== + equals = ?

CSE 331
SOFTWARE DESIGN & IMPLEMENTATION
EQUALITY

Autumn 2011

Programming: object equality

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- 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?

Equality: hard in reality as well

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- Using DNA, which of two identical twins committed a crime?
- "My grandfather's axe": after repeatedly replacing an axe's head and handle, is it still the same axe?
- If you are flying next to someone on an airplane, are you on the same flight? The same airline?
- And then there are *really* hard questions like social equality, gender equality, race equality, equal opportunity, etc.!

Properties of equality:
for any useful notion of equality

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- *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

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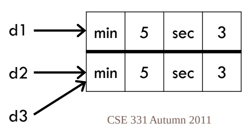
- The simplest and strongest (most restrictive) definition is *reference equality*
- `a == b` if and only if `a` and `b` refer (point) to the same object
- Easy to show that this definition ensures `==` is an equivalence relation

```
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

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```
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…

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

- Defining **equals** in the **Duration** class creates a method that is invoked upon executing **d.equals(…)** where **d** is a declared instance of **Duration**
- This co-exists with **equals** in the **Object** class that is invoked upon executing **o.equals(…)** where **o** is a declared instance of **Object** – even if it refers to an instance of **Duration**
- This gives two **equals** methods that can be invoked on instances of **Duration** with different results

@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

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- 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;
}
```

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

`equals`: account for `nano`

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```
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

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```
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`

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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

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- 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

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- 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

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- 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`

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- **`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! This is a sadly common example of the epic fail**

`Duration hashCode` implementations

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```
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

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- 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 (but why not?)
- For immutable objects, equality is inherently forever
  - The object's abstract value never changes (much more on "abstract value" in the ADT lectures) – very roughly, these are the values the client of a class uses (not the representation used internally)
- 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

Next steps

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- Assignment 1
  - Due Friday 11:59PM
- Assignment 2
  - out Friday
  - due in two parts, see calendar
- Lectures
  - Abstract data types (F, M)