Implements vs. Extends

On Monday, a student asked after class “how do you know whether to use implements or extends?”

Somehow I didn’t explicitly mention the difference between “implements” and “extends” during lecture.

- You must use “implements” if the hyperym is an interface and the hyponym is a class (e.g. hypernym List, hyponym AList).
- You must use “extends” in all other cases.

There’s no choice that you have to make, the Java designers just picked a different keyword for the two cases.

Announcements

Reminder drop deadline is today.

- If you are not done with project 1A, you are in deep danger.

CS61B

Lecture 10: Subtype Polymorphism vs. HoFs

- Dynamic Method Selection Puzzle
- Subtype Polymorphism vs. Explicit HoFs
- Application 1: Comparables
- Application 2: Comparators

Dynamic Method Selection Puzzle (Online Only)

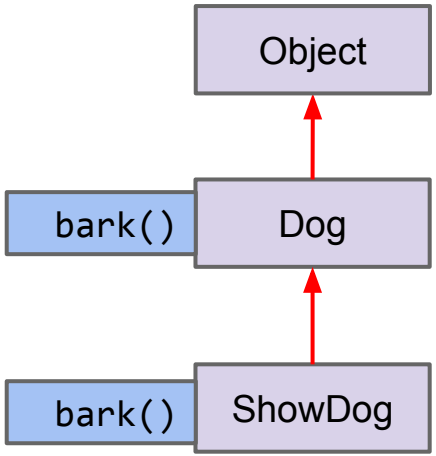
A Typing Puzzle

Suppose we have two classes:

- Dog: Implements bark() method.
- ShowDog: Extends Dog, overrides bark method.

Summarizing is-a relationships, we have:

- Every ShowDog is-a Dog
- Every Dog is-an Object.
  - All types in Java are a subtype of Object.



A Typing Puzzle

For each assignment, decide if it causes a compile error.

For each call to bark, decide whether: 1. Dog.bark() is called, 2. ShowDog.bark() is called, or 3. A syntax error results.

```
Object o2 = new ShowDog("Mortimer", "Corgi", 25, 512.2);

ShowDog sdx = ((ShowDog) o2);
sdx.bark();

Dog dx = ((Dog) o2);
dx.bark();

((Dog) o2).bark();

Object o3 = (Dog) o2;
o3.bark();
```

The rules:

- Compiler allows memory box to hold any subtype.
- Compiler allows calls based on static type.
- **Overridden non-static methods are selected at run time based on dynamic type**.
  - **Everything else is based on static type**, including overloaded methods. Note: No overloaded methods for problem at left.

A Typing Puzzle

String s = “35”;
Integer x = (Integer) s; // THIS CAST WILL FAIL
x.floatValue()

```
Object o2 = new ShowDog("Mortimer", "Corgi", 25, 512.2);
ShowDog sdx = ((ShowDog) o2);
sdx.bark();
Dog dx = ((Dog) o2);
dx.bark();
((Dog) o2).bark();
Object o3 = [          ];
o3.bark();
```

Showdog’s bark

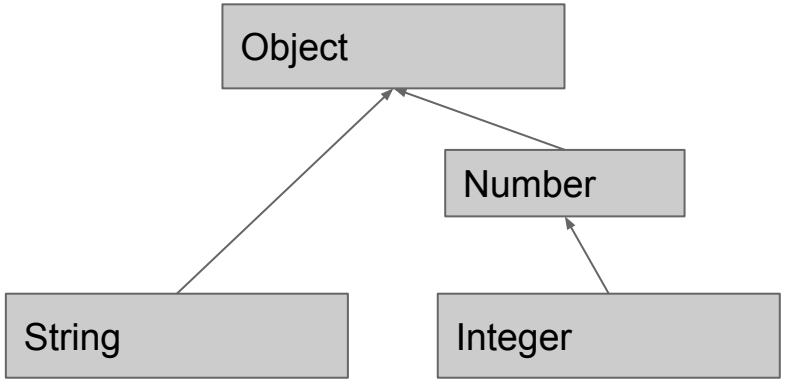
ShowDog’s bark

ShowDog’s bark

Variable or expression	Static Type	Dynamic Type
o2	Object	ShowDog
sdx	ShowDog	ShowDog
dx	Dog	ShowDog
((Dog) o2)	Dog	ShowDog
o3	Object	ShowDog

A Typing Puzzle

```
String s = “35”;
Integer x = (Integer) s; // THIS CAST WILL CAUSE A COMPILE ERROR
x.floatValue()
```




```
Number x = new Double(3.5);
Integer z = (Integer) x; // this cast is OK at compile time
                         // Josh what it would do at runtime. It’s a little weird.
```

A Typing Puzzle

For each assignment, decide if it causes a compile error.

