Exam 2 Review

Exam 2

- Exam 2 today Thursday April 1st at 6:55pm-8:45pm.
- Honor Code:
  - Open book, open notes, open slides.
  - No use of compilers, no search for answers on the Internet, no communication with others.
  - You must only submit ***your own*** answers.
- Type into Submitty (like Quizzes).

Topics

- ADTs
  - Benefits of ADT methodology, Specifying ADTs, Rep invariants, Representation exposure, Checking rep invariants, Abstraction functions

ADTs

- Abstract Data Type (ADT): higher-level data abstraction
  - The ADT is <u>operations</u> + <u>state</u>
  - A specification mechanism
  - A way of thinking about programs and design

An ADT Is a Set of Operations

- Operations operate on data representation
- ADT abstracts from organization to meaning of data
- ADT abstracts from structure to use
- Data representation does not matter!

```
class Roint {
   float x, y;
}
```

```
class Point {
   float r, theta;
}
```

- Instead, think of a type as a set of operations: create, x(), y(), r(), theta().
- Force clients to call operations to access data

Specifying an ADT

immutable	**mutable**
`class TypeName`	**`class TypeName`**
1. overview	1. overview
2. abstract fields	2. abstract fields
3. creators	3. creators
4. observers	4. observers
5. producers	5. producers (rare!)
~~6. mutators~~	6. mutators

Connecting Implementation to Specification

- Representation invariant: Object → boolean
  - Indicates whether data representation is well-formed. Only well-formed representations are meaningful
  - Defines the set of valid values
- Abstraction function: Object → abstract value
  - What the data structure really means
    - E.g., array [2, 3, -1] represents $-x^2 + 3x + 2$
  - How the data structure is to be interpreted

Representation Exposure

- Client can get control over rep and break the rep invariant! Consider

```
IntSet s = new IntSet();
s.add(1);
List<Integer> li = s.getElements();
li.add(1); // Breaks IntSet's rep invariant!
```

- Representation exposure is external access to the rep. AVOID!!!
- If you allow representation exposure, document why and how and feel bad about it

Representation Exposure

- Make a copy on the way out:

```
public List<Integer> getElements() {
   return new ArrayList<Integer>(data);
}
```

- Mutating a copy does not affect **`IntSet`**’s rep

```
IntSet s = new IntSet();
s.add(1);
List<Integer> li = s.getElements();
li.add(1); //mutates new copy, not IntSet’s rep
```

