CSE 331
Software Design & Implementation

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`==`, **`equals()`**, and all that

(Slides by David Notkin and Mike Ernst)

Programming: object equality

- The basic intuition is simple: two objects are equal if they are indistinguishable (have the same value)
- But our intuitions are incomplete in subtle ways:
  - Must the objects be the same object or “just” indistinguishable?
  - What is an object’s value? How do we interpret “the bits”?
  - What does it mean for two collections of objects to be equal?
    - Does each need to hold the same objects? In the same order? What if a collection contains itself?
    - Who decides? The programming language designer? You?
  - If a program uses inheritance, does equality change?
  - Is equality always an efficient operation? Is equality temporary or forever?

Properties of equality
for any useful notion of equality

- *Reflexive* `a.equals(a)`

  $3 \neq 3$ would be confusing

- *Symmetric* `a.equals(b)` $\Leftrightarrow$ `b.equals(a)`

  $3 = 4 \wedge 4 \neq 3$ would be confusing

- *Transitive* `a.equals(b)` $\wedge$ `b.equals(c)` $\Rightarrow$ `a.equals(c)`

  $((1+2) = 3 \wedge 3 = (5-2)) \wedge$
  $((1+2) \neq (5-2))$ would be confusing

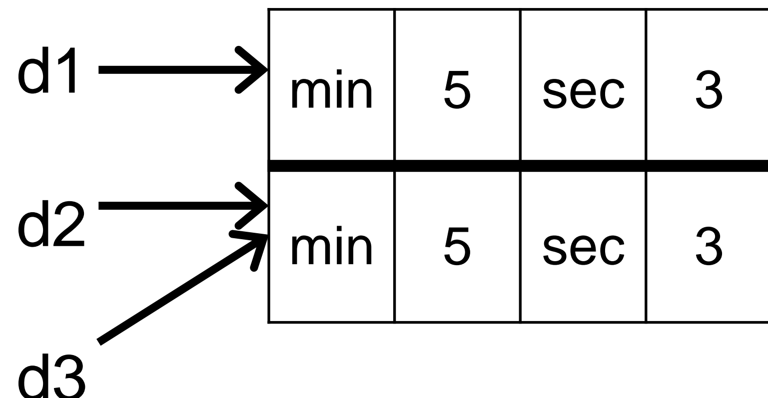
A relation that is reflexive, transitive, and symmetric is an *equivalence relation*

Reference equality

- The simplest and strongest (most restrictive) definition is *reference equality*
- `a == b` if and only if `a` and `b` refer (point) to the same object
- Easy to show that this definition ensures == is an equivalence relation

```
Duration d1 = new Duration(5,3);
Duration d2 = new Duration(5,3);
Duration d3 = p2;

// T/F: d1 == d2 ?
// T/F: d1 == d3 ?
// T/F: d2 == d3 ?
// T/F: d1.equals(d2) ?
// T/F: d2.equals(d3) ?
```



`Object.equals` method

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

- This implements reference equality
- What about the specification of **`Object.equals`**?
  - It’s a bit more complicated…

Equals specification

`public boolean equals(Object obj)`

Indicates whether some other object is "equal to" this one.

The **`equals`** method implements an equivalence relation:

- *[munch – definition of equivalence relation]*
- It is *consistent*: for any reference values **`x`** and **`y`**, multiple invocations of **`x.equals(y)`** consistently return true or consistently return false, provided no information used in equals comparisons on the object is modified.
- For any non-null reference value **`x`**, **`x.equals(null)`** should return false.

The **`equals`** method for class **`Object`** implements the most discriminating possible equivalence relation on objects; that is, for any reference values **`x`** and **`y`**, this method returns true if and only if **`x`** and **`y`** refer to the same object (**`x==y`** has the value true). …

[munch] Parameters & Returns & See Also

The `Object` contract

- Why complicated? Because the **`Object`** class is designed for inheritance
- Its specification will apply to all subtypes – that is, all Java subclasses – so its specification must be flexible
  - If **`a.equals(b)`** were specified to test **`a == b`**, then no class could change this and still be a subtype of **`Object`**
  - Instead the specification gives the basic properties that clients can rely on it to have in all subtypes of **`Object`**
- **`Object`**'s implementation of **`equals`** as **`a == b`** satisfies these properties but the specification is more flexible

Comparing objects less strictly

```
public class Duration {
    private final int min;
    private final int sec;
    public Duration(int min, int sec) {
        this.min = min;
        this.sec = sec;
    }
}
…
Duration d1 = new Duration(10,5);
Duration d2 = new Duration(10,5);
System.out.println(d1.equals(d2));
```

`false` – but we likely prefer it to be **`true`**

An obvious improvement

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

This defines an equivalence relation for **`Duration`** objects (proof by partial example and handwaving)

```
Duration d1 = new Duration(10,5);
Duration d2 = new Duration(10,5);
System.out.println(d1.equals(d2));
```

```
Object o1 = new Duration(10,5);
Object o2 = new Duration(10,5);
System.out.println(o1.equals(o2));  // False!
```

But oops

Overloading

- We have two **`equals`** methods:
  - **`equals(Object)`** in class **`Object`**
  - **`equals(Duration)`** in class **`Duration`**
- The one in **`Duration`** does ***not*** override the inherited one – it overloads it (different parameter type)
- If **`d`** has type **`Duration`**, **`d.equals(Duration)`** invokes the method in **`Duration`**
- If **`o`** has type **`Object`**, **`o.equals(Duration)`** invokes the **`equals(Object)`** method declared in **`Object`**
  - *Even if* the dynamic type of **`o`** is **`Duration`**!
  - **`Object`** does not have an **`equals(Duration)`** method. Method types are resolved using static types.
  - Dynamic types are used to select appropriate method at runtime (dynamic dispatch), but selected from possible methods with the correct static type.

