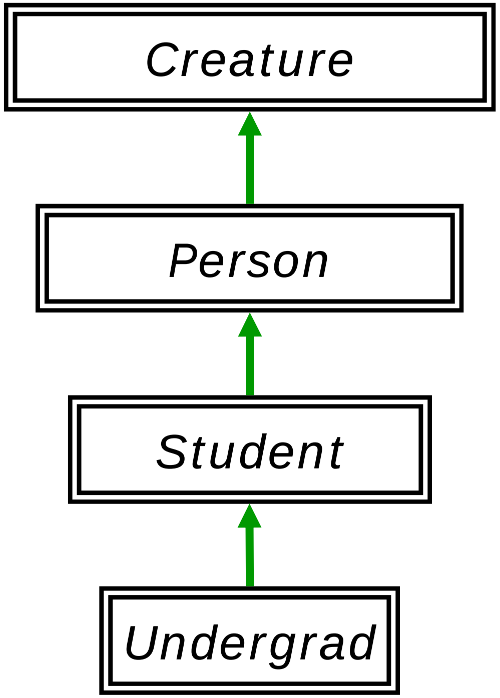
Assertions, Specifications, and Design-by-Contract

Lecture 19

Wider vs Narrower Interfaces

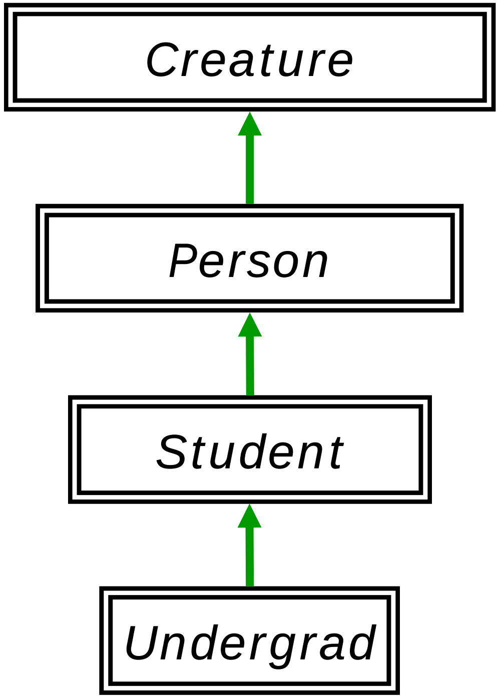
- Recall behavioral subtyping
- Substitution principle
  - If a client is correct wrt a “wide” type, that same client is still correct wrt a “narrower” one
- Question: When designing an interface, how wide/narrow should it be?



Design Issue #1: Which is Better?

- Answer: It depends!
- A wider spec:
  - Demanding on inputs, tolerant on outputs
  - Easier to implement
  - Harder to use
  - Less powerful
- A narrower spec:
  - Tolerant on inputs, demanding on outputs
  - Harder to implement
  - Easier to use
  - More powerful
- High-level tradeoff
  - Generality/flexibility, vs power/performance