Representation Exposure

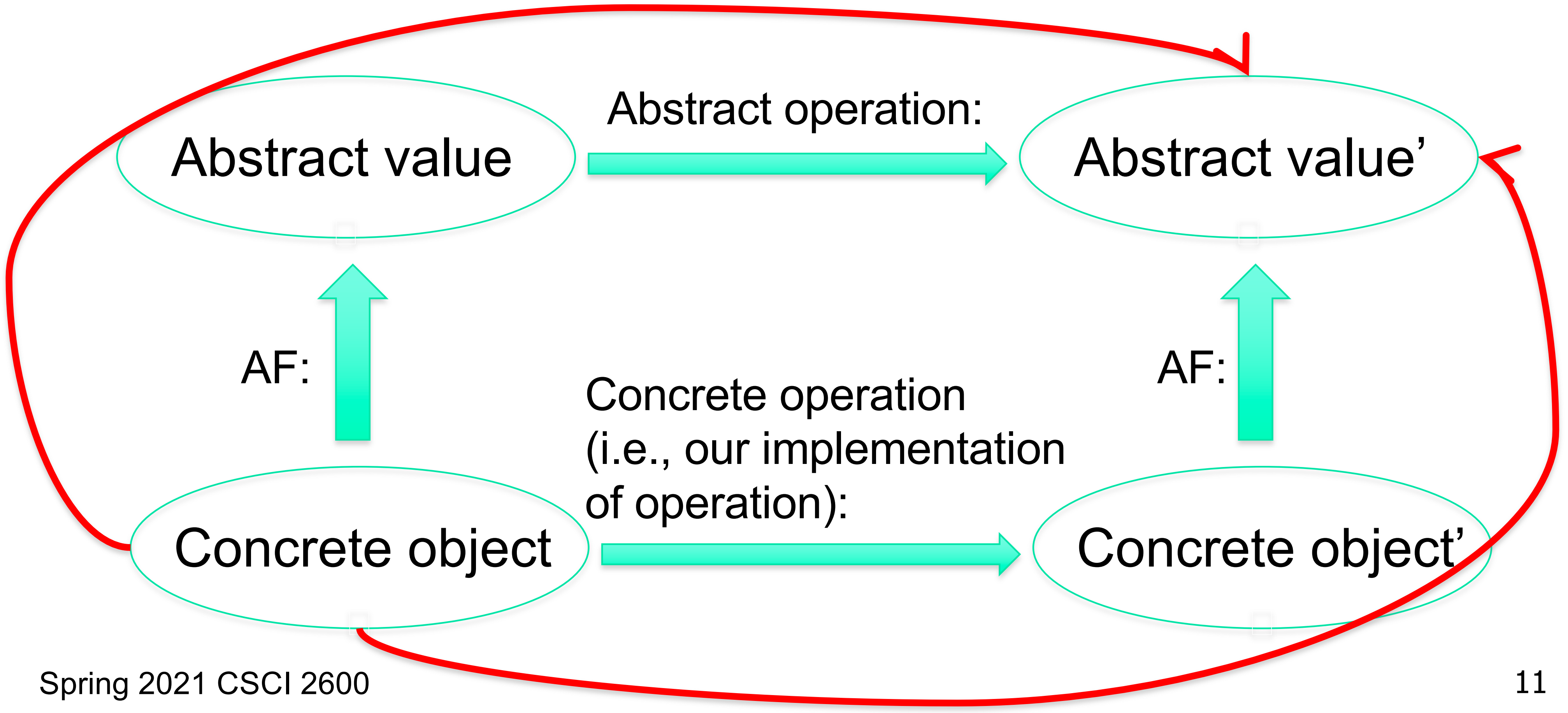
- Make a copy on the way in too:

```
public IntSet(ArrayList<Integer> elts) {
  data = new ArrayList<Integer>(elts);
  …
}
```

- Why?

Abstraction Function

- Abstraction function allows us to reason about correctness of the implementation



IntSet Example

$$\begin{tikzcd}
\{ 1,2,3 \} \arrow[r, "\text{abstract remove(1): this} - \{ 1 \}"] & \{ 2,3 \} \\
{[2,1,1,2,3]} \arrow[u, "\text{AF:}"] \arrow[r, "\text{Concrete remove(1)}"] & {[2,2,3]} \arrow[u, "\text{AF:}"']
\end{tikzcd}$$

Creating concrete object:
- Establish rep invariant
- Establish abstraction function

After every operations:
- Maintains rep invariant
- Maintains abstraction function

Topics

- Testing
  - Black box heuristics: equivalence partitioning, boundary value analysis, white box heuristics: control-flow graph (CFG), statement coverage, branch coverage, def-use coverage.

Testing Strategies

- Test case: specifies
  - <u>Inputs</u> + pre-test <u>state</u> of the software
  - Expected result (<u>outputs</u> and post-test <u>state</u>)
- Black box testing:
  - We ignore the code of the program. We look at the specification (roughly, given some input, was the produced output correct according to the spec?)
  - Choose inputs <u>without</u> looking at the code
- White box (clear box, glass box) testing:
  - We use knowledge of the code of the program (roughly, we write tests to “cover” internal paths)
  - Choose inputs <u>with</u> knowledge of implementation

Equivalence Partitioning

- Partition the input and/or output domains into equivalence classes
- Write tests with inputs from different equivalence classes in the input domain
- Write tests that produce outputs in different equivalence classes in the output domain

