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

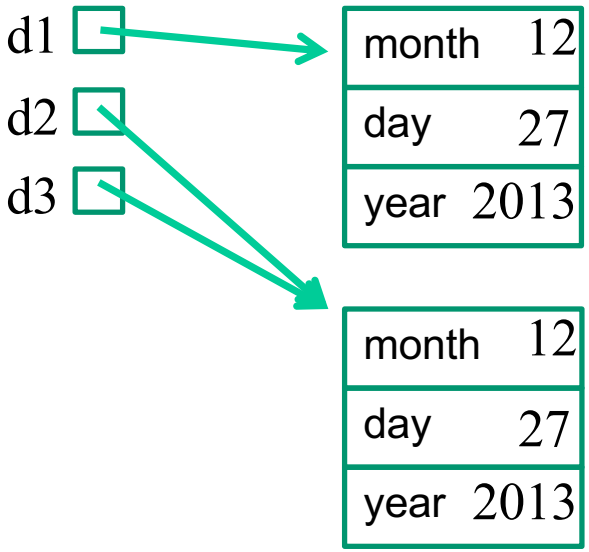
- In Java, collection classes depend on `equals` and `hashCode`
  - EJ 47: "Know and use the libraries"
    - "every programmer should be familiar with the contents of java.lang and java.util"
  - e.g., `List` may not work properly if `equals` is wrong
  - e.g., `HashSet` may not work properly of `hashCode`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

- You will need to use these for HW5+

- Same concepts exist in other languages

What might we want?

```
Date d1 = new Date(12,27,2013);
Date d2 = new Date(12,27,2013);
Date d3 = d2;
// d1==d2 ?
// d2==d3 ?
// d1.equals(d2) ?
// d2.equals(d3) ?
```



- Sometimes want equivalence relation bigger than ==
  - Java takes OOP approach of letting classes *override* **`equals`**
  - (can also be defined by a `Comparator`)

Expected properties of equality

Reflexive `a.equals(a) == true`

- Confusing if an object does not equal itself

Symmetric `a.equals(b)` **iff** `b.equals(a)`

- Confusing if order-of-arguments matters

Transitive `a.equals(b) && b.equals(c) => a.equals(c)`

- Confusing again to violate centuries of logical reasoning

A relation that is reflexive, transitive, and symmetric is an *equivalence relation*

Reference equality

- Reference equality means an object is equal only to itself
  - `a == b` only if `a` and `b` refer to (point to) the same object

- Reference equality is an equivalence relation
  - Reflexive
  - Symmetric
  - Transitive

- Reference equality is the *smallest* equivalence relation on objects
  - "Hardest" to show two objects are equal (must be same object)
  - Cannot be smaller without violating reflexivity
  - Sometimes but not always what we want

`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`

Why all this?

- Remember the goal is a contract:
  - weak enough to allow different useful overrides
  - strong enough so clients can assume equal-ish things
    - example: to implement a set
  - this gives a good balance in practice

- In summary:
  - equivalence relation on non-null objects
  - consistency, but allow for mutation to change the answer
  - asymmetric with **`null`** (other way raises exception)
    - weird but useful
    - often see, e.g., “left”.equals(direction) – false for null

An example

A class where we may want **`equals`** to mean equal contents

```
public class Duration {
    private final int min; // RI: min>=0
    private final int sec; // RI: 0<=sec<60
    public Duration(int min, int sec) {
        assert min>=0 && sec>=0 && sec<60;
        this.min = min;
        this.sec = sec;
    }
}
```

- Should be able to implement what we want and satisfy the **`equals`** contract…

How about this?

```
public class Duration {
    …
  public boolean equals(Duration d) {
     return this.min==d.min && this.sec==d.sec;
  }
}
```

Two bugs:

1. Violates contract for **`null`** (not that interesting)
   - Can add **`if(d==null) return false;`**
     - But our fix for the other bug will make this unnecessary
2. Does not override **`Object`**'s **`equals`** method (more interesting)

Overloading versus overriding

In Java:

- A class can have multiple methods with the same name and different parameters (number or type)
- A method *overrides* a superclass method only if it has the same name and exact same argument types

Overloading versus 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**

Overloading versus overriding

In Java:

- A class can have multiple methods with the same name and different parameters (number or type)
- A method *overrides* a superclass method only if it has the same name and exact same argument types

So, **`Duration`**'s **`boolean equals(Duration d)`** does *not* override **`Object`**'s **`boolean equals(Object d)`**

- Sometimes useful to avoid having to make up different method names
- Sometimes confusing since the rules for what-method-gets-called are complicated

Java Method Calls

- Signature of the method to call is chosen at **compile time**
  - suppose class has `equals(Object)` and `equals(Duration)`
  - Java chooses "best" match to the argument's **compile-time type**
  - if argument has type `Duration`, `equals(Duration)` is best match
  - if argument has any other type, `equals(Object)` is *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)

Example: *no* overriding

```
public class Duration {
  public boolean equals(Duration d) {…}
  …
}
Duration d1 = new Duration(10,5);
Duration d2 = new Duration(10,5);
Object o1 = d1;
Object o2 = d2;
d1.equals(d2); // true
o1.equals(o2); // false(!)
d1.equals(o2); // false(!)
o1.equals(d2); // false(!)
d1.equals(o1); // true [using Object's equals]
```

Example fixed (mostly)

```
public class Duration {
  public boolean equals(Object d) {…}
  …
}
Duration d1 = new Duration(10,5);
Duration d2 = new Duration(10,5);
Object o1 = d1;
Object o2 = d2;
d1.equals(d2); // true
o1.equals(o2); // true [overriding]
d1.equals(o2); // true [overriding]
o1.equals(d2); // true [overriding]
d1.equals(o1); // true [overriding]
```

But wait!

This doesn't compile:

```
public class Duration {
    …
   public boolean equals(Object o) {
      return this.min==o.min && this.sec==o.sec;
   }
}
```

Really fixed now

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

- Cast cannot fail
- We want equals to work on *any* pair of objects
- Gets **`null`** case right too (**`null instanceof C`** always **`false`**)
- So: rare use of cast that is correct and idiomatic
  - This is what you should do (cf. *Effective Java*)

Satisfies the contract

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

- Reflexive: Yes
- Symmetric: Yes, even if `o` is not a `Duration`!
  - (Assuming `o`'s `equals` method satisfies the contract)
- Transitive: Yes, similar reasoning to symmetric

Even better

- Defensive Tip: use the **`@Override`** annotation when overriding

```
public class Duration {
    @Override
    public boolean equals(Object o) {
        …
    }
}
```

- *Compiler warning* if not actually an override
  - Catches bug where argument is **`Duration`** or **`String`** or ...
  - Alerts reader to overriding
    - Concise, relevant, *checked* documentation

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
```

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 Mutability

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

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Contract (again essential for correct overriding):

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- 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)

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;
}
```