Easier to implement



Easier to use

Wider vs Narrower Methods

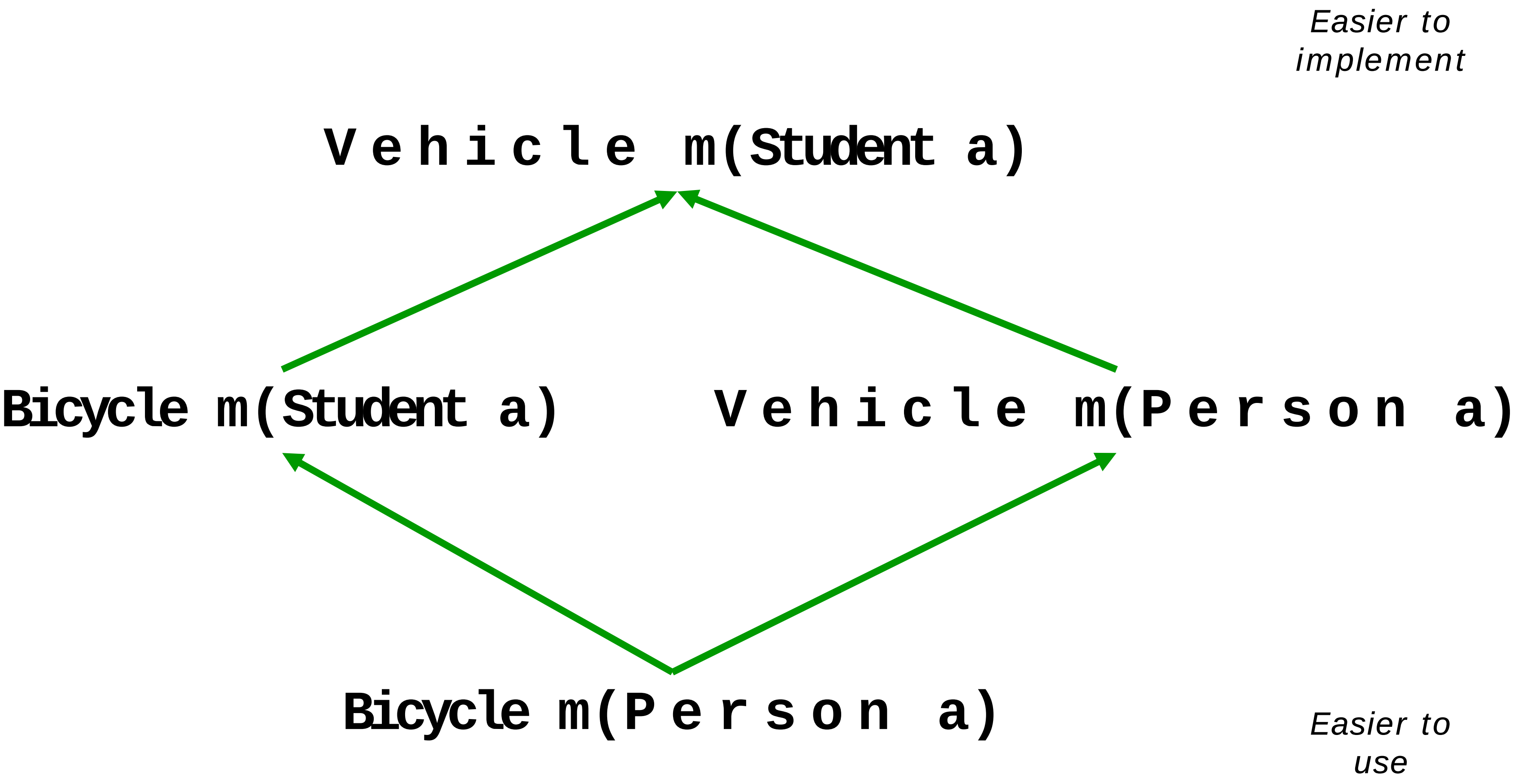
- Consider a method selectTransport
  - Return value: Vehicle or Bicycle?
  - Argument: Person or Student?

```
Vehicle                          Person
    ?      selectTransport(  ?          a)
Bicycle                          Student
```

- Vehicle is wider than Bicycle
- Person is wider than Student

```
Vehicle                          Person
    ?      selectTransport(  ?          a)
 Bicycle                           Student
```

Wider vs Narrower Methods



Easier to implement

Vehicle m(Student a)

Bicycle m(Student a)

Vehicle m(Person a)

Bicycle m(Person a)

Easier to use

Good Practice: Which Declared Type?