Boundary Value Analysis

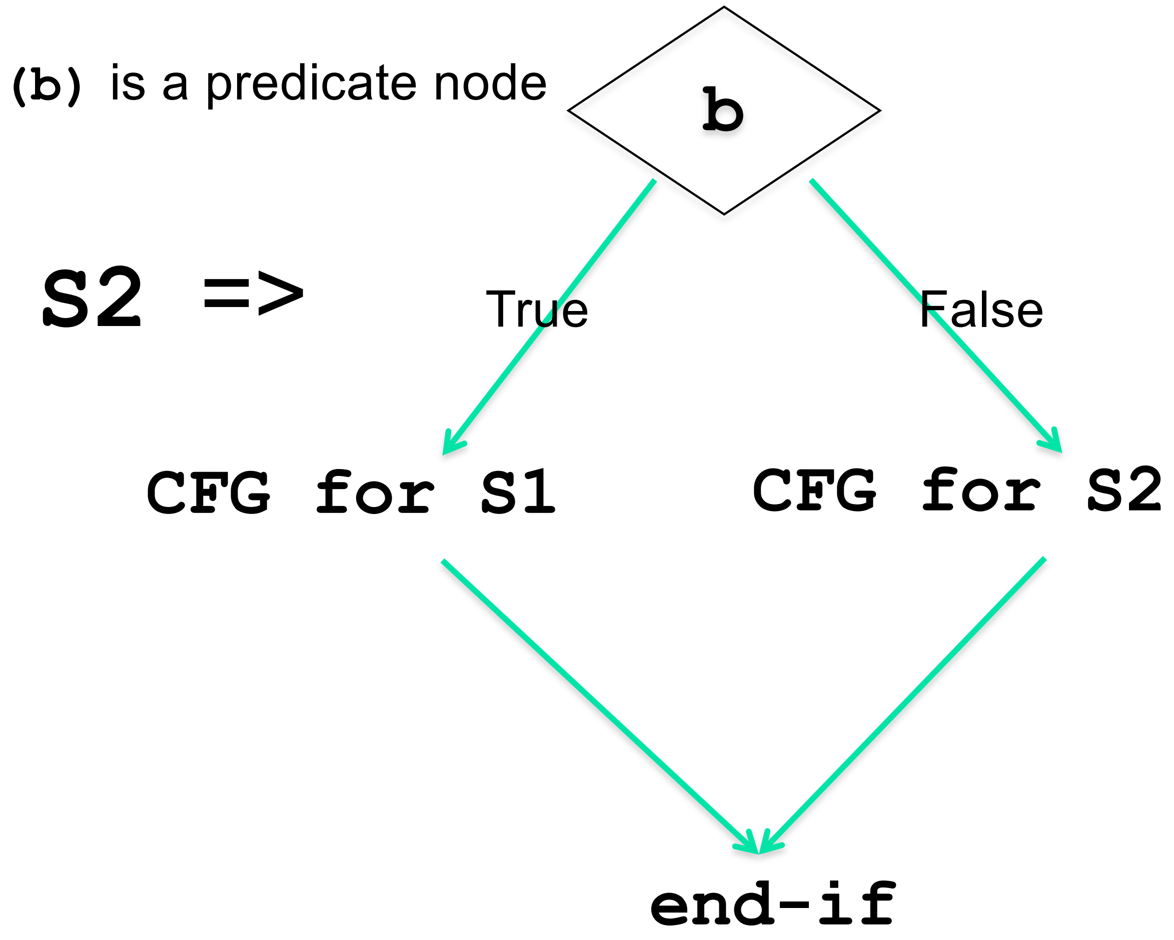
- Choose test inputs at the edges of input equivalence classes
- Choose test inputs that produce outputs at the edges of output equivalence classes
- Other boundary cases
  - Arithmetic: zero, overflow
  - Objects: null, circular list, aliasing

Control-flow Graph (CFG)

