CSE 331
Software Design & Implementation

Kevin Zatloukal

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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

`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()`**

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

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

Think of it as a pre-filter

- If two objects are equal, they *must* have the same hash code
  - *contrapositive*: if they have different hash codes, then they *must not* be equal

- 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

- Hash codes are usually cheap[er] to compute, so check first if you "usually expect not equal" – a pre-filter

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: 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;
   }
}
```

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;
}
```

Summary

- Contract for **`hashCode`** requires only
  - (self-)consistency
  - consistent with equals

- Java's **`hashCode`** must be consistent with **`equals`**
  - **if** you override **`equals`**, you **must** override **`hashCode`**

- Good performance of hash tables requires that non-equal objects *usually* have different hash codes
  - does not need to be perfect

`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`**

Really fixed now

```
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
- Gets **`null`** case right (**`null instanceof C`** always **`false`**)
- Cast cannot fail

Two subclasses

```
class CountedDuration extends Duration {
  public static numCountedDurations = 0;
  public CountedDuration(int min, int sec) {
    super(min,sec);
    ++numCountedDurations;
  }
}
class NanoDuration extends Duration {
  private final int nano;
  public NanoDuration(int min, int sec, int nano){
    super(min,sec);
    this.nano = nano;
  }
  public boolean equals(Object o) { … }
  …
}
```

`CountedDuration` is (probably) fine

- **`CountedDuration`** does not override **`equals`**
  - inherits **`Duration.equals(Object)`**

- Will (implicitly) treat any **`CountedDuration`** like a **`Duration`** when checking **`equals`**
  - **`o instanceof Duration`** is true if **`o`** is **`CountedDuration`**

- Any combination of **`Duration`** and **`CountedDuration`** objects can be compared
  - equal if same contents in **`min`** and **`sec`** fields
  - works because **`o instanceof Duration`** is **`true`** when **`o`** is an instance of **`CountedDuration`**

NanoDuration is (probably) not fine

- If we don’t override **equals** in **NanoDuration**, then objects with different **nano** fields will be equal

- Using what we have learned:

```
@Override
public boolean equals(Object o) {
  if (!(o instanceof NanoDuration))
    return false;
  NanoDuration nd = (NanoDuration) o;
  return super.equals(nd) && nano == nd.nano;
}
```

- But we have violated the **equals** contract
  - Hint: Compare a **Duration** and a **NanoDuration**

The symmetry bug

```
public boolean equals(Object o) {
  if (!(o instanceof NanoDuration))
    return false;
  NanoDuration nd = (NanoDuration) o;
  return super.equals(nd) && nano == nd.nano;
}
```

This is ***not symmetric***!

```
Duration d1 = new NanoDuration(5, 10, 15);
Duration d2 = new Duration(5, 10);
d1.equals(d2); // false
d2.equals(d1); // true
```

Fixing symmetry

This version restores symmetry by using **Duration**'s **equals** if the argument is a **Duration** (and not a **NanoDuration**)

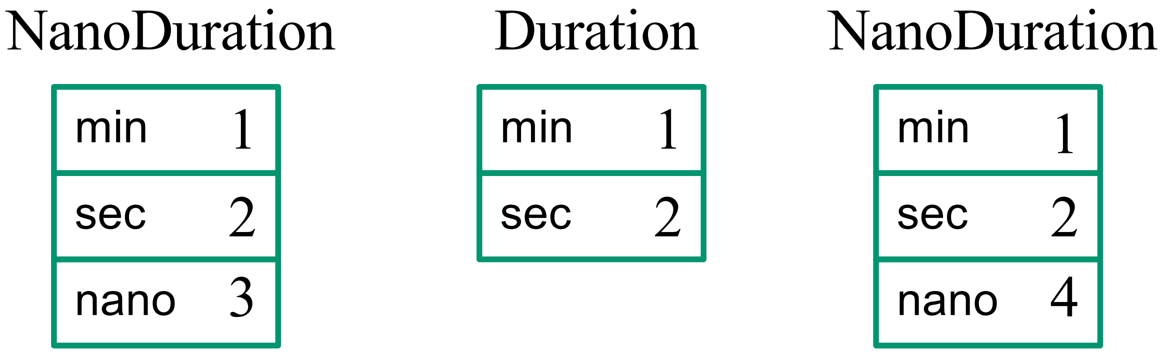
```
public boolean equals(Object o) {
  if (!(o instanceof Duration))
    return false;
  // if o is a normal Duration, compare without nano
  if (!(o instanceof NanoDuration))
    return super.equals(o);
  NanoDuration nd = (NanoDuration) o;
  return super.equals(nd) && nano == nd.nano;
}
```

Alas, this *still* violates the **equals** contract

- Transitivity…

The transitivity bug

