CSE 331
SOFTWARE DESIGN & IMPLEMENTATION
SUBTYPING AND SUBCLASSING

Autumn 2011

Very quick 331 recap

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- Procedural specification and implementations that satisfy these specifications
  - For specification **S** and program **P**, `P satisfies S iff`
    - Every behavior of **P** is permitted by **S**
    - "The behavior of **P** is a subset of **S**"
- Abstract data type specification and implementations that satisfy such specifications – more complicated, but the same idea
- These are approaches for defining, reasoning about, testing and implementing software that satisfy specific expectations

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Similarity

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- Sometimes it is valuable to take advantage of existing specifications and/or implementations to develop a *similar* piece of software
- That is, we'd like to develop a similar artifact (specification or implementation) not entirely from scratch, but rather as a delta from the original
  - **A' = A + ΔA'**
- Describing the differences and sharing the similarities can simplify development, increase confidence in the properties of the artifact, help in understanding the problem space, etc.

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Similarity in the world

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- Philosophers including Plato, Aristotle, Hegel and others have discussed this for millennia – often in the context of equality/identity
- In what way are two chairs similar? How does a child recognize a (new kind of) chair?
- Why are platypi mammals even though they lay eggs instead of bearing live offspring?
- Should we classify species using taxonomies (like Linnaeus) or phylogenetics (like DNA)?

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Similarity in software development

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- The field has many ways to exploit this notion of similarity – examples include
  - Procedures with parameters – share the algorithm, differ in the data
  - Object-oriented subclassing
  - Object-oriented subtyping
  - Monads in functional programming
  - And many more…
- Just like similarity is confusing in the world, it can be confusing – but very valuable – in software development

These are related but distinct; and the distinctions are often confusing and confused

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Substitutability

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- The notion of satisfiability considered when an implementation met the expectations of a specification
- *Substitutability* will be the key issue in subtyping – can one specification (and its satisfying implementation) be substituted for another specification (and its satisfying implementation)?

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Comparing specifications

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- A core notion underlying substitutability is the notion of comparing two specifications
- Specification: a stronger specification (**S**) can always be substituted for a weaker specification (**W**)
  - The stronger spec **S** is defined over a (possibly proper) superset of **W**'s inputs and returns a (possibly proper) subset of **W**'s outputs – as **S** includes all of **W**'s behaviors, it will work wherever **W** works
- Implementation: A procedure (**P**) satisfying a stronger specification (**S**) can be used anywhere that a weaker specification (**W**) is required
  - **P** satisfies **S** and **S** works wherever **W** works, so **P** also satisfies **W**

Example: weaker/stronger

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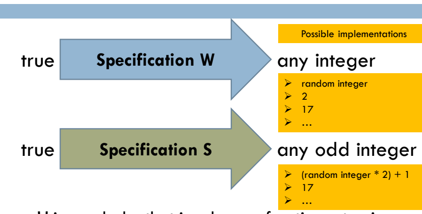

- Wherever **W** is needed – that is, where a function returning any integer will suffice – **S** will work because it returns an integer as **W** promises
- **W** cannot substitute for **S**, because of the expectation that **S** produces an odd integer, which **W** might not do

Example: weaker/stronger

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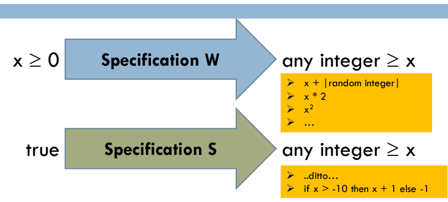

- A client depending on **W** can depend on **S**, because whenever **W**'s precondition is satisfied, so is **S**'s precondition

Example: weaker/stronger

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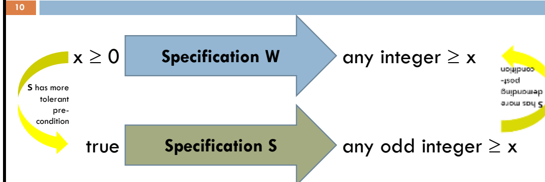

- Stronger specifications are
  - More tolerant on the inputs
  - But more demanding on the outputs
- Weaker specifications are
  - More demanding on the inputs
  - But more tolerant on the outputs