- Assignment **`x=y+z`** => node in CFG: $\boxed{\texttt{x=y+z}}$

- If-then-else

`if (b) S1 else S2 =>`

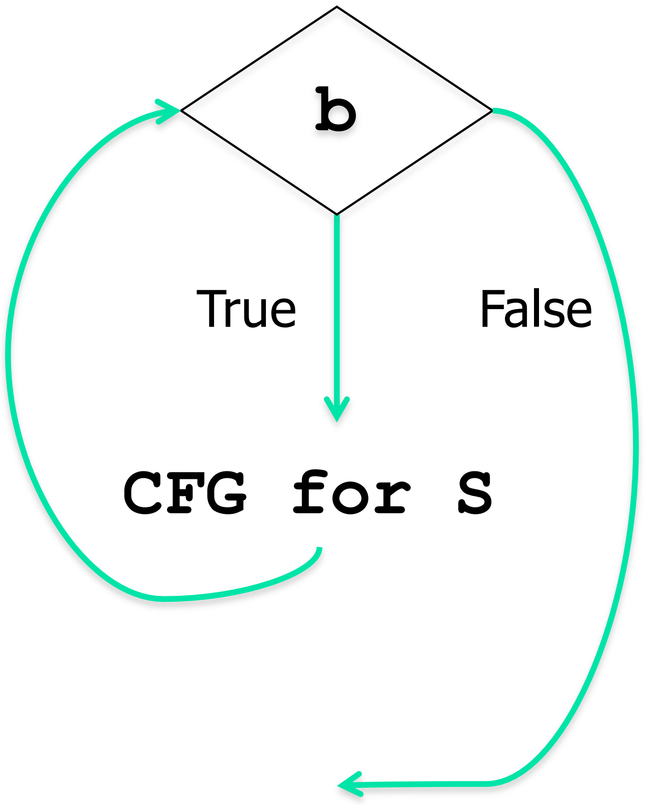


Control-flow Graph (CFG)

- Loop

`while (b) S   =>`

`(b)` is a predicate node



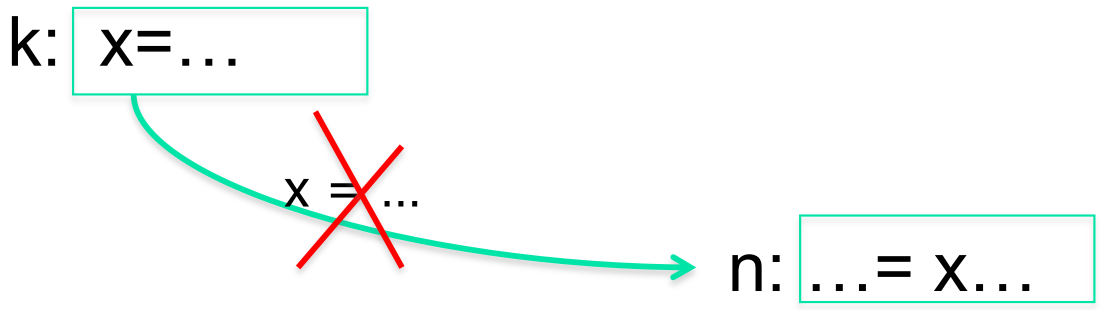
Coverage

- Statement coverage: Write a test suite that covers all statements, or in other words, all nodes in the CFG

- Branch coverage: write a test suite that covers all branch edges at predicate nodes
  - The True and False edge at if-then-else
  - The two branch edges corresponding to the condition of a loop
  - All alternatives in a SWITCH statement

White Box Testing: Dataflow-based Testing

- A definition (def) of x is x at the left-hand-side
  - E.g., x = y+z, x = x+1, x = foo(y)
- A use of x is when x is at the right-hand side
  - E.g., z = x+y, x = x+y, x>y, z = foo(x)
- A def-use pair of x is a pair of nodes, k and n in the CFG, s.t. k is a def of x, n is a use of x, and there is a path from k to n free of definition of x



White Box Testing: Dataflow-based Testing

- Dataflow-based testing targets: write tests that cover paths between def-use pairs
- Intuition:
  - If code computed a wrong value at a def of x, the more uses of this def of x we "cover", the higher the possibility that we'll expose the error
  - If code had erroneous use of x, the more def-use pairs we "cover", the higher the possibility that we'll expose the error at the use of x