- How specific should the declared type of an argument / return value be?

  ```
  Vehicle selectTransport(Person a)
  Bicycle selectTransport(Person a)
  Vehicle selectTransport(Student a)
  Bicycle selectTransport(Student a)
  ```

- Typical advice:
  - “As specific as possible, without revealing implementation details”
  - “As general as possible, while still being useful to client”
- The right way to think about it:
  - The type is dictated by the mathematical (abstract, client-side) model

Requires Clause

- Obligation on client
  - If client satisfies this obligation, component method must terminate *without an exception*, satisfying ensures
- If requires is not satisfied, method could do anything, including:
  - Terminate in whatever state it wants
  - Not terminate
  - Throw an exception
- This last case, though, should be included in specification
  - Document the "exceptional requires clause"
    - Condition under which method throws exception
  - Also document this case's ensures clause

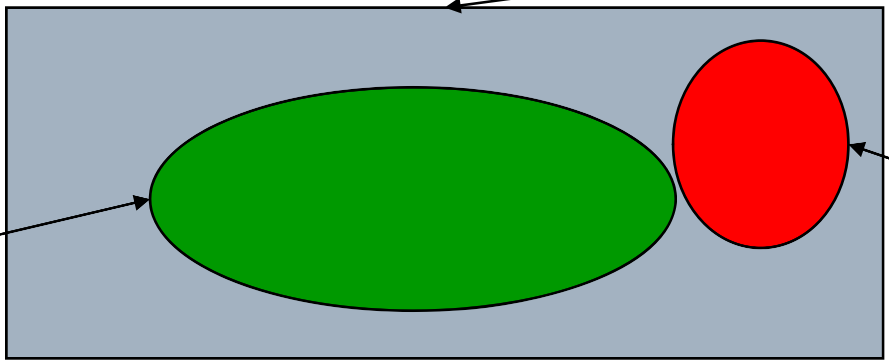
Requires and Throws

```
@requires n is even
void f(int n) { … }

@requires n is even
@throws IllegalArgumentException if #n is odd
void g(int n) { … }

f(5); //anything could happen
g(7); //must throw exception
```

All states



Requires clause (@requires)

Exceptional requires clause (@throws)

Design Issue #2: Violated Requires

- How should a violation of the requires clause be handled?
  - What to include in “exceptional requires”?
- Answer: Use checked exceptions when
  - Client can not unilaterally guarantee that the requires holds (lack of control)
  - It is likely to be prohibitively expensive for the client to check whether the requires holds
- Recall example of lack of control
  - Guaranteeing existence of a file
- Wrong answer:
  - Include everything outside of requires clause
  - Exceptional requires clause is !requires

Example: BigNatural Constructors

- BigNatural has 2 constructors

```
//@requires v >= 0
SlowBigNatural(int v) { ... }
//@requires s is a well-formed representation of
// natural number with no leading 0’s
SlowBigNatural(String s) { ... }
```

- Checking first requires is easy for client
  - So, do NOT use an exception for negative argument
- Checking second requires is hard for client
  - So, CAN use an exception for malformed argument
- Or, another design:
  - Provide a (static) boolean method that returns whether or not a String is well-formed
  - Burden now back on client to check that the requires holds, presumably by using this method
    - Performance cost for checking twice?

Comparison

```
if (v >= 0) { //sometimes safe to omit
  b = new SlowBigNatural(v);
  . . .
}
```

```
try {           //compiler: can never omit!
  b = new SlowBigNatural(v);
  . . .
}
catch (NegativeArgumentException e) {
  . . . //some code to recover?
}
```

Disjoint Normal/Exception'l Requires

- Prefer mutually exclusive requires and exceptional requires clauses

```
class Collections {
  /**
   * Copies all of the elements from one list into
   * another. After the operation, the index of each
   * copied element in the destination list will be
   * identical to its index in the source list. The
   * destination list must be at least as long as the
   * source list. If it is longer, the remaining elements
   * in the destination list are unaffected.
   *
   * @param dest The destination list.
   * @param src The source list.
   * @throws IndexOutOfBoundsException if the destination
   * list is too small to contain the entire source List.
   */
 static <T> void copy (List<T> dest, List<T> src)
```

