Discussion: How many times a day does a clock’s hands overlap?
Reminders

• Think of HW5 as starter code for HW6
• Helper classes are implementation details
• See .test vs .expected on message board

Upcoming Deadlines

• HW5 due Thursday (7/20)
### Last Time...

- Equality w/ Inheritance
- Bugs vs. Errors
- Assertions and `checkRep`
- Exceptions
  - Checked exceptions
  - Unchecked exceptions

### Today’s Agenda

- Miscellaneous
- True Subtyping
- Java Subtyping
- Subtypes vs. Subclasses
Miscellaneous
Exceptions vs. Assertions: review

Use an **assertion** for internal consistency checks that should not fail
  - in this class, check your reasoning (pre, post, invariants)

Use an **exception** when
  - used in a dynamic / unpredictable context (client can’t predict)
  - in this class, when you want a client to handle a case (requires, pre)
  - unlike assertions, exceptions are part of the specification

Use a **special value** when
  - it is a common case (not really exceptional)
  - clients are likely (?) to remember to check for it
Special values in C/C++/others

• For errors and exceptional conditions in Java, use exceptions!
• But C doesn’t have exceptions and older C++ projects avoid them
• Over decades, a common C/C++ idiom has emerged
  - error-prone but you can get used to it 😞
  - affects how you read code
  - put “results” in “out-parameters” (C/C++ feature)
  - result indicates success or failure

```c
    type result;
    if (!computeSomething(&result)) { ... return 1; }
    // no "exception", use result
```
• Bad, but less bad than error-code-in-global-variable
Open-Closed Principle

Software should be *open for extension*, but *closed for modification*

- when features are added to your system, do so by adding new classes or reusing existing ones in new ways
- if possible, don't make changes by modifying existing ones
  - changing existing behavior will likely introduce bugs

Related: code to interfaces (esp. for arguments), not to classes

Ex: accept a **List** parameter, not **ArrayList** or **LinkedList**

EJ Tip #52: Refer to objects by their interfaces
Subtyping
What is high quality?

Code is high quality when it is

1. **Correct**
   Everything else is of secondary importance

2. Easy to **change**
   Most work is making changes to existing systems

3. Easy to **understand**
   Needed for 1 & 2 above
What is subtyping?

Sometimes “every $B$ is an $A$”
- examples in a library database:
  - every book is a library holding
  - every CD is a library holding

For subtyping, “$B$ is a subtype of $A$” means:
- “every object that satisfies the rules for a $B$ also satisfies the rules for an $A$”
- (B is a strengthening of A)

Goal: code written using A's **spec** operates correctly if given a B
- benefit: clarify design, share tests, (sometimes) share code
Subtypes are substitutable

Subtypes are substitutable for supertypes
- Liskov substitution principle
- instances of subtype won't surprise client by failing to satisfy the supertype's specification
- instances of subtype won't surprise client with more expectations than the supertype's specification

We say B is a (true) subtype of A if B has a stronger specification than A
- (or is equally strong)
- this is not the same as a Java subtype (e.g. subclass)
- Java subclasses that are not true subtypes: confusing & dangerous
  • but unfortunately common 😞
Subtyping vs. subclassing

Substitution (subtype) is a matter of specifications
- B is a subtype of A iff an object of B can masquerade as an object of A in any context
- B is a subtype if its spec is a strengthening of A’s spec

Inheritance (subclass) is a matter of implementations
- factor out repeated code
- to create a new class, write only the differences

Java purposely merges these notions for classes:
- every subclass is a Java subtype
- but not necessarily a true subtype
- and Java casting rules assume true subtypes!
Inheritance makes adding functionality easy

Suppose we run a web store with a class for *products*...

class Product {
    private String title;
    private String description;
    private int price; // in cents

    public int getPrice() {
        return price;
    }
    public int getTax() {
        return (int)(getPrice() * 0.086);
    }

    ...
}

... and we need a class for *products that are on sale*
Copy and Paste

class SaleProduct {
    private String title;
    private String description;
    private int price; // in cents
    private float factor;

    public int getPrice() {
        return (int)(price*factor);
    }
    public int getTax() {
        return (int)(getPrice() * 0.086);
    }
    ...
}

Not a good choice. — Why? (hint: properties of high quality code)
Inheritance makes small extensions small

Better:

class SaleProduct extends Product {
    private float factor;

    public int getPrice() {
        return (int)(super.getPrice()*factor);
    }
}

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Benefits of subclassing & inheritance

• Don’t repeat unchanged fields and methods
  – in implementation:
    • simpler maintenance: fix bugs once (changeability)
  – in specification:
    • clients who understand the superclass specification need only study novel parts of the subclass (readability)
    • differences not buried under mass of similarities
  – modularity: can ignore private fields and methods of superclass (if properly designed)

• Ability to substitute new implementations (modularity)
  – no client code changes required to use new subclasses
Subclassing can be misused

• Java does not enforce that subclass is a (true) subtype

• Poor design can produce subclasses that depend on implementation details of superclasses
  – super- and sub-classes are often **highly interdependent** (i.e., tightly coupled)
  – “fragile base class problem”

• **Subtyping and implementation inheritance are orthogonal!**
  – subclassing gives you both
  – sometimes you want just one. **instead use:**
    • *interfaces*: subtyping without inheritance
    • *composition*: use implementation without subtyping
class Counter {
    private int count;

    public void method1() {
        count++;
    }
    public int method2() {
        count++;
    }
}
"Fragile Base Class" Problem

class Counter {
    private int count;

    public void method1() {
        method2();
    }
    public int method2() {
        count++;  
    }
}

Is this ok?
“Fragile Base Class” Problem

class Counter {
    private int count;

    public void method1() {
        method2();
    }

    public int method2() {
        count++;
    }
}

class MyCounter extends Counter {
    @Override
    public int method2() {
        method1();
    }
}
(Non-) Examples
A tale of two shapes...

interface Rectangle {
    // effects: fits shape to given size:
    //          this.width = w and this.height = h
    void setSize(int w, int h);
}

interface Square extends Rectangle {
    // some code here
}
Is every square a rectangle?