A Buggy `gcd`

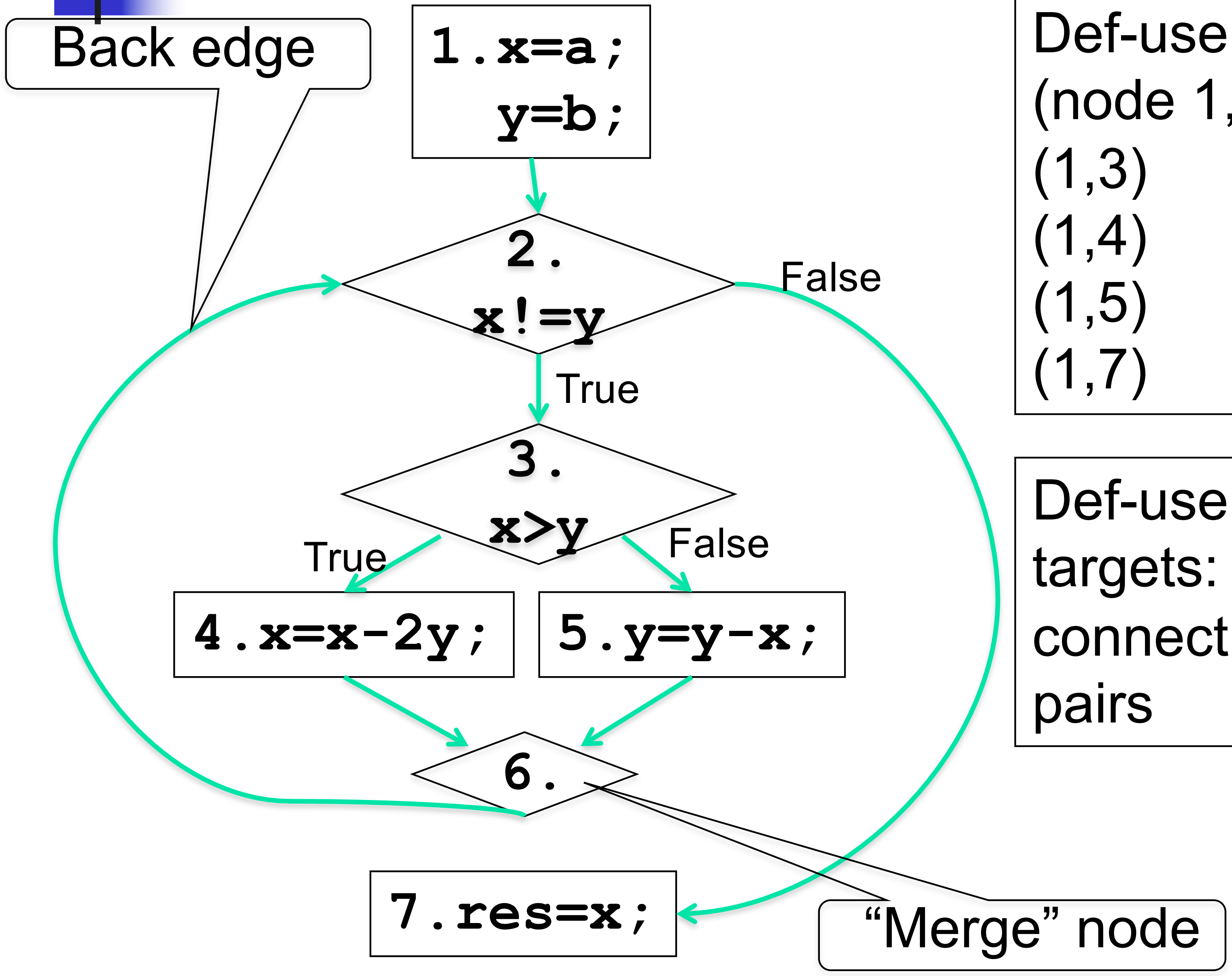
// requires a,b > 0

```
static int gcd(int a, int b) {
     int x=a;
     int y=b;
     while (x != y) {
          if (x > y) {
               x = x – 2y;
          } else {
               y = y – x;
          }
     }
     return x;
}
```

Let’s test with **`gcd(15,6)`** and **`gcd(4,8)`**.

