Equality

CSE 331

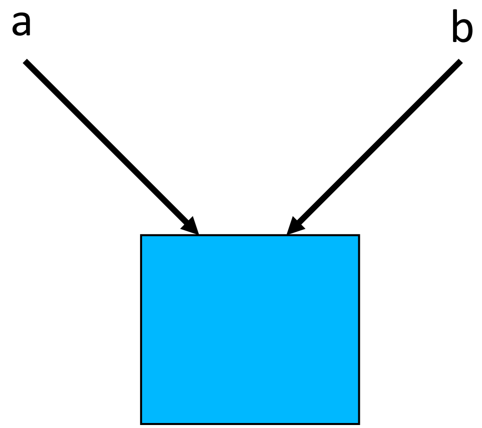
Autumn 2010

Object equality

- A simple idea – we have intuitions about equality:
  - Two objects are equal if they have the same value
  - Two objects are equal if they are indistinguishable
- A subtle idea – our intuitions are not complete:
  - Is equality temporary or forever?
  - How does equality behave in the presence of inheritance?
  - Is equality of collections related to equality of elements?
    - What about self-containment?
  - How can we make equality an efficient operation?

Reference equality

- a == b
- True if a and b point to the same object



- Strongest definition of equality
- Weaker definitions of equality can be useful

Object.equals method

- The Object.equals method is very simple

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

- Yet its specification is much more elaborate.
- Why?

Equals specification

public boolean **equals**(Object obj)

Indicates whether some other object is "equal to" this one. The equals method implements an equivalence relation:

- It is *reflexive*: for any reference value x, x.equals(x) should return true.
- It is *symmetric*: for any reference values x and y, x.equals(y) should return true if and only if y.equals(x) returns true.
- It is *transitive*: for any reference values x, y, and z, if x.equals(y) returns true and y.equals(z) returns true, then x.equals(z) should return true.
- 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).

Parameters:

obj - the reference object with which to compare.

Returns:

true if this object is the same as the obj argument; false otherwise.

See Also:

Boolean.hashCode(), Hashtable

The Object contract

- Object class is designed for inheritance
- Its specification will apply to all subtypes – all Java classes
- So, its specification must be flexible
  - Specification for equals cannot later be weakened
  - If a.equals(b) were specified to test a==b, then no class could change this and still be a true subtype of Object
  - Instead spec for equals enumerates basic properties that clients can rely on it to have in subtypes of Object
  - a==b is compatible with these properties, but so are other tests

Properties of equals

- Equality is reflexive
  - a.equals(a) is true
- Equality is symmetric
  - a.equals(b) $\Leftrightarrow$ b.equals(a)
- Equality is transitive
  - a.equals(b) and b.equals(c) $\Rightarrow$ a.equals(c)
- No object equals null
  - a.equals(null) = false

- There are a few other conditions that we'll ignore for now
- The default implementation (reference equality) works fine for these properties

Beyond reference equality

```
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 maybe we would like this to be true

An incorrect equals method

- Let's try adding an equals method that compares fields

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

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

- This is reflexive, symmetric, transitive for Duration objects

Must override Object.equals

- This was overloading, not overriding

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

- Use the @Override annotation
- Overloading: defining a new method with the same name as an existing method, but with a different type signature – both are visible
- Overriding: replacing a new from a superclass with one for the subclass

A correct equals method for Duration

```
@Override  // compiler warning if type mismatch
public boolean equals(Object o) {
    if (! (o instanceof Duration))
        return false;
    Duration d = (Duration) o;
    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
```

Equality and inheritance

- Add a nano-second 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;
    }
  // If we inherit equals() from Duration, nano will be ignored
  // and objects with different nanos will be equal.
}
```

Symmetry bug

- A first attempt at an equals method for NanoDuration

```
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);
System.out.println(d1.equals(d2)); // false
System.out.println(d2.equals(d1)); // true
```

Symmetry fix but…

```
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;
}
```

- However, this is not transitive!