Disjoint Normal/Exception’l Requires

```
class Collections {
  /**
   * @requires |dest| >= |src|
   * @alters  dest
   * @ensures |dest| = |#dest|
   *        Exists a list suf such that
   *            (#dest ends in suf and
   *             dest = src + suf)
   * @param dest the destination list
   * @param src the source list
   * @throws IndexOutOfBoundsException
   *         if |dest| < |src|, dest = #dest
   */
 static <T> void copy (List<T> dest,
                       List<T> src)
```

Good Practice: Doc Exceptions

- Document every checked exception
  - @throws clause for each, giving exceptional requires
- Throw (and document) exceptions at the right level of abstraction
  - Avoid revealing implementation specifics
  - eg IndexOutOfBounds vs ArrayIndexOutOfBounds
- Document “some” runtime exceptions
  - The ones the client should reasonably care about (?)
  - Never include these in method signature
  - Danger: no real enforcement mechanism
    - Consistency within project? Client attention?
  - Parent’s @throws for *unchecked* exceptions *not* inherited
    - Use {@inheritDoc} to explicitly bring this in
    - Documentation for *checked* exceptions *is* inherited (if child declares)

Implications for JUnit

- Throwing exceptions is part of promised behavior
  - JUnit test cases should exercise this behavior
  - Seeing exception is a “pass” for test case
- @Test annotation with “expected” parameter

```
@Test(expected=
        IndexOutOfBoundsException.class)
public void empty() {
        (new ArrayList<Object>()).get(0);
}
```

Assertions

- An assertion is a statement that should always evaluate to true
- Keyword: assert
  - **`assert`** *eval-expr* [**:** *detail-expr*];

    ```
    assert tail.next == null : “No list end”;
    ```
- If the eval-expr does not evaluate to true, an AssertionError is thrown
  - An error (ie extends Error) since an assertion violation is unrecoverable
  - detail-expr can be either
    - A String (becomes the informal description)
    - A Throwable (gets chained as the cause)

Roles of Assertions

- Checking convention (ie representation invariant)
  - At the end of the constructor
  - At the end of every (mutator) method
- Checking requires
  - Defensive programming: check assumptions
- Checking ensures
  - Verify implementation has delivered promised behavior
- Checking flow-of-control
  - Example: “assert false” at a point that should never be reached
  - Style note: “throw (new AssertionError())” usually preferred to “assert false”
- Checking loop invariants

Turning Assertions On (and Off)

- Assertions are *disabled* by default
  - Enabled with a command-line argument

    ```
    $ java MyProg -enableassertions
    ```

  - Class-level and package-level control
    - -ea (-da) to enable (disable) all assertions
    - -ea:edu.osu.Tester to enable only in class Tester
    - -ea:edu.osu... to enable only in package edu.osu
- In Eclipse, use “VM arguments”
  - Java > Installed JREs > Edit > Default VM Args
  - (Or use Run Configurations for finer control)
- *Never* use assertions with side-effects
  - Example: assert i++ < max;
  - Program behavior changes if assertions are on/off
- Resist temptation to disable assertions for performance
  - Benefit is likely to be negligible
  - Robustness always outweighs speed

Good Practice: Public Methods

- Widely-accepted Java coding practice:
  - Never use assert to check *requires* of *public* methods
  - Prefer a RuntimeException (eg IllegalArgumentException)
  - OK for requires of private methods
  - OK for ensures of all methods (private and public)
- But a violation of requires clause is not recoverable (by client), so it should be an Error, not an Exception!
  - Really, these contract checks belong in a separate component (a checking wrapper)
  - But without better linguistic support for such things, assertions will have to do
- Contrary to Sun recommendations, use asserts liberally, even for public methods
  - assert (requires || exceptional-requires)

Summary

- Interface design: How wide should a specification be?
  - Trade-off: Generality vs power
- Interface design: How should a violation of requires be handled?
  - Exceptions when client lacks enough control
  - Exceptions when check is too expensive for client
- Exceptions
  - Part of component’s interface (visible)
  - Requires vs exceptional requires clauses
- Testing exceptions with JUnit
- Assertions
  - Can be turned on/off at execution time