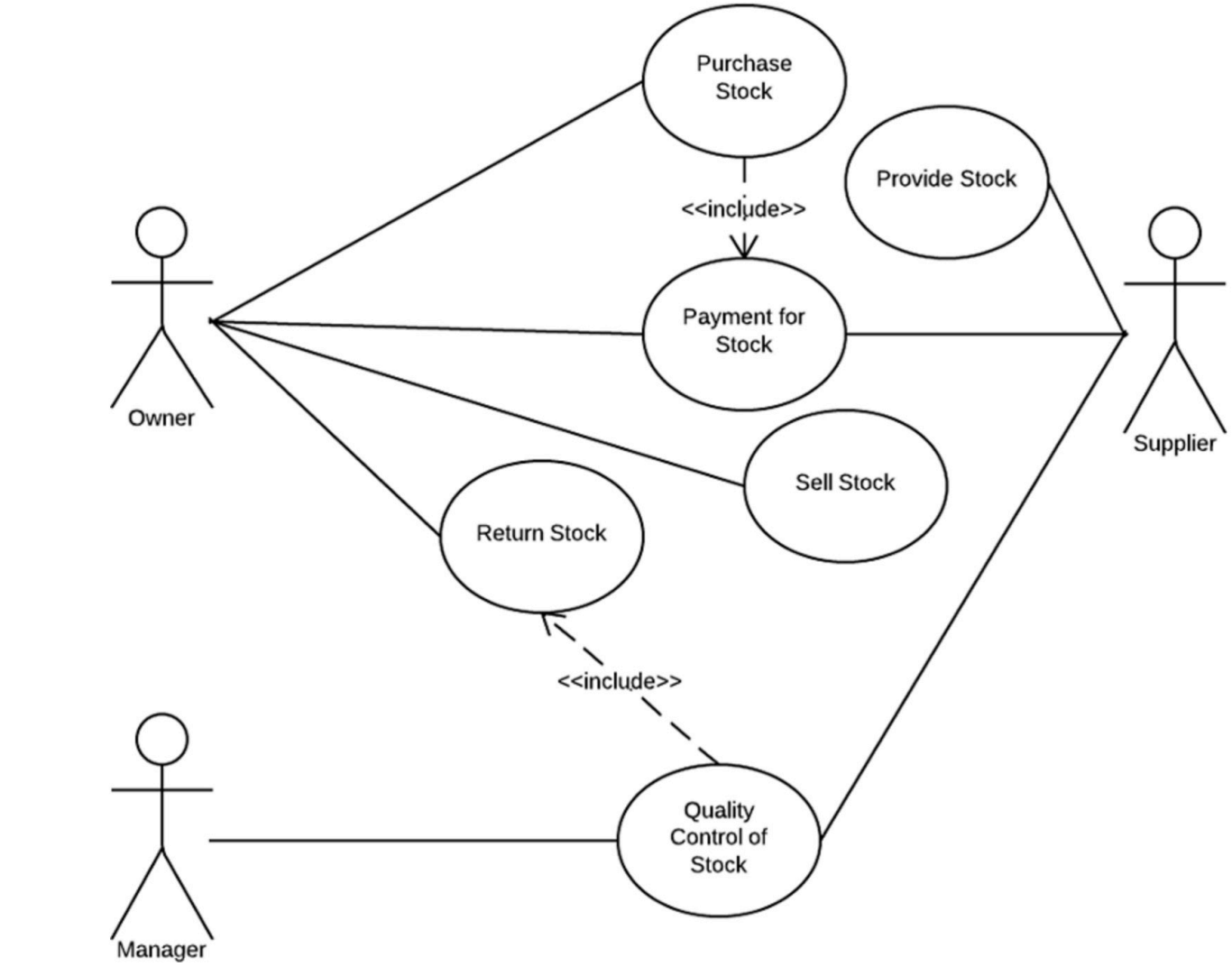
UML: Unified Modeling Language



UML: Unified Modeling Language



UML: Unified Modeling Language



UML in this course

- UML class diagrams
- UML interaction diagrams
  - Sequence diagrams
  - Communication diagrams