Do not mistake strong/weak as good/bad or as bad/good

Example: incomparable

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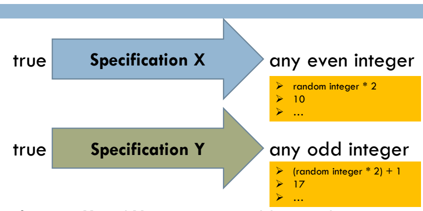

- The specifications **X** and **Y** are incomparable – neither is stronger or weaker than the other one
- A client of either cannot substitute the other and still work in general

Said another way…

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- A stronger specification is
  - **harder to satisfy** (implement) because it promises more – that is, its `effects` clause is harder to satisfy and/or there are fewer objects in `modifies` clause – but
  - **easier to use** (more guarantees) by the client – that is, the `requires` clause is easier to satisfy
- A weaker specification is
  - **easier to satisfy** (more implementations satisfy it) because it promises less – that is, the `effects` clause is easier to satisfy and/or there are more objects in `modifies` clause – but
  - **harder to use** (makes fewer guarantees) because it asks more of the client – that is, the `requires` clause is harder to satisfy

What about subtyping?

- Subtyping uses substitutability to express the "is-a" relationship
  - A circle is-a shape; a rhombus is-a shape
  - A platypus is-a mammal; a mammal is-a vertebrate animal
  - A `java.math.BigInteger` is-a `java.lang.Number` is-a `java.lang.Object`
- When a programmer declares **B** to be a *subtype* of **A** that it means "every object that satisfies the specification of **B** also satisfies the specification of **A**"
  - Sometimes we call this a *true subtype* relationship – see next slide

Be careful!!!!!

- We are still talking about specifications, not implementations!
  - **`java.math.BigInteger`** might share absolutely positively no code at all with **`java.lang.Object`**
- Java subtypes/subclasses are not necessarily true subtypes
  - No type system, including Java's, can determine the behavioral properties that would be needed to ensure this – the details are beyond the scope of 331
  - Java subtypes that are not true subtypes are confusing at best and dangerous at worst

Subclassing

- Subclassing uses inheritance to share code – take advantage of the similarity of parts of the implementation – enables incremental changes to classes
- Every Java subclass is a Java subtype but is *not necessarily a true subtype*
- Checking for true subtypes requires full specifications (and deeper checking, again beyond the scope of type systems)

Java subtypes

- Java types are defined by classes, interfaces, and primitives
- B is Java subtype of A if there is a declared relationship (B extends A, B implements A)
- Compiler checks that, for each corresponding method
  - same argument types
  - compatible result types
  - no additional declared exceptions
- Again: *not* the same as checking for a true subtype! No semantic behavior is considered

Adding functionality

- Suppose we run a web store with a class for **`Products`** …

```
class Product {
  private String title, description;
  private float price;
  public float getPrice() { return price; }
  public float getTax() { return getPrice() * 0.05f; }
  // ...
}
```

- … and we decide we want another class for **`Products`** that are on sale

We could cut-and-paste


```
class SaleProduct {
   private String title, description;
   private float price;
   private float factor;
   public float getPrice() { return price*factor; }
   public float getTax() { return getPrice() * 0.05f;}
    //...
}
```

- Good idea? Bad idea? Why?

Inheritance allows small extensions

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- The code for the extension is in some sense comparable in size to the extension
- It's much better to do this

```
class SaleProduct extends Product {
  private float factor;
  public float getPrice() {
    return super.getPrice()*factor;
  }
  //...
}
```


Benefits of subclassing & inheritance

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- Don't repeat unchanged fields and methods
  - Simpler maintenance of implementation: just fix bugs once
  - Clients who understand the superclass specification need only study novel parts of subclass
- Modularity: can ignore private fields and methods of superclass (if properly defined)
  - Differences are not buried under mass of similarities
- Ability to substitute new implementations
  - Clients need not change their code to use new subclasses

Subclassing can be misused

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- Poor planning leads to muddled inheritance hierarchy
  - Relationships may not match untutored intuition
- If subclass is tightly coupled with superclass
  - Can depend on implementation details of superclass
  - Changes in superclass can break subclass ("fragile base class")
- Subtyping is the source of most benefits of subclassing
  - Just because you want to inherit an implementation does not mean you want to inherit a type – and vice versa!