For each call to bark, decide whether: 1. Dog.bark() is called, 2. ShowDog.bark() is called, or 3. A syntax error results.

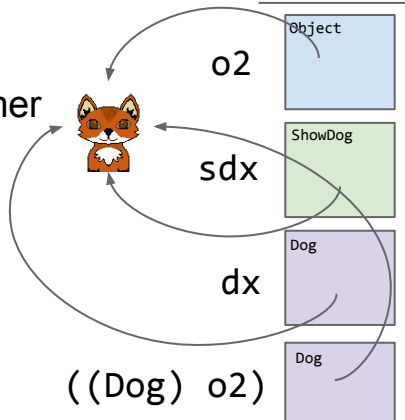
```
Object o2 = new ShowDog("Mortimer", "Corgi", 25, 512.2);

ShowDog sdx = ((ShowDog) o2);
sdx.bark();

Dog dx = ((Dog) o2);
dx.bark();

((Dog) o2).bark();

Object o3 = (Dog) o2;
o3.bark();
```

Showdog's bark

ShowDog's bark

ShowDog:

- Mortimer
- Corgi
- 25
- 512.2



	Static Type	Dynamic Type
o2	Object	ShowDog
sdx	ShowDog	ShowDog
dx	Dog	ShowDog
((Dog) o2)	Dog	ShowDog

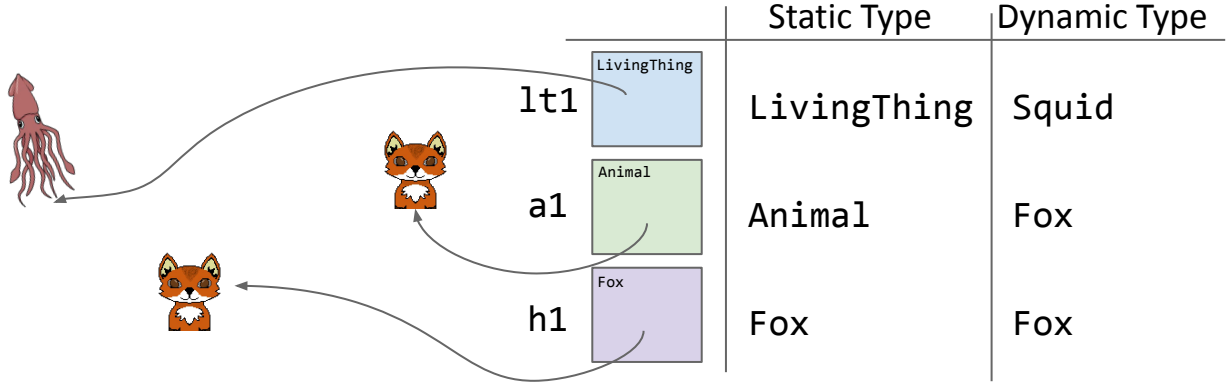
Static Type vs. Dynamic Type

Every variable in Java has a “compile-time type”, a.k.a. “static type”.

- This is the type specified at **declaration**. Never changes!

Variables also have a “run-time type”, a.k.a. “dynamic type”.

- This is the type specified at **instantiation** (e.g. when using `new`).
- Equal to the type of the object being pointed at.



Static Methods, Variables, and Inheritance

You may find questions on old 61B exams, worksheets, etc. that consider:

- What if a subclass has variables with the same name as a superclass?
- What if subclass has a static method with the same signature as a superclass method?
  - For static methods, we do not use the term overriding for this.

These two practices above are called “hiding”.