UML class diagrams (interfaces and inheritance)

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

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

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

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

UML class diagrams (classes)

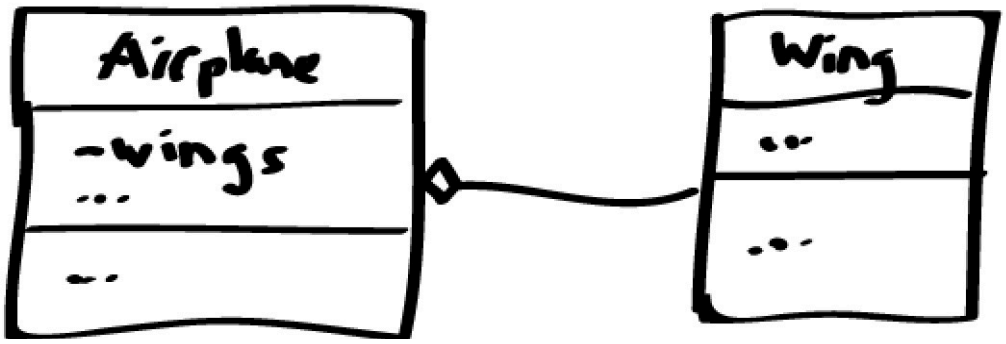
```
public abstract class AbstractAccount
        implements Account {
   protected long balance = 0;
   public long getBalance() {
        return balance;
   }
   abstract public void monthlyAdjustment();
   // other methods…
}

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

UML you should know

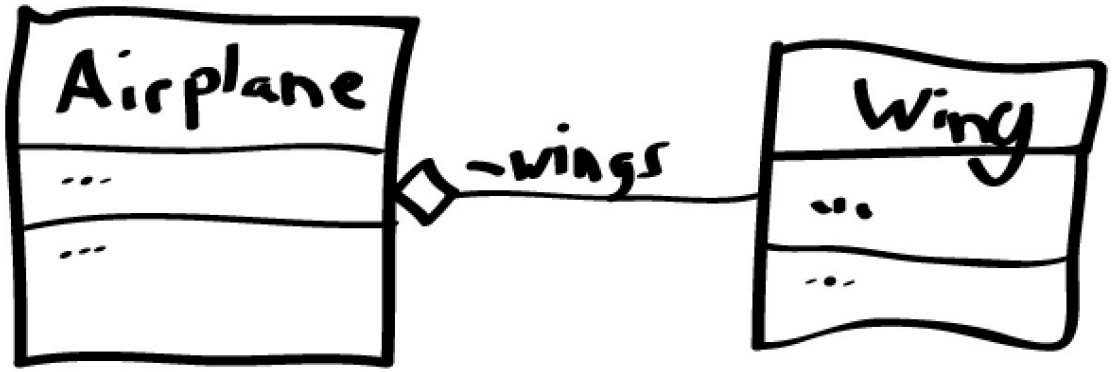
- Interfaces vs. classes
- Fields vs. methods
- Relationships:
  - "extends" (inheritance)
  - "implements" (realization)
  - "has a" (aggregation)
  - non-specific association
- Visibility: + (public) - (private) # (protected)
- Basic best practices…

UML advice

- Best used to show the big picture
  - Omit unimportant details
    - But show they are there: …
- Avoid redundancy
  - e.g., bad:



good:



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One design scenario

- Amazon.com processes millions of orders each year, selling in 75 countries, all 50 states, and thousands of cities worldwide. These countries, states, and cities have hundreds of distinct sales tax policies and, for any order and destination, Amazon.com must be able to compute the correct sales tax for the order and destination.

Another design scenario

- A vision processing system must detect lines in an image. For different applications the line detection requirements vary. E.g., for a vision system in a driverless car the system must process 30 images per second, but it's OK to miss some lines in some images. A face recognition system can spend 3-5 seconds analyzing an image, but requires accurate detection of subtle lines on a face.

A third design scenario

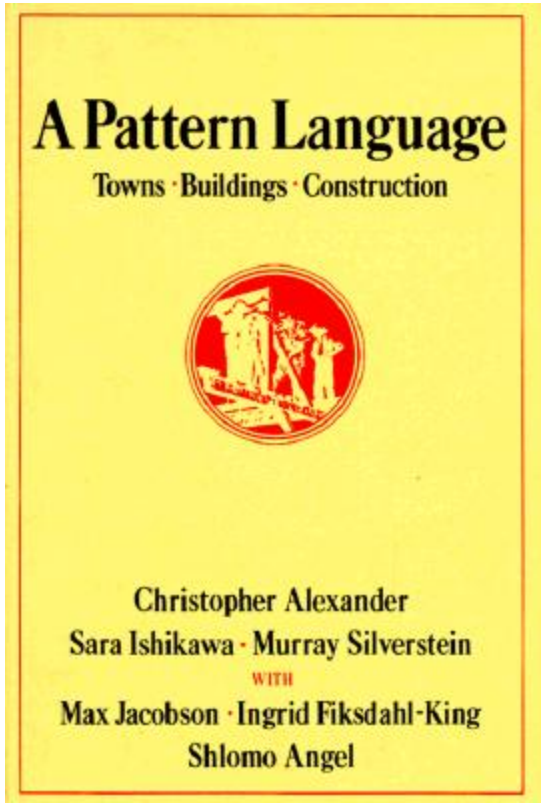
- Suppose we need to sort a list in different orders…

