6.005 Elements of Software Construction

Fall 2008

6.005 elements of software construction

rep invariants, equality, visitors

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plan for today

recall strategy for avoiding bugs

- make them impossible
- don't insert them
- make them easy to find

topics

- advice on implementing types
- equality and how to code it
- rep invariants & how to exploit them

patterns

- Iterator and Visitor

advice on implementing types

step 1: design a rep

desiderata

- easy to program (and get right!)
- good enough performance

usually

- a couple of fields of existing types suffices
- so before inventing a complex type, check Java collections and your own

sometimes

- a tricky structure or algorithm is needed
- first, see if someone's done it before (eg, look it up in CLR book)

always

- write a rep invariant to clarify the design

step 2: write the methods

more on hashCode
in part 3 of course

required methods first

- from Object class: equals, hashCode, to String
- from any interface the class implements
- when overriding, mark with @Override

constructors

- for an immutable type, some private constructors often help

producers (return new values of type) and observers (return other types)

- whenever possible, build on each other
- separate core methods (eg, size) from those that sit on top (eg. isEmpty)

incomplete methods

- use UnsupportedOperationException to get it to compile

step 3: rep invariant

code the rep invariant

- as a checkRep method
- for immutables, call it at the end of all constructors

as you write the operations

- ask yourself **why** they preserve the rep invariant

step 4: assertions and tests

runtime assertions

- are your friend: use them freely
- turn on by adding `-ea` to VM args in Eclipse

write JUnit test suite for your class

- will help you find bugs earlier, and make debugging easier
- take the trouble to write a `toString` that produces helpful output

equality: basics

fundamentals

objects often used as keys

- need to compare them
- eg, Literal used as key in Environment

Java convention

- the class Object has a method that every class inherits

  Object.equals: Object -> boolean

- by convention, this method is used to compare objects for equality
- collections especially assume this: call equals on keys
- the inherited method is usually wrong for immutable types
- so must override by explicitly declaring a method

  MyType.equals: Object -> boolean

why inherited equality fails

the problem

- Object.equals compares objects with ==
- this makes any two distinct objects unequal
- even if they have the same value

example

- the "same" pairs are unequal:

```
public class Pair {
    private int fst, snd;
    public Pair (int f, int s) {fst=f; snd=s;}

    public static void main (String[] args) {
        Pair p1 = new Pair (1, 2);
        Pair p2 = new Pair (1, 2);
        System.out.println (p1 == p2 ? "yes" : "no");
        System.out.println (p1.equals(p2) ? "yes" : "no");
    }
}
```

standard equals method

correct code for Pair.equals

- compare the fields

```
@Override
public boolean equals (Object that) {
    if (this == that) return true;
    if (!(that instanceof Pair)) return false;
    Pair p = (Pair) that;
    return p.fst == fst && p.snd == snd;
}
```

remember: comparison is with any object reference

- need to check type of arg, and whether null
- you may be tempted to write this, but don't: it will just overload equals

```
public boolean equals (Pair that) {...}
```

- write @Override and compiler will catch the bug

a design puzzle

interning objects

- suppose you have a structure containing objects of type C
- you want to intern them: that is, have one object for each value
- so you write this code, but it won't work (why not?)

```
public class C {
    private String s;
    public static Map<C,C> allocated = new ListMap<C,C>();
    public C intern () {
        C c = allocated.get(this);
        if (c == null) {
            allocated = allocated.put(this, this);
            return this;
        }
        return c;
    }
}
```

approaches

the problem: one equals method

- if it compares references with ==, then lookup won't find match
- it it compares values, then interning is pointless!

have collection take equality predicate as argument

- can't use standard Java collections: will have to make your own
- but see use of comparator objects in ordered types like java.util.TreeSet