```
Duration d1 = new NanoDuration(1, 2, 3);
Duration d2 = new Duration(1, 2);
Duration d3 = new NanoDuration(1, 2, 4);
d1.equals(d2);   // true
d2.equals(d3);   // true
d1.equals(d3);   // false!
```



NanoDuration	
min	1
sec	2
nano	3

Duration	
min	1
sec	2

NanoDuration	
min	1
sec	2
nano	4

No perfect solution

- *Effective Java* says not to (re)override **`equals`** like this
  - (unless superclass is non-instantiable)
  - generally good advice
  - but there is one way to satisfy `equals` contract (see below)

- Two less-than-perfect approaches on next two slides:
  1. Don’t make **`NanoDuration`** a subclass of **`Duration`**
      - fact that equals should be different is a hint it’s not a subtype
  2. Change **`Duration`**’s **`equals`** so only **`Duration`** objects that are not (proper) subclasses of **`Duration`** are equal

Option 1: avoid subclassing

Choose composition over subclassing (Effective Java)

- often good advice in general (we'll discuss more later on)
- many programmers overuse subclassing

```
public class NanoDuration {
  private final Duration duration;
  private final int nano;
  …
}
```

Solves some problems:

- clients can choose which type of equality to use

Introduces others:

- can't use `NanoDurations` where `Durations` are expected (since it is not a subtype)

Option 2: the `getClass` trick

Check if `o` is a `Duration` and ***not*** *a subtype*:

```
@Overrides
public boolean equals(Object o) { // in Duration
  if (o == null)
    return false;
  if (!o.getClass().equals(getClass()))
    return false;
  Duration d = (Duration) o;
  return d.min == min && d.sec == sec;
}
```

But this breaks `CountedDuration`!

- subclasses do not "act like" instances of superclass because behavior of `equals` changes with subclasses
- generally considered wrong to "break" subtyping like this

Subclassing summary

- Subtypes *should* be useable wherever the type is used
  - Liskov substitution principle

- Unresolvable tension between
  - what we want for equality: *treat subclasses differently*
  - what we want for subtyping: *treat subclasses the same*

- No perfect solution for all cases...
- Choose whether you want subtyping or not
  - in former case, don’t override equals (make it final)
  - in latter case, can still use composition instead
    - this matches the advice in *Effective Java* and from us (later)
  - almost always best to avoid getClass trick

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: mutating an object in a data structure

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

Can violate rep invariant of a **`Set`** by mutating after insertion

```
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);
}
```

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 when using **`HashSet`** or **`HashMap`**

Especially hard bugs to detect! (Be frightened!)

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

- why we need **`@modifies`**

Another container wrinkle: self-containment

`equals` and **`hashCode`** on containers are recursive:

```
class ArrayList<E> {
  public int hashCode() {
     int code = 1;
     for (Object o : list)
       code = 31*code + (o==null ? 0 : o.hashCode());
    return code;
  }
```

This causes an infinite loop:

```
List<Object> lst = new ArrayList<Object>();
lst.add(lst);
lst.hashCode();
```

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
  - requires consistency with **`hashCode`**
  - concepts more general than Java

- Mutation and/or subtyping make things even murkier
  - good reason not to overuse/misuse either