What’s the statement coverage? Branch?

CFG for Buggy GCD



Def-use pairs for x:	
(node 1, node 2)	(4,2)
(1,3)	(4,3)
(1,4)	(4,4)
(1,5)	(4,5)
(1,7)	(4,7)

Def-use coverage targets: cover paths connecting def-use pairs

Def-use Coverage Targets

- The All-defs coverage target: for every def x, cover at least one path (free of definition of x), to at least one use x
- The All-uses coverage target: for every def-use pair of x, cover at least one path (free of definition of x) from the def x to the use x
- The All-du-paths coverage target: for every def-use pair of x, cover every path (free of definition of x) from the def x to the use x

Topics

- Exceptions
  - Preconditions vs. exceptions, throwing and catching, propagation down the call stack, exceptions vs. special values, checked vs. unchecked exceptions

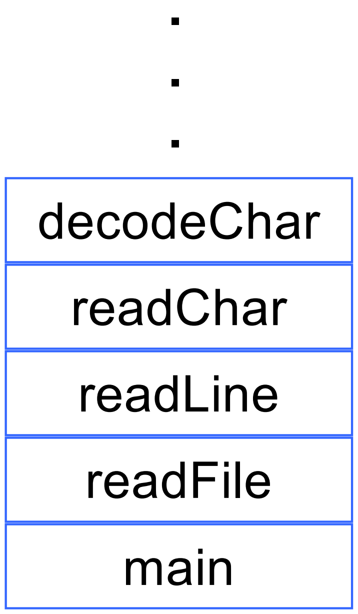
Preconditions vs. Exceptions

- In certain cases, preconditions are a valid choice
  - When checking is expensive. E.g., binarySearch
  - In private methods, usually used in local context

- Whenever possible, <u>remove preconditions</u> from public methods and specify behavior
  - Usually, this entails throwing an Exception
  - Stronger spec, easier to use by client

Throwing and Catching

- Java maintains a call stack of methods that are currently executing
- When an exception is thrown, control transfers to the nearest method with a matching **`catch`** block
  - If none found, top-level handler
- Exceptions allow for non-local error handling
  - A method far down the call stack can handle a deep error!



Informing the Client of a Problem

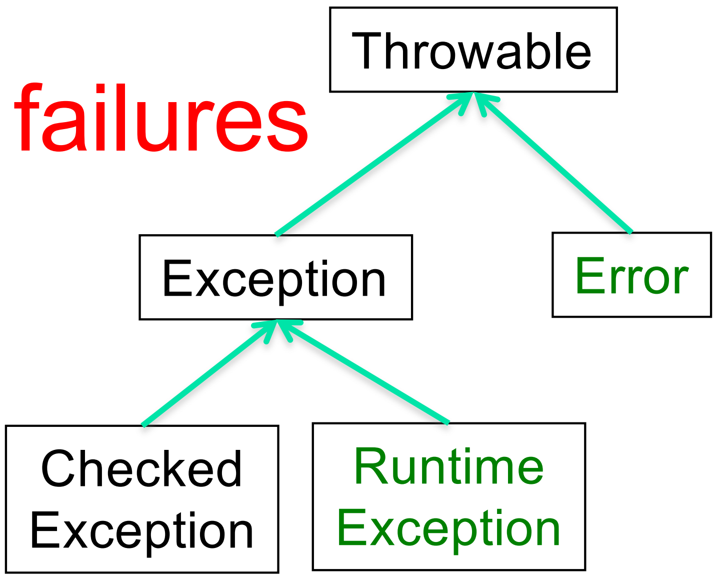
- Special value
  - **`null – Map.get(x)`**
  - **`-1 – List.indexOf(x)`**
  - **`NaN – sqrt`** of negative number
- Problems with using special value
  - Hard to distinguish from real values
  - Error-prone: programmer forgets to check result? The value is illegal and will cause problems later
  - Ugly
- Exceptions are generally a better way to inform of a problem

Two Distinct Uses of Exceptions

- Failures
  - Unexpected by your code
  - Usually unrecoverable. If condition is left unchecked, exception propagates down the stack
- Special results
  - Expected by your code
  - Unknowable for the client of your code
  - Always check and handle locally. Take special action and continue computing