Every square is a rectangle

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

Which is the best option for `Square.setSize()`?

`interface Square implements Rectangle {…}`

1.
```
// requires: w = h
// effects: fits shape to given size
void setSize(int w, int h);
```
2.
```
// effects: sets all edges to given size
void setSize(int edgeLength);
```
3.
```
// effects:  sets this.width and this.height to 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 and rectangle are unrelated

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- `Square` is not a true subtype of `Rectangle`
  - Rectangles are expected to have a width and height that can be changed independently
  - Squares violate that expectation, could surprise client
- `Rectangle` is not a true subtype of `Square`
  - Squares are expected to have equal widths and heights
  - Rectangles violate that expectation, could surprise client
- Inheritance isn't always intuitive – it does encourage clear thinking and prevents errors
  - Possible solution might be to make them incomparable (perhaps as siblings under a common parent)
  - Why isn't the elementary school "every square is a rectangle" true when we think about them as true subtypes?

(im)mutability!

Substitution principle: redux

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- Constraints on methods
  - For each method in a supertype, the subtype must have a corresponding overriding method
  - Also may introduce new methods
- Each overriding method must
  - Ask nothing extra of client ("weaker precondition")
    - `requires` clause is at most as strict as in the 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

Substitution: specification weakening

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- Method inputs
  - Argument types may be replaced with supertypes ("contravariance")
  - This doesn't place any extra demand on the client.
    - Java forbids any change
- Method results
  - Result type may be replaced with a subtype ("covariance")
    - This doesn't violate any expectation of the client
  - No new exceptions (for values in the domain)
  - Existing exceptions can be replaced with subtypes
    - This doesn't violate any expectation of the client

Substitution exercise

Small groups: 2-3 minutes

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- Suppose we have a method which, when given one product, recommends another
  `Product recommend(Product ref);`
- Which of these are possible forms of method in a true subtype?
  - `Product recommend(SaleProduct ref);` ❑ bad
  - `SaleProduct recommend(Product ref);` ❑ OK
  - `Product recommend(Object ref);` ❑ OK (Java overloading)
  - `Product recommend(Product ref) throws NoSaleException;` ❑ bad
- Same kind of reasoning for exception subtyping and for **`modifies`** clause

Interfaces and abstract classes

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- Provide interfaces for your functionality
  - Lets client write code to satisfy interfaces rather than to satisfy concrete classes
  - Allows different implementations later
  - Facilitates composition, wrapper classes – we'll see more of this over the term
- Consider providing helper/template abstract classes
  - Can minimize number of methods that new implementation must provide
  - Makes writing new implementations much easier
  - Using them is optional, so they don't limit freedom to create radically different implementations

Why interfaces instead of classes

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- Java design decisions
  - A class has exactly one superclass
  - A class may implement multiple interfaces
  - An interface may extend multiple interfaces
- Observation
  - multiple superclasses are difficult to use and to implement
  - multiple interfaces, single superclass gets most of the benefit

Concrete, abstract, or interface?

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- Telephone: $10 landline, speakerphone, cellphone, Skype, VOIP phone
- TV: CRT, Plasma, LCD
- Table: dining table, desk, coffee table
- Coffee: espresso, frappuccino, decaf, Iced coffee
- Computer: laptop, desktop, server, smart phone
- CPU: x86, AMD64, PowerPC
- Professor: Ernst, Notkin, Stepp, Perkins

Depends on the similarity

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- …that one wants to benefit from
- The specification of the related objects?
- The implementation of the related objects – or parts thereof?
- Not all similarity is similar
- So thinking about the kind of similarity you want to exploit in software development will drive many design decisions
  - Better to do this consciously than subconsciously

Next steps

- Assignment 2: part B due Friday 11:59PM
- Assignment 3: out on Friday – how to handle pairs?
- Lectures: F (modular design), M (design patterns)
- Upcoming: Friday 10/28, in class midterm – open book, open note, closed neighbor, closed electronic devices