


# 6.170 Lecture 11 Equality



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## 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 happens to equality given self-containment and other non-hierarchical forms?
- How can we make equality an efficient operation?
- How do our ideas of equality play out in large systems?

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## 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 (read it).  
Why?

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## the Object Contract

Object class is designed for inheritance  
Its specification will apply to all subtypes  
In other words, all Java classes  
So 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

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## basic specification for equals

- Equality is reflexive  
a.equals(a) is true
- Equality is symmetric  
a.equals(b) <=> b.equals(a)
- Equality is transitive  
a.equals(b) and b.equals(c) => a.equals(c)
- No object equals null  
a.equals(null) = false

(other conditions omitted for now)

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## default Object.equals implementation

- Equality is reflexive  
a == a
- Equality is symmetric  
a == b <=> b == a
- Equality is transitive  
a == b and b == c => a == c
- No object equals null  
(a == null) = false for any non-null reference

Default implementation (“referential equality”) works fine

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## beyond referential equality

Often want to compare objects less strictly

```
public class Duration {
    private final int day;
    private final int sec;
    public Duration(int day, int sec) {
        this.day = day; this.sec = sec;
    }
}
```

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

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## beyond referential equality

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public class Duration {
    private final int day;
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    public Duration(int day, int sec) {
        this.day = day; 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 - why not?
```

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## an equals method

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

```
public boolean equals(Duration d) {
    if (d == null)
        return false;
    return d.day == day && d.sec == sec;
}
```

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

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## an equals method

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        return false;
    return d.day == day && 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  
But it doesn't override the Object.equals method

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## the problem

Here's the problem:

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

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## the problem

Here's the problem:

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

This will make our life complicated

Example: Durations may behave strangely in Collections

Avoid overloading methods

If same name but different arguments, then Java considers it unrelated

Occasional uses for optimization, especially when the semantics are identical

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## try again

Here's an alternative equals method for Duration:

```
@Override // compiler will warn if type mismatch
public boolean equals(Object o) {
    if (!(o instanceof Duration))
        return false;
    Duration d = (Duration) o;
    return d.day == day && d.sec == sec;
}
```

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

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## try again

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public boolean equals(Object o) {
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        return false;
    Duration d = (Duration) o;
    return d.day == day && d.sec == sec;
}
```

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

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## equality and inheritance

Let's add a nano-second field for fractional seconds

```
public class NanoDuration extends Duration {
    private final int nano;
    public NanoDuration(int day, int sec, int nano) {
        super(day,sec);
        this.nano = nano;
    }
    // What should we do about equals?
    // If we inherit from Duration, nano will be ignored
    // and objects with different nanos will be equal
}
```

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## symmetry bug

Here's 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;
}
```

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

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## symmetry bug

Here's 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;
}
```

```
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));
```

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## symmetry bug

Here's 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;
}
```

```
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
```

This has a problem – it is not symmetric!

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## symmetry fix for NanoDuration.equals

```
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;
}
```

This has a problem – it is not transitive!

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## 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));
System.out.println(d2.equals(d3));
System.out.println(d1.equals(d3));
```

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## 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

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## checking exact class

Here's how in Duration we could avoid ever comparing against an instance of a subtype:

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

But now every subtype must override equals

Even if it wants the identical definition

Hard to compare subtypes to one another

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## another solution: avoid inheritance

Can use composition:

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

Now there is no presumption that NanoDurations and Durations may be equal

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## an important special case

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

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## equality and efficiency

### Equality tests can be slow

- E.g. testing if two text documents are equal
- Or testing for equality between millions of objects

### Useful to be able 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 prefilers for equality

- Do objects have same hash code?
- If not, they are not equal
- If so, then they are worth testing for equality

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## 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.”

[Hashtables are explained in the Javadocs, Bloch, 6.046.]

### The general contract of hashCode is:

“Whenever it is invoked on the same object, the hashCode method must consistently return the same integer, provided no information used in equals comparisons on the object is modified.”

“If two objects are equal according to the equals(Object) method, then calling the hashCode method on each of the two objects must produce the same integer result.”