- It is bad style.
- There is no good reason to ever do this.
- The rules for resolving the conflict are a bit confusing to learn.
- I decided last year to stop teaching it in 61B.
- But if you want to learn it, see https://docs.oracle.com/javase/tutorial/java/IandI/override.html

Subtype Polymorphism

Subtype Polymorphism

The biggest idea of the last couple of lectures: ***Subtype Polymorphism***

- Polymorphism: "providing a single interface to entities of different types"

a.k.a. compile-time type

Consider a variable `deque` of static type `Deque`:

- When you call `deque.addFirst()`, the actual behavior is based on the dynamic type. ← a.k.a. run-time type
- Java automatically selects the right behavior using what is sometimes called "dynamic method selection".

Curious about alternatives to subtype polymorphism? See wiki or CS164.

http://www.stroustrup.com/glossary.html#Gpolymorphism

Subtype Polymorphism vs. Explicit Higher Order Functions

Suppose we want to write a program that prints a string representation of the larger of two objects.

Sometimes called a “callback”.

Explicit HoF Approach

```
def print_larger(x, y, compare, stringify):
    if compare(x, y):
        return stringify(x)
    return stringify(y)
```

Subtype Polymorphism Approach

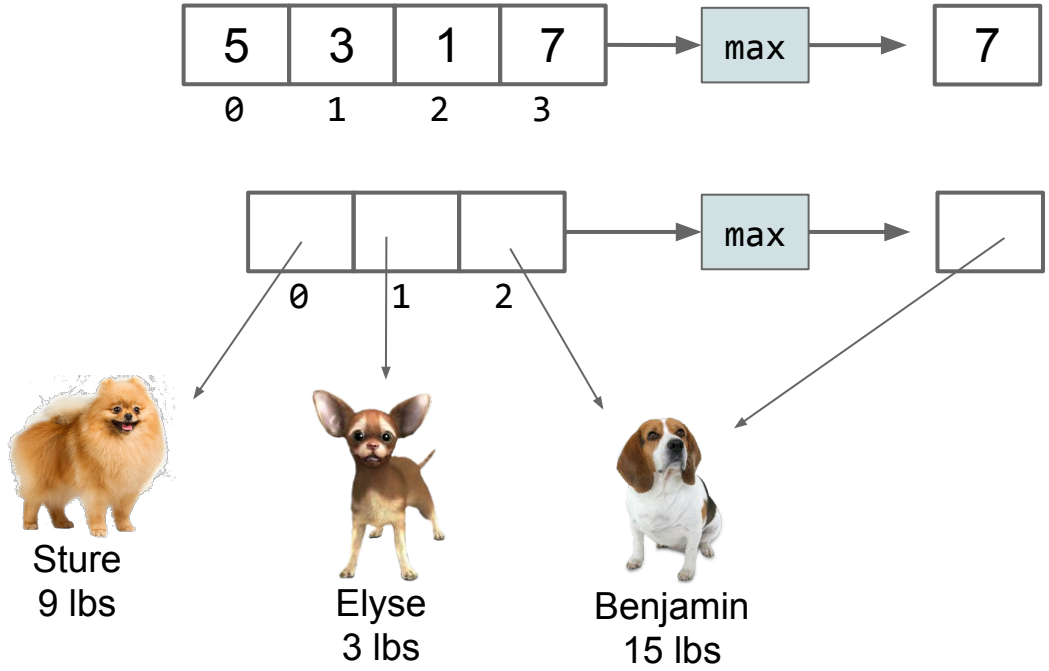
```
def print_larger(x, y):
    if x.largerThan(y):
        return x.str()
    return y.str()
```

Not to be confused with the amazing Dr. Ernest Kaulbach, who taught my Old English class.

DIY Comparison

Goal: The One True Max Function

Suppose we want to write a function `max()` that returns the max of any array, regardless of type.



Test Your Type Checking Understanding: yellkey.com/left

Suppose we want to write a function `max()` that returns the max of any array, regardless of type. How many compilation errors are there in the code shown?