Java Exceptions: Checked vs. Unchecked Exceptions

- Checked exceptions. For special results
  - Library: must declare in signature
  - Client: must either catch or declare in signature
  - It is guaranteed there is a dynamically enclosing catch
- Unchecked exceptions. For failures
  - Library: no need to declare
  - Client: no need to catch
  - RuntimeException and Error



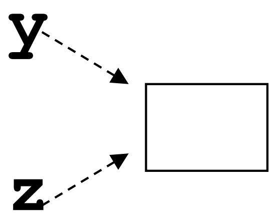
Topics

- Equality
  - Properties of equality, reference vs. value equality, equality and inheritance, **`equals`** and **`hashCode`**, equality and mutation

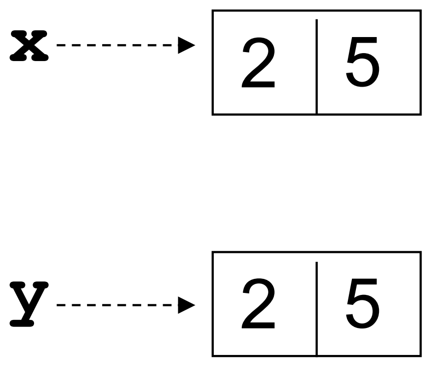
Equality: `==` and `equals()`

- In Java, `==` tests for reference equality. This is the strongest form of equality

- Usually we need a weaker form of equality, value equality



- In our `Point` example, we want `x` to be "equal" to `y` because the `x` and `y` objects hold the same value
  - Need to override Object.equals



Properties of Equality

- Equality is an equivalence relation
  - Reflexive a.equals(a)
  - Symmetric a.equals(b) ⇔ b.equals(a)
  - Transitive a.equals(b) ∧ b.equals(c) ⇒ a.equals(c)

Equality and Inheritance

- Let **`B extend A`**
- “Natural” definition of **`B.equals(Object)`** may lose symmetry
- “Fix” may render **`equals()`** non-transitive

- One can avoid these issues by defining equality for exact classes (has pitfalls too)

```
if (!o.getClass().equals(getClass()))
  return false;
```

`equals` and `hashCode`

- **`hashCode`** computes an index for the object (to be used in hashtables)
- Javadoc for **`Object.hashCode()`**:
  - "Returns a hash code value of the object. This method is supported for the benefit of hashtables such as those provided by HashMap."
  - Self-consistent: **`o.hashCode() == o.hashCode()`**

  … as long as **`o`** does not change between the calls
  - Consistent with **`equals()`** method: **`a.equals(b)`** **`=> a.hashCode() == b.hashCode()`**

Equality, mutation and time

- If two objects are equal now, will they always be equal?
  - In mathematics, the answer is “yes”
  - In Java, the answer is “you choose”
  - The Object spec does not specify this
- For immutable objects
  - Abstract value never changes, equality is eternal
- For mutable objects
  - We can either compare abstract values now, or
  - be eternal (can’t have both since value can change)

Equality and Mutation

- Client may violate rep invariant of a Set container (rep invariant: there are no duplicates in set) by mutating elements after insertion

```
Set<Date> s = new HashSet<Date>();
Date d1 = new Date(0);
Date d2 = new Date(1);
s.add(d1);
s.add(d2);
d2.setTime(0); // mutation after d2 already in the Set!
for (Date d : s) { System.out.println(d); }
```

Topics

- <u>Subtyping vs. subclassing</u>
  - Subtype polymorphism, true subtypes and the LSP, specification strength and comparing specifications (again), Function subtyping

Subtype Polymorphism

- Subtype polymorphism – the ability to use a subclass where a superclass is expected
  - Thus, dynamic method binding

    override `A.m`
    - `class A { void m() { … } }`
    - `class B extends A { void m() { … } }`
    - `class C extends A { void m() { … } }`
    - Client: `A a; … a.m();` // Call `a.m()` can bind to any of `A.m`, `B.m` or `C.m` at runtime!
- Subtype polymorphism is a language feature --- essential object-oriented language feature
  - Java subtype: B extends A or B implements I
  - A Java subtype is not necessarily a true subtype!