use component as key instead of whole object

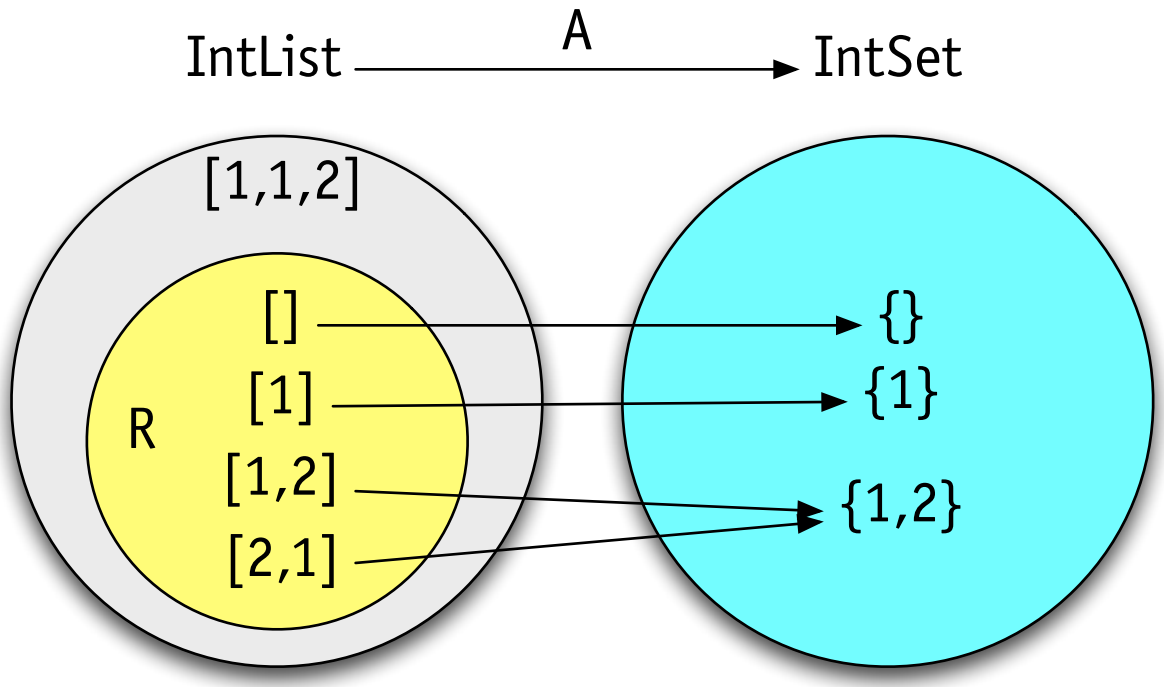
- eg, allocated maps String to C
- this is how the factory method of PosLiteral works (previous lecture)

for key, make wrapper around C object with its own equals

- not terrible, but a bit ugly

rep invariants

R/A



rep invariant R

- defines set of legal representation values
- documented and implemented as checkRep

abstraction function A

- interprets legal representation values as abstract values
- documented and implemented as toString

how to establish invariants

for state machines

- establish invariant in initial state
- ensure that all transitions preserve invariant

for mutable types, the same approach

- a mutable object *is* a state machine

for immutable types, a similar story

- objects can't change
- assume any argument you're given satisfies the invariant
- ensure any result you create satisfies it too

who gets to preserve the invariant?

- by hiding the rep, can limit to the methods of the ADT itself

implications

a strong invariant means

- methods can assume more about arguments
- allows checks to be omitted and optimizations to be applied
- but methods must do more to ensure results satisfy invariant

rep design = rep invariant

- the choice of rep invariant characterizes the design of the rep!

common invariants

these invariants

- are commonly used
- provide concrete benefits

examples

- **no nulls**: no need to check before calling method
- **acyclic**: no need to worry about looping
- **ordered**: can navigate efficiently; can stop when key value is passed
- **no duplicates**: can stop when find first match
- **caching**: can do fast look up

example: invariant for Clause

writing the invariant

rep invariant for Clause written as executable method

```
public class Clause {
    private final List<Literal> literals;
    static final boolean CHECKREP = true;
    void checkRep () {checkRep (literals);}
    void checkRep (List<Literal> ls) {
        assert ls != null : "Clause, invariant: literals non-null";
        if (!ls.isEmpty()) {
            Literal first = ls.first(); List<Literal> rest = ls.rest();
            assert first != null : "Clause, invariant: no null elements";
            assert !rest.contains(first) : "Clause, invariant: no duplicates";
            assert !rest.contains(first.getNegation()) : "Clause, invariant: no literal
and its negation";
            checkRep (rest);
        }
    }
    private Clause(List<Literal> literals) {
        this.literals = literals;
        if (CHECKREP) checkRep();
    }...
}
```

flag to turn expensive check off

messages give invariant informally

check rep for each constructed value

what's the computational cost of checkRep?

exploiting the invariant

an equals method for Clause

```
@Override
public boolean equals (Object that) {
    if (this == that) return true;
    if (!(that instanceof Clause)) return false;
    Clause c = (Clause) that;
    if (size() != c.size()) return false;
    for (Literal l: literals)
        if (!(c.contains(l))) return false;
    return true;
}
```

how invariant is exploited

- since literals is non-null, can use in for-loop without null check

  implicit call to literals.iterator will throw exception if literals is null

- since no duplicate literals, can check containment in one direction only

  that is, given two sets S and T: $S = T \Leftrightarrow \#S = \#T \wedge S \subseteq T$

preserving the invariant

no free lunch

- you have to do some work to establish the invariant

example: Clause.add

```
/**
 * Add a literal to this clause; if already contains the literal's negation, return null
 * Requires: l is non-null
 * @return the new clause with the literal added, or null
 */
public Clause add(Literal l) {
        if (literals.contains(l)) return this;
        if (literals.contains(l.getNegation())) return null;
        return new Clause(literals.add(l));
    }
```