A. 0
B. 1
C. 2
D. 3

```java
public static Object max(Object[] items) {
  int maxDex = 0;
  for (int i = 0; i < items.length; i += 1) {
    if (items[i] > items[maxDex]) {
      maxDex = i;                    }}
  return items[maxDex];
}
```

Maximizer.java

```java
public static void main(String[] args) {
  Dog[] dogs = {new Dog("Elyse", 3), new Dog("Sture", 9),
                new Dog("Benjamin", 15)};
  Dog maxDog = (Dog) max(dogs);
  maxDog.bark();
}
```

DogLauncher.java

Writing a General Max Function

and give up on our dream of a one true max function

Objects cannot be compared to other objects with >

- One (bad) way to fix this: Write a max method in the Dog class.

```
public static Object max(Object[] items) {
  int maxDex = 0;
  for (int i = 0; i < items.length; i += 1) {
    if (items[i] > items[maxDex]) {
      maxDex = i;                    }}
  return items[maxDex];
}
```

Maximizer.java

```
public static void main(String[] args) {
  Dog[] dogs = {new Dog("Elyse", 3), new Dog("Sture", 9),
                new Dog("Benjamin", 15)};
  Dog maxDog = (Dog) max(dogs);
  maxDog.bark();
}
```

DogLauncher.java

Dog.maxDog

One approach to maximizing a Dog array: Leave it to the Dog class.

- What is the disadvantage of this?

```
/** Returns maximum of dogs. */
public static Dog maxDog(Dog[] dogs) {
    if (dogs == null || dogs.length == 0) {
        return null; }
    Dog maxDog = dogs[0];
    for (Dog d : dogs) {
        if (d.size > maxDog.size) {
            maxDog = d;           }}
    return maxDog;
}
```

```
Dog[] dogs = new Dog[]{d1, d2, d3};
Dog largest = Dog.maxDog(dogs);
```

The Fundamental Problem

Objects cannot be compared to other objects with >

- How could we fix our Maximizer class using inheritance / HoFs?

```
public static Object max(Object[] items) {
  int maxDex = 0;
  for (int i = 0; i < items.length; i += 1) {
    if (items[i] > items[maxDex]) {
      maxDex = i;                    }}
  return items[maxDex];
}
```

Maximizer.java

```
public static void main(String[] args) {
  Dog[] dogs = {new Dog("Elyse", 3), new Dog("Sture", 9),
                new Dog("Benjamin", 15)};
  Dog maxDog = (Dog) max(dogs);
  maxDog.bark();
}
```

DogLauncher.java

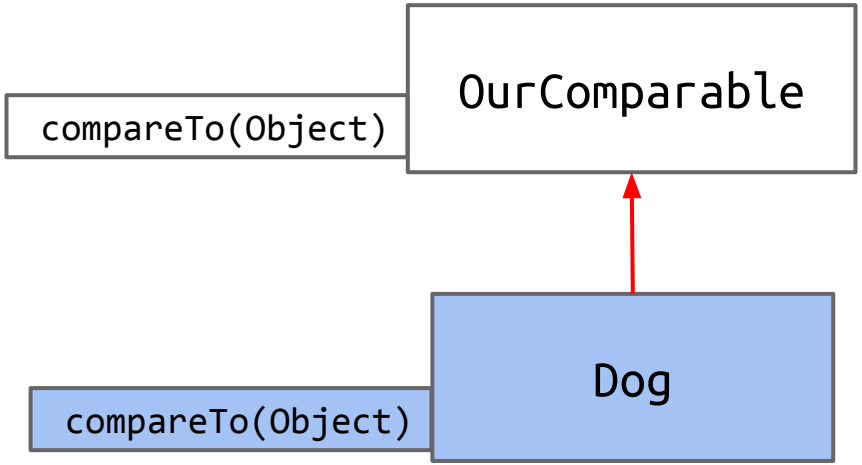
Solution

interface inheritance says **what** a class can do, in this case compare.

Create an interface that guarantees a comparison method.

- Have Dog implement this interface.
- Write Maximizer class in terms of this interface.

```
public static OurComparable max(OurComparable[] items) { ...
```



The OurComparable Interface

```
public interface OurComparable {
    int compareTo(Object obj);
}
```

Could have also been OurComparable. No meaningful difference.

Specification, returns:

- Negative number if ***this*** is less than obj.
- 0 if ***this*** is equal to object.
- Positive number if ***this*** is greater than obj.