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

final Comparator ASCENDING =  (i, j) -> i < j;
final Comparator DESCENDING = (i, j) -> i > j;

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

Design patterns

"Each pattern describes a problem which occurs over and over again in our environment, and then describes the core of the solution to that problem, in such a way that you can use this solution a million times over, without ever doing it the same way twice"

– Christopher Alexander, Architect (1977)

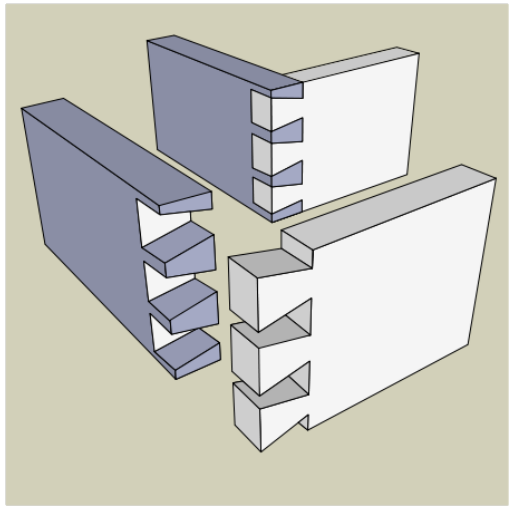


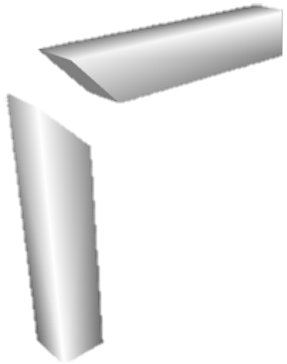
How not to discuss design (from Shalloway and Trott)

- Carpentry:
  - How do you think we should build these drawers?
  - Well, I think we should make the joint by cutting straight down into the wood, and then cut back up 45 degrees, and then going straight back down, and then back up the other way 45 degrees, and then going straight down, and repeating…
- Software Engineering:
  - How do you think we should write this method?
  - I think we should write this if statement to handle … followed by a while loop … with a break statement so that…

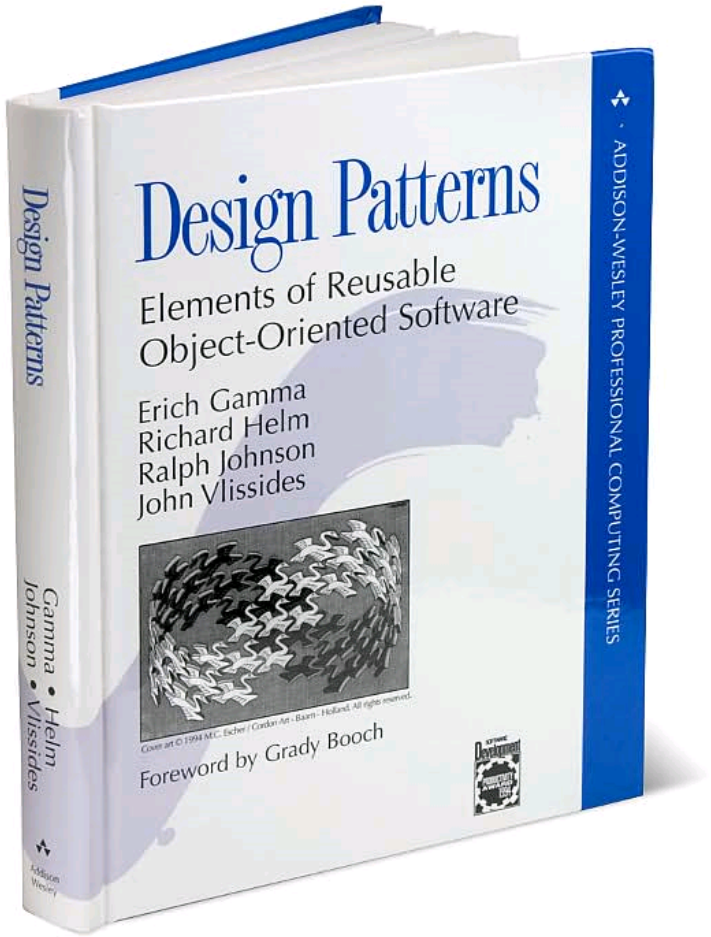
Discussion with design patterns

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





History: *Design Patterns* (1994)



Elements of a design pattern

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

Strategy pattern

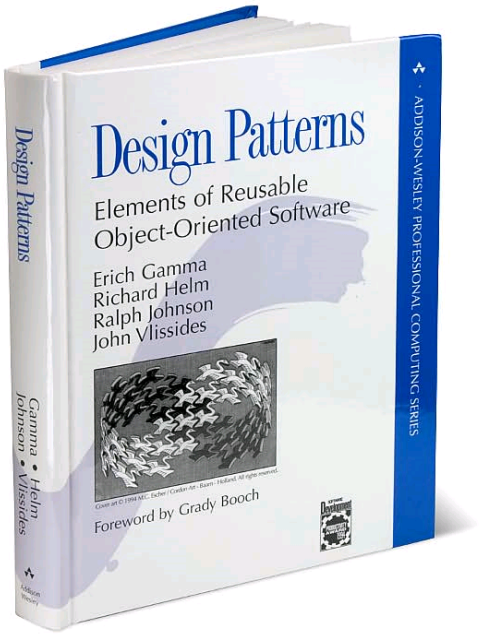
- Problem: Clients need different variants of an algorithm
- Solution: Create an interface for the algorithm, with an implementing class for each variant of the algorithm
- Consequences:
  - Easily extensible for new algorithm implementations
  - Separates algorithm from client context
  - Introduces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

Patterns are more than just structure

- Consider: A modern car engine is constantly monitored by a software system. The monitoring system must obtain data from many distinct engine sensors, such as an oil temperature sensor, an oxygen sensor, etc. More sensors may be added in the future.

Design pattern conclusions

- Provide shared language
- Convey shared experience
- Can be system and language specific



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Recall `instanceof`

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

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

Warning: This code is bad.

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

Recall `instanceof`

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

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

Warning: This code is bad.

Avoiding `instanceof` with the template method pattern

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

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

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

Avoiding `instanceof` with the template method pattern

```
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();
   }
   …
}
```

Instead:

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

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

- Both support variation in a larger context
- Template method uses inheritance + an overridable method
- Strategy uses an interface and polymorphism (via composition)
  - 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:

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

- Java 1.5: for-each 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
```

- To use explicitly, e.g.:

```
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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- 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`
  - 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

- 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`
  - 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"))
    it.remove();
}
```

Conclusions

- UML can be useful
- Design patterns facilitate communication and learning
- Today's design patterns facilitate reuse and change:
  - Strategy pattern
  - Template pattern
  - Iterator pattern