// effects: fits shape to given size:
//          this.width = w and this.height = h
void setSize(int w, int h);

What is wrong with these options for Square’s setSize specification?

1. // effects: sets all edges to given size
   void setSize(int edgeLength);

2. // requires: w = h
   // effects: fits shape to given size
   void setSize(int w, int h);

3. // effects: sets this.width = w and this.height = w
   void setSize(int w, int h);

4. // effects: fits shape to given size
   // throws BadSizeException if w != h
   void setSize(int w, int h) throws BadSizeException;
Square, Rectangle Unrelated (Subtypes)

Square is not a (true subtype of) Rectangle:
- Rectangle is expected to have a width and height that can be mutated independently
- Square violates that expectation, could surprise client

Rectangle is not a (true subtype of) Square:
- Square is expected to have equal widths and heights
- Rectangle violates that expectation, could surprise client

Subtyping is not always intuitive
- but it forces clear thinking and prevents errors

Solutions:
- make them unrelated (or siblings)
- make them immutable!
  - recovers elementary-school intuition
Benefits of Immutability

Seen so far:

1. No worries about **representation exposure**
   - mutable objects need copy-in & copy-out

2. No worries about **equals consistency violations**
   - (no good way to check for this at all!)

3. **Subtyping** relationships more often work as expected
   - e.g., Square is then a subtype of Rectangle
class Hashtable {
    public void put(Object key, Object value){...}
    public Object get(Object key){...}
}

// Keys and values are strings.
class Properties extends Hashtable {
    public void setProperty(String key, String val) {
        put(key,val);
    }
    public String getProperty(String key) {
        return (String)get(key);
    }
}

Properties p = new Properties();
Hashtable tbl = p;
tbl.put("One", 1);
p.getProperty("One"); // crash!
Violation of rep invariant

**Properties** class has a simple rep invariant:
- keys and values are **Strings**

But client can treat **Properties** as a **Hashtable**
- can put in arbitrary content, break rep invariant

From Javadoc:

> Because Properties inherits from Hashtable, the put and putAll methods can be applied to a Properties object. ... If the store or save method is called on a "compromised" Properties object that contains a non-String key or value, the call will fail.
Solution: Composition

class Properties {
    private Hashtable hashtable;

    public void setProperty(String key, String value) {
        hashtable.put(key, value);
    }

    public String getProperty(String key) {
        return (String) hashtable.get(key);
    }

    ...
}

You do not need to be a subclass of any class whose code you want to use!

Now, there are no get and put methods on Properties. (Best choice.)
Subtypes vs. Subclasses
Substitution principle for methods

Constraints on methods
- For each supertype method, subtype must have such a method
  • (could be inherited or overridden)

Each overridden method must strengthen (or match) the spec:
- ask nothing more of client (“weaker precondition”)
  • requires clause is at most as strict as in supertype’s method
- guarantee at least as much (“stronger postcondition”)
  • effects clause is at least as strict as in the supertype method
  • no new entries in modifies clause
  • promise more (or the same) in returns & throws clauses
    - cannot change return values or switch between return and throws
Spec strengthening: argument/result types

For method **inputs**:
- argument types in A’s foo *could* be replaced with supertypes in B’s foo
- places no extra demand on the clients
- **but** Java *does not have* such overriding
  - these are different methods in Java!

For method **outputs**:
- result type of A’s foo may be replaced by a subtype in B’s foo
- no new exceptions (for values in the domain)
- existing exceptions can be replaced with subtypes (none of this violates what client can rely on)
class Product {
    private int price; // in cents
    public int getPrice() {
        return price;
    }
    public int getTax() {
        return (int)(getPrice() * 0.086);
    }
}

class SaleProduct extends Product {
    private float factor;
    public int getPrice() {
        return (int)(super.getPrice()*factor);
    }
}
Exercise: True subtypes

Suppose we have a method which, when given one product, recommends another:

```java
class Product {
    Product recommend(Product ref);
}
```

Which of these are possible methods in `SaleProduct` (a true subtype of `Product`)?

```java
Product recommend(SaleProduct ref);  // bad
SaleProduct recommend(Product ref);  // good
Product recommend(Object ref);       // good
Product recommend(Product ref)       // bad
    throws NoSaleException;
```

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Suppose we have a method which, when given one product, recommends another:

```java
class Product {
    Product recommend(Product ref);
}
```

Which of these are possible methods in `SaleProduct` (a Java subtype of `Product`)?

- `Product recommend(SaleProduct ref);` // bad
- `SaleProduct recommend(Product ref);` // good
- `Product recommend(Object ref);` // compiles, but in Java is overloading
- `Product recommend(Product ref)`
  throws NoSaleException; // bad
Before next class...

1. Ask questions about HW5!
   - Unique experience to design an ADT yourself
   - Focuses on testing and specifications