General Maximization Function Through Inheritance

```
public interface OurComparable {
    int compareTo(Object obj);
}
```

```
public class Dog implements OurComparable {
    public int compareTo(Object obj) {
        /** Warning, cast can cause runtime error! */
        Dog uddaDog = (Dog) obj;
        return this.size - uddaDog.size;
    }…
```

```
public class Maximizer {
    public static OurComparable max(OurComparable[] a) {
    ...
}
```

```
Dog[] dogs = new Dog[]{d1, d2, d3};
Dog largest = (Dog) Maximizer.max(dogs);
```

General Maximization Function Through Inheritance

Benefits of this approach:

- No need for array maximization code in every custom type (i.e. no `Dog.maxDog(Dog[])` function required).
- Code that operates on multiple types (mostly) gracefully, e.g.

```
OurComparable[] objs = getItems("somefile.txt");
return Maximizer.max(objs);
```

Interfaces Quiz #1: yellkey.com/end

```
public class DogLauncher {
  public static void main(String[] args) {
    ...
    Dog[] dogs = new Dog[]{d1, d2, d3};
    System.out.println(Maximizer.max(dogs));
  }
}
```

```
public class Dog
implements OurComparable {
  ...
  public int compareTo(Object o) {
    Dog uddaDog = (Dog) o;
    return this.size
           - uddaDog.size;
  } ...
```

Q: If we omit compareTo(), which file will fail to **compile**?

A. DogLauncher.java
B. Dog.java
C. Maximizer.java
D. OurComparable.java

```
public class Maximizer {
  public static OurComparable max(
          OurComparable[] items) {
    ...
    int cmp = items[i].
      compareTo(items[maxDex]);
    ...
  }...
```

Interfaces Quiz #2: yellkey.com/remove

```
public class DogLauncher {
  public static void main(String[] args) {
    ...
    Dog[] dogs = new Dog[]{d1, d2, d3};
    System.out.println(Maximizer.max(dogs));
  }
}
```

```
public class Dog
implements OurComparable {
  ...
  public int compareTo(Object o) {
    Dog uddaDog = (Dog) o;
    return this.size
           - uddaDog.size;
  } ...
```

Q: If we omit `implements OurComparable`, which file will fail to **compile**?

A. DogLauncher.java
B. Dog.java
C. Maximizer.java
D. OurComparable.java

```
public class Maximizer {
  public static OurComparable max(
          OurComparable[] items) {
    ...
    int cmp = items[i].
      compareTo(items[maxDex]);
    ...
  }...
```

Answers to Quiz

Problem 1: Dog will fail to compile because it does not implement all abstract methods required by OurComparable interface. (And I suppose DogLauncher will fail as well since Dog.class doesn't exist)

Problem 2: DogLauncher will fail, because it tries to pass things that are not OurComparables, and Maximizer expects OurComparables.

Comparables

The Issues With OurComparable

Two issues:

- Awkward casting to/from Objects.
- We made it up.
  - No existing classes implement OurComparable (e.g. String, etc).
  - No existing classes use OurComparable (e.g. no built-in max function that uses OurComparable)

```
public class Dog implements OurComparable {
    public int compareTo(Object obj) {
        /** Warning, cast can cause runtime error! */
        Dog uddaDog = (Dog) obj;
        return this.size - uddaDog.size;
    } …
```

```
Dog[] dogs = new Dog[]{d1, d2, d3};
Dog largest = (Dog) Maximizer.max(dogs);
```

The Issues With OurComparable

Two issues:

- Awkward casting to/from Objects.
- We made it up.
  - No existing classes implement OurComparable (e.g. String, etc).
  - No existing classes use OurComparable (e.g. no built-in max function that uses OurComparable)

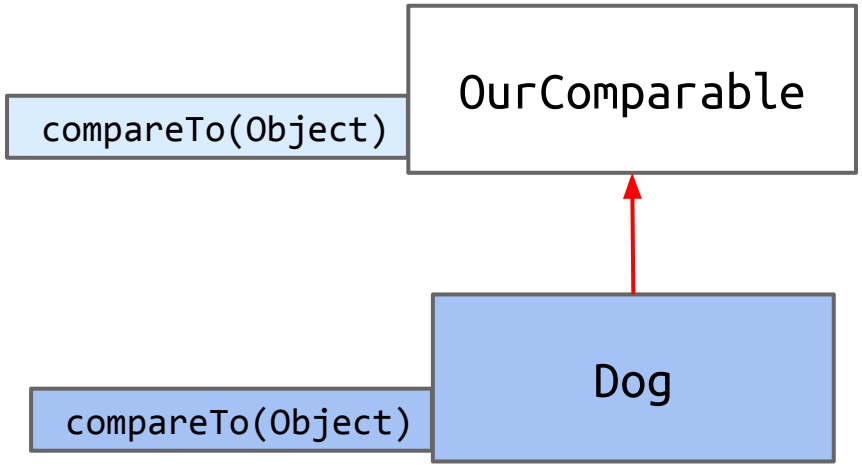
The industrial strength approach: Use the built-in Comparable interface.