- what impact does each part of the invariant have?

exploiting the invariant

exercise: how does reduce exploit the invariant?

```
/**
 * Requires: literal is non-null
 * @return clause obtained by setting literal to true
 * or null if the entire clause becomes true
 */
public Clause reduce(Literal literal) {
    List<Literal> reducedLiterals = reduce(literals, literal);
    if (reducedLiterals == null) return null;
    else return new Clause(reducedLiterals);
}
private static List<Literal> reduce(List<Literal> literals, Literal l) {
    if (literals.isEmpty()) return literals;
    Literal first = literals.first();
    List<Literal> rest = literals.rest();
    if (first.equals(l)) return null;
    else if (first.equals(l.getNegation())) return rest;
    else {
        List<Literal> restR = reduce(rest, l);
        if (restR == null) return null;
        return restR.add(first);
    }
}
```

iterator pattern

iteration in Java

recall how our solver found a minimal clause

- iterate over clauses

```
Clause min = null;
 for (Clause c : clauses) {
     if (c.isEmpty()) return null;
     if (min == null || c.size() < min.size()) min = c;
     }
  ...
```

how does this work?

- hidden iterator at play

the iterator pattern

a Java shorthand

- the statement

```
for (E e: c) {...}
```

- is short for

```
Iterator i = c.iterator();
while (i.hasNext()) {
    E e = i.next();
    ...
    }
```

iterator interface

```
public interface Iterator<E> {
    boolean hasNext ();
    E next ();
    void remove ();
}
```

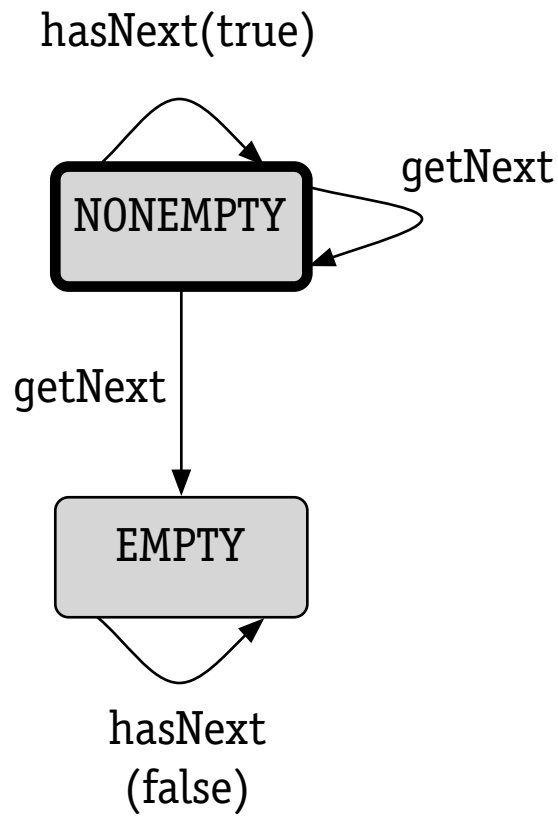
list iterator

```
public class ListIterator<E> implements Iterator<E> {
    List<E> remaining;
    public ListIterator (List<E> list) {
        remaining = list;
    }
    public boolean hasNext () {
        return !remaining.isEmpty();
    }
    public E next () {
        E first = remaining.first ();
        remaining = remaining.rest();
        return first;
    }
}
```

iterator method

```
public abstract class List<E> implements Iterable<E>
    public Iterator<E> iterator () {
        return new ListIterator<E>(this);
        }
}
```

iterator state machine



why a stateful object in a side-effect free program?

- the only convenient way to do iteration in Java
- so long as iterator used only in for loop as shown, no mutability issues arise

visitor pattern

localizing functions

Interpreter pattern: look what we're doing

- declare function over datatype

```
size: List<T> -> int   where   List<T>  = Empty + Cons (first: T, rest: List<T>)
```

- break function into cases, one per variant

```
size (Empty) = 0
size (Cons(first:e, rest: l)) = 1 + size(l)
```

- but then split cases across classes! can't we keep them together?
- in functional language can do exactly this: (in ML, eg)

```
fun size Empty = 0
    | Cons(e, l) = 1 + size(l)
```

solution: localize function definition in "visitor"

- hard to grasp first time, but easy once you know the pattern
- a useful and common idiom, esp. for compilers
- good check of your understanding of dynamic dispatch & overloading

basic visitor structure

- visitor

```
public interface ListIntVisitor<E> {
    int onEmpty (Empty<E> l);
    int onCons (Cons<E> l);
}
public class SizeVisitor<E> implements ListIntVisitor<E>{
    public int onEmpty(Empty<E> l) {return 0;}
    public int onCons(Cons<E> l) {return 1 + l.rest().accept(this);}
}
```