`@Override equals` in `Duration`

```
@Override                    // compiler warning if type mismatch
public boolean equals(Object o) {
  if (! (o instanceof Duration))   // Parameter must also be
    return false;                  //     a Duration instance
  Duration d = (Duration) o;       // cast to treat o as
                                   //     a Duration
  return d.min == min && d.sec == sec;
}

Object d1 = new Duration(10,5);
Object d2 = new Duration(10,5);
System.out.println(d1.equals(d2));    // True
```

- *overriding* re-defines an inherited method from a superclass – same name & parameter list & return type
- **`Durations`** now have to be compared as **`Durations`** (or as **`Objects`**, but not as a mixture)

Equality and inheritance

- Add a nanosecond field for fractional seconds

```
public class NanoDuration extends Duration {
  private final int nano;
  public NanoDuration(int min, int sec, int nano) {
    super(min, sec);
    this.nano = nano;
}
```

Inherited **`equals()`** from **`Duration`** ignores **`nano`** so **`Duration`** instances with different **`nano`**s will be **`equal`**

`equals`: account for `nano`

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

But this is not symmetric! **Oops!**

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

Let’s get symmetry

```
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;
}
```

But this is not transitive! **Oops!**

```
Duration d1 = new NanoDuration(5,10,15);
Duration d2 = new Duration(5,10);
Duration d3 = new NanoDuration(5,10,30);
System.out.println(d1.equals(d2)); // true
System.out.println(d2.equals(d3)); // true
System.out.println(d1.equals(d3)); // false!
```

Fix in **`Duration`**

Replaces earlier version

```
if (! (o instanceof Duration))
  return false;
```

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

- Check exact class instead of **`instanceOf`**
- Equivalent change in **`NanoDuration`**

General issues

- Every subtype must override **`equals`** – even if it wants the identical definition
- Take care when comparing subtypes to one another
  - On your own: Consider an **`ArithmeticDuration`** class that adds operators but no new fields

Another solution: avoid inheritance

- Use composition instead

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

- Now instances of **`NanoDuration`** and of **`Duration`** are unrelated – there is no presumption that they can be **`equal`** or unequal or even compared to one another…
- Solves some problems, introduces others – for example, can't use **`NanoDuration`**s where **`Duration`**s are expected (because one is not a subtype of the other)

Efficiency of equality

- Equality tests can be slow: Are two objects with millions of sub-objects equal? Are two video files equal?
- It is often useful to quickly pre-filter – for example

```
if (video1.length() != video2.length())
  return false
else do full equality check
```

- Java requires each class to define a standard pre-filter – a `hashCode()` method that produces a single hash value (a 32-bit signed integer) from an instance of the class
- If two objects have different hash codes, they are *guaranteed* to be different
- If they have the same hash code, they *may* be equal objects and should be checked in full

Unless you define `hashCode()` improperly!!!

specification for Object.hashCode

- **`public int hashCode()`**

  "Returns a hash code value for the object. This method is supported for the benefit of hashtables such as those provided by **`java.util.HashMap`**."
- The general contract of **`hashCode`** is
  - Deterministic: **`o.hashCode() == o.hashCode()`**
    - ... so long as **`o`** doesn't change between the calls
  - Consistent with equality
    - **`a.equals(b)`** ⇒ **`a.hashCode()==b.hashCode()`**
    - Change **`equals()`**? Must you update **`hashCode()`**?
    - ALMOST ALWAYS! I MEAN ALWAYS!

Duration hashCode implementations

Many possibilities…

```
public int hashCode() {
    return 1;          // always safe, no pre-filtering
}

public int hashCode() {
    return min;        // safe, inefficient for Durations
                       // differing only in sec field
}

public int hashCode() {
    return min+sec;    // safe and efficient
}

public int hashCode() {
    return new Random().newInt(50000); // danger! danger!
}
```

Equality, mutation, and time

- If two objects are `equal` now, will they always be `equal`?
  - In mathematics, “yes”
  - In Java, “you choose” – the `Object` contract doesn't specify this
- For immutable objects, equality is inherently forever
  - The object’s abstract value never changes (c.f. “abstract value” in the ADT lectures) – be sure not to depend on possibly changing internal values
- For mutable objects, equality can either
  - Compare abstract values field-by-field or
  - Be eternal (how can a class with mutable instances have eternal equality?)
  - But not both! (Since abstract value can change.)