Transitivity bug

```
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!
```

- What is the solution?
  - Can check exact class in Duration, rather than just use instanceof
  - But then can't do any minor subclassing; for example to make an ArithmeticDuration class that offers no new fields, just a few new operators

checking exact class

- Duration can avoid comparing against an instance of a subtype

```
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;
}
```

- But now every subtype must override equals
  - Even if it wants the identical definition
  - Hard to compare subtypes to one another

Another solution: avoid inheritance

- Can use composition:

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

- NanoDurations and Durations are unrelated
  - There is no presumption that NanoDurations and Durations may be equal
  - Can't use NanoDurations where Durations are expected

Date and Timestamp in Java

- public class Timestamp extends Date
  - "A thin wrapper around java.util.Date that ... adds the ability to hold the SQL TIMESTAMP nanos value and provides formatting and parsing operations ..."
- Caveat 1
  - "The Timestamp.equals(Object) method is not symmetric with respect to the java.util.Date.equals(Object) method."
- Caveat 2
  - "Also, the hashcode method uses the underlying java.util.Date implementation and therefore does not include nanos in its computation."

Date and Timestamp in Java

- Caveat 3
  - "Due to the differences between the Timestamp class and the java.util.Date class mentioned above, it is recommended that code not view Timestamp values generically as an instance of java.util.Date. The inheritance relationship between Timestamp and java.util.Date really denotes implementation inheritance, and not type inheritance."

- Translation:
  - "Timestamps are not Dates. Ignore that extends Dates bit in the class declaration."

Timestamp: overloading error

- public boolean **equals**(Timestamp ts)

  "Tests to see if this Timestamp object is equal to the given Timestamp object."

- public boolean **equals**(Object ts)

  "Tests to see if this Timestamp object is equal to the given object. This version of the method equals has been added to fix the incorrect signature of Timestamp.equals(Timestamp) and to preserve backward compatibility with existing class files. Note: This method is not symmetric with respect to the equals(Object) method in the base class."

A special case: uninstantiable types

- No equality problem if superclass cannot be instantiated!
  - For example, suppose Duration were abstract
  - Then no troublesome comparisons can arise between Duration and NanoDuration instances
- This may be why this problem is not very intuitive
  - In real life, “superclasses” can't be instantiated
  - We have specific apples and oranges, never unspecialized Fruit

Efficiency of equality

- Equality tests can be slow
  - E.g. testing if two text documents are equal
  - Or testing for equality between millions of objects
- Useful to quickly prefilter
  - E.g. are documents same length?
  - If not, they are not equal
  - If so, then they are worth testing for equality
- Hash codes are efficient prefilters for equality
  - Do objects have same hash code?
  - If not, they are not equal
  - If so, then they are worth testing for equality

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:
  - Self-consistent:
    - **`o.hashCode() == o.hashCode()`**
    - ...so long as **`o`** doesn’t change between the calls
  - Consistent with equality:
    - **`a.equals(b)`** ⇒ **`a.hashCode()==b.hashCode()`**

Many possible hashCode implementations

```
public class Duration {

  public int hashCode() {
    return 1;          // always safe, but makes hash tables
  }                    // inefficient (no prefiltering)

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

  public int hashCode() {
    return min+sec;    // safe, and changes in any field
  }
}
```

Consistency of equals and hashCode

- Suppose we change the spec for Duration.equals

```
// Return true if o and this represent the same number of seconds
    public boolean equals(Object o) {
      if (! (o instanceof Duration))
        return false;
      Duration d = (Duration) o;
      return 60*min+sec == 60*d.min+d.sec;
    }
```

- We must update hashCode, or we will get inconsistent behavior. This works

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

Equality, mutation, and time

- If two objects are equal now, will they always be equal?
  - In mathematics, the answer is “yes”
  - In Java, the answer is “you choose”
  - The Object contract doesn't specify this (why not?)
- For immutable objects
  - Abstract value never changes
  - Equality is automatically forever
- For mutable objects, equality can either:
  - Compare abstract values (field-by-field comparison)
  - Or be eternal
  - Can't do both! Since abstract value can change.

examples

- StringBuffer is mutable, and takes the “eternal” approach

```
StringBuffer s1 = new StringBuffer("hello");
StringBuffer s2 = new StringBuffer("hello");
System.out.println(s1.equals(s1)); // true
System.out.println(s1.equals(s2)); // false
```

