CSE 331
Software Design & Implementation

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Identity, `equals`, and `hashCode`

Overview

- Using the libraries reduces bugs in most cases
  - take advantage of code already inspected & tested

- In Java, collection classes depend on `equals` and `hashCode`
  - EJ 47: "Know and use the libraries"
    - "every programmer should be familiar with the contents of java.lang and java.util"
  - e.g., `List` may not work properly if `equals` is wrong
  - e.g., `HashSet` may not work properly of `hashCode` is wrong

`Object.equals` method

```
public class Object {
  public boolean equals(Object o) {
    return this == o;
  }
  …
}
```

- Implements reference equality
- Subclasses can override to implement a different equality
- But library includes a *contract* **`equals`** should satisfy
  - Reference equality satisfies it
  - So should *any* overriding implementation
  - Balances flexibility in notion-implemented and what-clients-can-assume even in presence of overriding

`equals` specification

`public boolean equals(Object obj)` should be:

- *reflexive*: for any reference value `x`, `x.equals(x) == true`
- *symmetric*: for any reference values `x` and `y`, `x.equals(y) == y.equals(x)`
- *transitive*: for any reference values `x`, `y`, and `z`, if `x.equals(y)` and `y.equals(z)` are `true`, then `x.equals(z)` is `true`
- *consistent*: for any reference values `x` and `y`, multiple invocations of `x.equals(y)` consistently return `true` or consistently return `false` (provided neither is mutated)
- For any *non-null* reference value `x`, `x.equals(null)` should return `false`

Overriding equals

```
public class Duration {
    @Override
    public boolean equals(Object o) {
       if (!(o instanceof Duration))
         return false;
       Duration d = (Duration) o;
       return this.min==d.min && this.sec==d.sec;
    }
}
```

- Correct and idiomatic Java
- Cast cannot fail
- Gets `null` case right too (`null instanceof C` always `false`)

Overloading vs Overriding

- Methods in Java are identified by the *signature*
  - name + argument types

- Classes can have only one method with a given signature
  - subclass method **overrides** superclass method with its own

- Classes can have many methods with the same name
  - e.g., `List.add(Object)` and `List.add(int, Object)`
  - this is called **overloading**

Java Method Calls

- Signature of the method to call is chosen at **compile time**
  - suppose class has `equals(Object)` and `equals(Duration)`
  - `x.equals(d1)` becomes a call to `equals(Duration)`, best match
  - `x.equals(o1)` becomes a call to `equals(Object)`, only match

- Finding the method with that signature to call happens at **run time**
  - Java looks in the actual class of x (at run time)
  - if it has a method with that signature, that method is called
  - otherwise, it continues looking in the superclass (recursively)

DEMO

```
public static void main(String[] args) {
  Duration d1 = new Duration(10,5);
  Duration d2 = new Duration(10,5);
  Object o1 = d1;
  Object o2 = d2;
  System.out.println(d1.equals(d2));  // equals(Duration)   true
  System.out.println(o1.equals(o2));  // equals(Object)     false
  System.out.println(d1.equals(o2));  // equals(Object)     false
  System.out.println(o1.equals(d2));  // equals(Object)     false
  System.out.println(d1.equals(o1));  // equals(Object)     true
}
```

javap –c Duration

```
27: getstatic     #19                 // Field java/lang/System.out:Ljava/io/PrintStream;
30: aload_1
31: aload_2
32: invokevirtual #25                 // Method equals:(LDuration;)Z
35: invokevirtual #29                 // Method java/io/PrintStream.println:(Z)V
38: getstatic     #19                 // Field java/lang/System.out:Ljava/io/PrintStream;
41: aload_3
42: aload         4
44: invokevirtual #35                 // Method java/lang/Object.equals:(Ljava/lang/Object;)Z
47: invokevirtual #29                 // Method java/io/PrintStream.println:(Z)V
50: getstatic     #19                 // Field java/lang/System.out:Ljava/io/PrintStream;
53: aload_1
54: aload         4
56: invokevirtual #38                 // Method equals:(Ljava/lang/Object;)Z
59: invokevirtual #29                 // Method java/io/PrintStream.println:(Z)V
62: getstatic     #19                 // Field java/lang/System.out:Ljava/io/PrintStream;
65: aload_3
66: aload_2
67: invokevirtual #35                 // Method java/lang/Object.equals:(Ljava/lang/Object;)Z
70: invokevirtual #29                 // Method java/io/PrintStream.println:(Z)V
73: getstatic     #19                 // Field java/lang/System.out:Ljava/io/PrintStream;
76: aload_1
77: aload_3
78: invokevirtual #38                 // Method equals:(Ljava/lang/Object;)Z
81: invokevirtual #29                 // Method java/io/PrintStream.println:(Z)V
84: return
```

Equality, mutation, and time

If two objects are equal now, will they always be equal?