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## hashCode for Duration?

Any of these hashCode implementations would work.

```
public int hashCode() {
    return 1; // always safe, but makes hash tables
} // completely inefficient (no prefiltering)
public int hashCode() {
    return day; // safe, but inefficient for Durations
} // that differ in sec field only
public int hashCode() {
    return day+sec; // safe, and changes in any field
} // will tend to change code
```

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## equals and hashCode

Suppose that day and sec do not have to be equal for Duration to be equal – suffices for same total number of seconds to be represented

```
public boolean equals(Object o) {
    if (!(o instanceof Duration))
        return false;
    Duration d = (Duration) o;
    return 24*60*60*day+sec ==
        24*60*60*d.day+d.sec;
}
```

Now we have to update our hash codes as well, or we will get inconsistent behavior. This works:

```
public int hashCode() {
    return 24*60*60*day+sec;
}
```

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## equality and time

If two objects are equal now, will they always be equal?

- In mathematics, answer is “yes”
- For Java, answer is “you choose”
- Object contract doesn't nail this down

### 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

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## 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 referential (==) equality, which is the only way to guarantee eternal equality for mutable objects. Compare:

```
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
```

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## two types of 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 StringBuffer with same content are not

Two objects are “observationally equivalent” if:

There is no sequence of *observer* operations that can distinguish them (that is, we exclude mutators)

Two Strings, Dates, or StringBuffer with same content are observationally equivalent

We exclude == (limits equality to referential equality)

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## approaches to equality

Liskov approach

**equals** method is always behavioral equivalence

· referential equality for mutable objects

· value equality for immutable objects

**similar** method is observational equivalence

· value equality for both mutable and immutable object

Java approach

Mixed! Read specs, especially in the Collections

Collection equality is observational equality

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## equality and mutation

```
Set<Date> s = new HashSet<Date>();
Date d1 = new Date(0);
Date d2 = new Date(0);
s.add(d1);
s.add(d2);

for (Date d : s) {
    System.out.println(d);
}
```

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## equality and mutation

```
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) {
    System.out.println(d);
}
```

Date class implements observational equality

Can therefore violate rep invariant of a Set container by mutating after insertion

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## caveats in specs

Equality for set elements would ideally be behavioral

But no guarantee (or requirement) that this is so in Java

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

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## 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());
}
```

Then if we try something like this:

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

We get an infinite loop

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## Leftovers from Lecture 9

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## Interfaces and abstract classes

### Provide interfaces for your functionality

Lets client code to interfaces rather than concrete classes

Allows different implementations later

Facilitates composition, wrapper classes

- Basis of lots of useful, clever tricks
- We'll see more of these later

### Consider providing helper/template abstract classes

Can minimize number of methods that new implementation must provide

Makes writing new implementations much easier

Using them is entirely optional, so they don't limit freedom to create radically different implementations

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## Why interfaces instead of classes

### Java design decisions:

A class has exactly one superclass

A class may implement multiple interfaces

An interface may extend multiple interfaces

### Observation:

multiple superclasses are difficult to use and to implement  
multiple interfaces, single superclass gets most of the benefit

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## Dangers of inheritance

### Inheritance is a powerful way to achieve code reuse

### But inheritance breaks encapsulation

A subclass may need to depend on unspecified details of the implementation of its superclass

- e.g. pattern of self-calls

### Subclass must evolve in tandem with superclass

Safe within a package where implementation of both is under control of same programmer

### Otherwise, authors of superclass must design and document specifically for the purpose of being extended

Often better to avoid implementation inheritance and use composition instead

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## Concrete, Abstract or Interface?

### Telephone

\$9.99 homephone, Speakerphone, cellphone, Skype, VOIP phone

### TV

CRT, Plasma, DLP, LCD

### Table

Dining table, Desk, Coffee table

### Coffee

Espresso, Frappuccino, Decaf, Ice coffee

### Computer

Laptop, Desktop, Server, Palmtop

### CPU

Pentium, PowerPC, TigerSHARC

### Professor

Amarasighe, Ernst

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