- This is reference (==) equality, which is the only way to guarantee eternal equality for mutable objects. Compare to

```
Date d1 = new Date(0); // Jan 1, 1970 00:00:00 GMT
Date d2 = new Date(0);
System.out.println(d1.equals(d2)); // true
d2.setTime(1);                     // a millisecond later
System.out.println(d1.equals(d2)); // false
```

Behavioral and observatonal equivalence

- Two objects are “behaviorally equivalent” if:
  - There is no sequence of operations that can distinguish them
  - This is “eternal” equality
  - Two Strings with same content are behaviorally equivalent, two Dates or StringBuffers with same content are not
- Two objects are “observationally equivalent” if:
  - There is no sequence of observer operations that can distinguish them
    - Excluding mutators
    - Excluding == (permitting == would require reference equality)
  - Two Strings, Dates, or StringBuffers with same content are observationally equivalent

Equality and mutation

- Date class implements observational equality
- Can therefore violate rep invariant of a Set container 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 identical Dates
    System.out.println(d);
}
```

Pitfalls of observational equivalence

- Equality for set elements would ideally be behavioral
- Java makes no such guarantee (or requirement)
- So 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

Mutation and hash codes

- Sets also assume hash codes don't change
- Mutation and observational equivalence can break this assumption too

```
List<String> friends =
  new LinkedList<String>(Arrays.asList("yoda","zaphod"));
List<String> enemies = ...;   // any other list
Set<List<String>> h = new HashSet<List<String>>();
h.add(friends);
h.add(enemies);
friends.add("weatherwax");
System.out.println(h.contains(friends)); // probably false
for (List<String> lst : h) {
      System.out.println(lst.equals(friends));
}   // one "true" will be printed - inconsistent!
```

More container wrinkles: self-containment

- equals and hashCode methods on containers are recursive, e.g. hashCode for List<E>

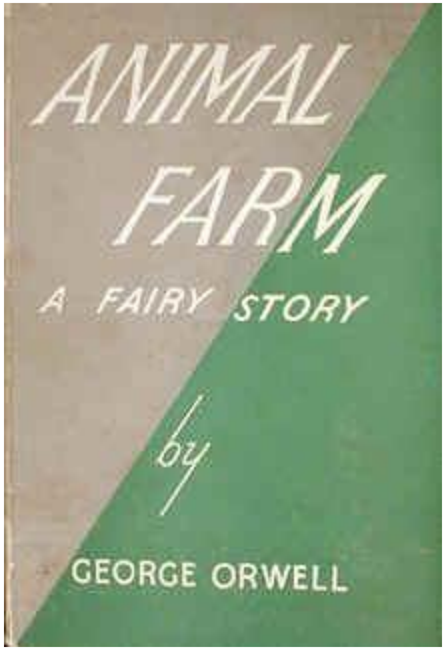
```
int code = 1;
 for (Object o : list) {
    code = 31*code + (o==null ? 0 :
  o.hashCode());
 }
```

- This causes an infinite loop

```
List<Object> lst = new LinkedList<Object>();
lst.add(lst);
int code = lst.hashCode();
```

Summary: All equals are not equal!

- reference equality
- behavioral equality
- observational equality



Summary: Java specifics

- Mixes different types of equality
  - Objects different from collections
- Extendable specifications
  - Objects, subtypes can be less strict
- Only enforced by the specification
- Speed hack
  - hashCode

Summary: object-oriented Issues

- Inheritance
  - Subtypes inheriting equal can break the spec. Many subtle issues.
  - Forcing all subtypes to implement is cumbersome
- Mutable objects
  - Much more difficult to deal with
  - Observational equality
  - Can break reference equality in eollections
- Abstract classes
  - If only the subclass is instantiated, we are ok…

Summary: software engineering

- Equality is such a simple concept
- But…
  - Programs are used in unintended ways
  - Programs are extended in unintended ways
- Many unintended consequences
- In equality, these are addressed using a combination of:
  - Flexibility
  - Carefully written specifications
  - Manual enforcement of the specifications
    - perhaps by reasoning and/or testing