Benefits of Subtype Polymorphism

- “Science” of software design teaches Design Patterns
- Design patterns promote design for extensibility and reuse
- Nearly all design patterns make use of subtype polymorphism

Subtypes are Substitutable

- Subtypes are substitutable for supertypes
  - Instances of subtype won’t surprise client by expecting more than the supertype
  - Instances of subtypes won’t surprise client by failing to satisfy supertype postcondition
- B is a true subtype (or “behavioral” subtype) of A if B has stronger specification than A
  - Not the same as Java subtype!
  - Java subtypes that are not true subtypes are confusing and dangerous

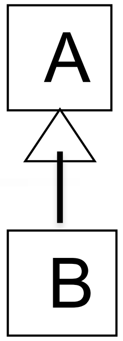
Liskov Substitution Principle (LSP)

- Due to Barbara Liskov, Turing Award 2008
- LSP: A subclass B should be substitutable for its superclass A. I.e., B is a true subtype of A
- To ensure that B is substitutable:
  - B does not remove methods from A
  - For each B.m that “replaces” A.m, B.m’s specification is stronger than A.m’s specification
    - Client: **`A a; … a.m(int x, int y);`** Call **`a.m`** can bind to B’s **`m`**. B’s **`m`** should not surprise client

Function Subtyping

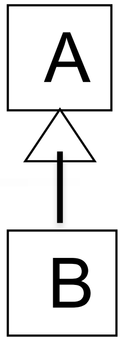
- In programming languages function subtyping deals with substitutability of functions
  - Question: under what conditions on the parameter and return types A,B,C and D, is function A f(B) substitutable for C f(D)
  - Reasons at the level of the type signature
  - Rule: A f(B) is a function subtype of C f(D) if A is a subtype of C and B is a supertype of D
    - Guarantees substitutability

Type Signature of Substituting Method is Stronger



- Method parameters (inputs):
  - Parameter types of A.m may be replaced by <u>super</u>types in <u>sub</u>class B.m. ”contravariance”
    - E.g., A.m(String p) and B.m(Object p)
  - B.m places <u>no extra requirements</u> on the client!
    - E.g., client: `A a; … a.m(q)`. Client knows to provide `q` a String. Thus, client code will work fine with `B.m(Object p)`, which asks <u>for less</u>: an Object, and clearly, every String is an Object
  - Java <u>does not allow change of parameter types</u> in an overriding method. More on Java overriding shortly

Type Signature of Substituting Method is Stronger



- Method returns (results):
  - Return type of A.m may be replaced by subype in subclass B.m. "covariance"
    - E.g., Object A.m() and String B.m()
  - B.m does not violate expectations of the client!
    - E.g., client: `A a; … Object o = a.m()`. Client expects an Object. Thus, String will work fine
  - No new exceptions unless B.m has weaker preconditions. Exceptions subtypes are ok.
  - Java does allow a subtype return type in an overriding method!

Reasoning about Specs

- Function subtyping reasons with type signatures
- Remember, type signature is a specification
  - Precondition: requires arguments of given type
  - Postcondition: promises result of given type
- Compiler checks function subtyping
- Specifications add reasoning about behavior and effects
  - Precondition: stated by requires clause
  - Postcondition: stated by modifies, effects, returns and throws clauses

Reason about Specs

- "Behavioral" subtyping generalizes function subtyping
- B.m is a true subtype (behavioral subtype) of A.m
  - B.m has <u>weaker</u> precondition than A.m
    - Generalizes "B.m's parameter is a <u>super</u>type of A.m's parameter" premise of function subtyping rule
    - Contravariance
  - B.m has <u>stronger</u> postcondition than A.m
    - Generalizes "B.m's return is a <u>sub</u>type of A.m's return"
    - Covariance
  - These 2 conditions guarantee B.m's spec is stronger than A.m's spec, and B.m is substitutable for A.m