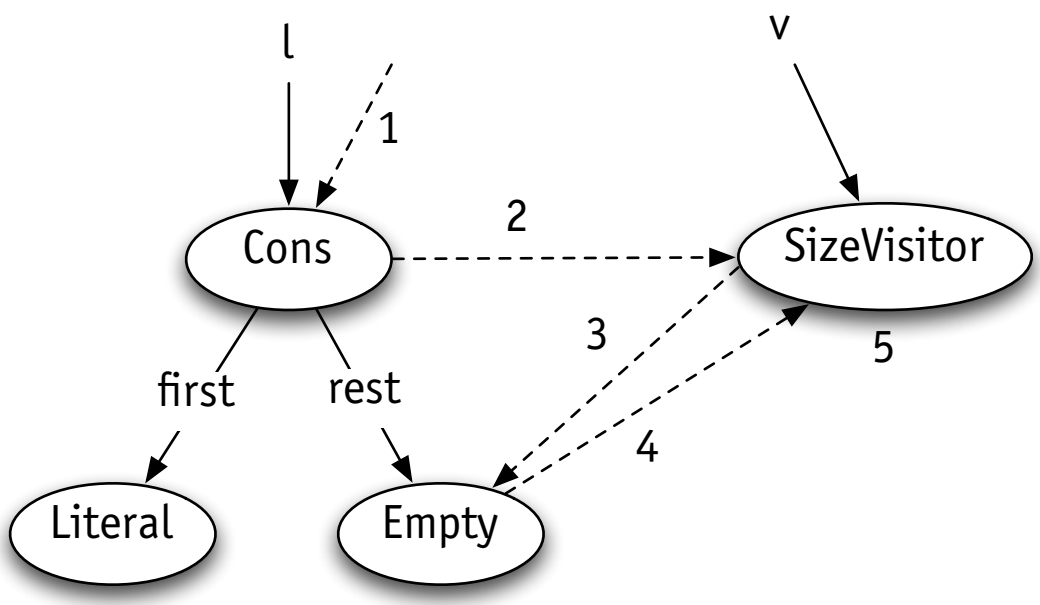
- datatype and variants

```
public abstract class List<E> {
    public abstract int accept(ListIntVisitor<E> visitor);
}
public class Empty<E> extends List<E> {
    public int accept(ListIntVisitor visitor) {return visitor.onEmpty(this);}
}
public class Cons<E> extends List<E> {
    public int accept(ListIntVisitor<E> visitor) {return visitor.onCons(this);}
}
```

- usage

```
int size = myList.accept(new SizeVisitor<E>());
```

the visitor carousel



1:l.accept(v)
2:v.onCons(l)
3:l.rest().accept(v) + 1
4:v.onEmpty(e)
5: return 0

note how

- control passes back and forth between visitor and datatype objects
- function is computed at visitor (steps 3 and 5)

going polymorphic

accept methods only work for visitor that returns integer

```
public interface ListIntVisitor<E> {
    int onEmpty (Empty<E> l);
    int onCons (Cons<E> l);
}
```

so make the visitor polymorphic

- new interface

```
public interface ListVisitor<E,T> {
    T onEmpty (Empty<E> l);
    T onCons (Cons<E> l);
}
```

- new accept methods

```
public <T> T accept(ListVisitor<E,T> visitor) {return visitor.onEmptyList(this);}
```

- new visitor

```
public class SizeVisitor<E> implements ListVisitor<E,Integer>{
    public Integer onEmpty(Empty<E> l) {return 0;}
    public Integer onCons(Cons<E> l) {return 1 + l.rest().accept(this);}
}
```

final refinement

accept method is almost boilerplate

```
public class Cons<E> extends List<E> {
    public int accept(ListIntVisitor<E> visitor) {return visitor.onCons(this);}
}
```

can make identical by exploiting overloading

- new interface

```
public interface ListVisitor<E,T> {
    T visit (Empty<E> l);
    T visit (Cons<E> l);
}
```

- new accept method: same in all variants

```
public <T> T accept(ListVisitor<E,T> visitor) {return visitor.visit(this);}
```

- new visitor

```
public class SizeVisitor<E> implements ListVisitor<E,Integer>{
    public Integer visit (Empty<E> l) {return 0;}
    public Integer visit (Cons<E> l) {return 1 + l.rest().accept(this);}
}
```

summary

principles

use rep invariants to prevent bugs

- and to make them easier to find
- design of type = rep invariant

equality is tricky

- for immutables, compare contents not object refs
- (not covered in lecture) if you override equals, must override hashCode too

visitor pattern

- some boilerplate code in datatypes
- allows one function/class