- in mathematics, “yes”
- in Java, “you choose”
- `Object` contract doesn't specify

For immutable objects:

- abstract value never changes
- equality should be forever (even if rep changes)

For mutable objects, either:

- use reference equality (never changes)
- not forever: mutation changes abstract value hence equals

Common source of bugs...

Examples

`StringBuilder` is mutable and sticks with reference-equality:

```
StringBuilder s1 = new StringBuilder("hello");
StringBuilder s2 = new StringBuilder("hello");
s1.equals(s1); // true
s1.equals(s2); // false
```

By contrast:

```
Date d1 = new Date(0); // Jan 1, 1970 00:00:00 GMT
Date d2 = new Date(0);

d1.equals(d2); // true
d2.setTime(1);
d1.equals(d2); // false
```

Behavioral and observational equivalence

Two objects are "behaviorally equivalent" if there is no sequence of operations (excluding ==) that can distinguish them

Two objects are "observationally equivalent" if there is no sequence of *observer* operations that can distinguish them

- excludes mutators and ==

Equality and mutation

`Date` class implements (only) observational equality

```
Set<Date> s = new HashSet<Date>();
Date d1 = new Date(0);
Date d2 = new Date(1000);
s.add(d1);
s.add(d2);
d2.setTime(0);

for (Date d : s) { // prints two of same date
    System.out.println(d);
}
```

Violates rep invariant of a `Set` by mutating after insertion

Pitfalls of observational equivalence

Have to make do with caveats in specs:

> *"Note: Great care must be exercised if mutable objects are used as set elements. The behavior of a set is not specified if the value of an object is changed in a manner that affects equals comparisons while the object is an element in the set."*

Same problem applies to keys in maps

Same problem applies to mutations that change hash codes

Especially hard bugs to detect! (Be frightened!)

- failure doesn't show up on the line with the bug (e.g., setTime)

Easy to cause when modules don't list everything they **mutate**

- why we need `@modifies`

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!)

Some other languages have tools to prevent this
- e.g., Python
- I would include similar tools in any new language

Summary

- Different notions of equality:
  - reference equality stronger than
  - behavioral equality stronger than
  - observational equality

- Java's **`equals`** has an elaborate specification, but does not require any one of the above notions
  - concepts more general than Java

- Mutation and/or subtyping make things even murkier
  - more on this later…
  - good reason not to overuse/misuse either

`hashCode`

Another method in **`Object`**:

```
public int hashCode()
```

"Returns a hash code value for the object. This method is supported for the benefit of hash tables such as those provided by **`java.util.HashMap`**."

Contract (again essential for correct overriding):

- Self-consistent: **`o.hashCode()`** is fixed (unless **`o`** is mutated)
- Consistent with equality:

  `a.equals(b)` implies **`a.hashCode() == b.hashCode()`**

Contrapositive: **`a.hashCode() != b.hashCode()`** implies **`!a.equals(b)`**

Think of it as a pre-filter

- If two objects are equal, they *must* have the same hash code
  - up to implementers of **`equals`** and **`hashCode`** to satisfy this
  - **if** you override **`equals`**, you **must** override **`hashCode`**

- If objects have same hash code, they *may or may not* be equal
  - "usually not" leads to better performance
  - **`hashCode`** in **`Object`** tries to (but may not) give every object a different hash code

- If hash codes are cheaper to compute, you could first check if those are the same before doing a full comparison – a pre-filter

`hashCode`

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Want **`!a.equals(b)`** implies **`a.hashCode() != b.hashCode()`**

- but not actually in contract and (not true in most implementations)

Asides

- Hash codes are used for hash tables
  - common implementation of collection ADTs
  - see CSE332
  - libraries won't work if your classes break relevant contracts

- Cheaper pre-filtering is a more general idea
  - Example: Are two large video files the exact same video?
    - Quick pre-filter: Are the files the same size?

Recall: Duration example

```
public class Duration {
   private final int min; // RI: min>=0
   private final int sec; // RI: 0<=sec<60

   @Override
   public boolean equals(Object o) {
      if (!(o instanceof Duration))
        return false;
      Duration d = (Duration) o;
      return this.min==d.min && this.sec==d.sec;
   }
}
```

Doing it

- So: we have to override **`hashCode`** in **`Duration`**
  - Must obey contract
  - Aim for non-equals objects usually having different results
- Correct but expect poor performance:

```
public int hashCode() { return 1; }
```

- A bit better:

```
public int hashCode() { return min; }
```

- Better:

```
public int hashCode() { return min ^ sec; }
```

- Best

```
public int hashCode() { return 60*min+sec; }
```

Correctness depends on `equals`

Suppose we change the spec for `Duration`'s `equals`:

```
public boolean equals(Object o) {
  if (!(o instanceof Duration))
    return false;
  Duration d = (Duration) o;
  return min == d.min && sec/10 == d.sec/10;
}
```

Must update `hashCode` – why?

```
public int hashCode() {
  return 6*min+sec/10;
}
```