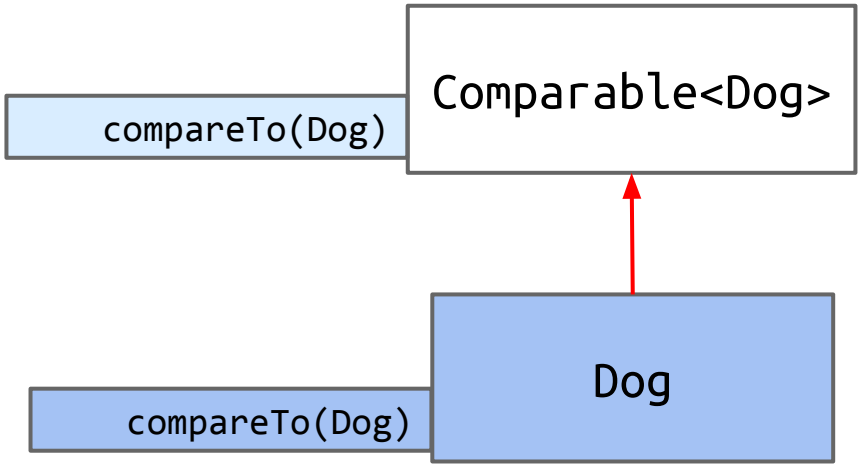
- Already defined and used by tons of libraries. Uses generics.

```
public interface Comparable<T> {
     public int compareTo(T obj);
}
```

```
public interface OurComparable {
     public int compareTo(Object obj);
}
```

Comparable vs. OurComparable





Comparable Advantages

- Lots of built in classes implement Comparable (e.g. String).
- Lots of libraries use the Comparable interface (e.g. Arrays.sort)
- Avoids need for casts.

```
public class Dog implements Comparable<Dog> {
    public int compareTo(Dog uddaDog) {
        return this.size - uddaDog.size;
    }
```

← Much better!

```
public class Dog implements OurComparable {
    public int compareTo(Object obj) {
        Dog uddaDog = (Dog) obj;
       return this.size - uddaDog.size;
   } …
```

Implementing Comparable allows library functions to compare custom types (e.g. finding max).

```
Dog[] dogs = new Dog[]{d1, d2, d3};
Dog largest = Collections.max(Arrays.asList(dogs));
```

Comparators

Natural Order

The term “Natural Order” is sometimes used to refer to the ordering implied by a `Comparable`’s `compareTo` method.

- Example: Dog objects (as we’ve defined them) have a natural order given by their size.

“Doge”, size: 5

“Grigometh”, size: 200

“Clifford”, size: 9000

Natural Order

May wish to order objects in a different way.

- Example: By Name.

“Clifford”, size: 9000

“Doge”, size: 5

“Grigometh”, size: 200

Subtype Polymorphism vs. Explicit Higher Order Functions

Suppose we want to write a program that prints a string representation of the larger of two objects according to some specific comparison function.

Explicit HoF Approach

```
def print_larger(x, y, compare, stringify):
    if compare(x, y):
        return stringify(x)
    return stringify(y)
```

Subtype Polymorphism Approach??

```
def print_larger(T x, T y):
    if x.largerThan(y):
        return x.str()
    return y.str()
```

Can simply pass a different compare function.

Subtype Polymorphism vs. Explicit Higher Order Functions

Suppose we want to write a program that prints a string representation of the larger of two objects according to some specific comparison function.

Explicit HoF Approach

```
def print_larger(x, y, compare, stringify):
    if compare(x, y):
        return stringify(x)
    return stringify(y)
```

Subtype Polymorphism Approach

```
def print_larger(T x, T y, comparator<T> c):
    if c.compare(x, y):
        return x.str()
    return y.str()
```

Can simply pass a different compare function.

Additional Orders in Java

In some languages, we'd write two comparison functions and simply pass the one we want :

- sizeCompare()
- nameCompare()

The standard Java approach: Create `sizeComparator` and `nameComparator` classes that implement the `Comparator` interface.

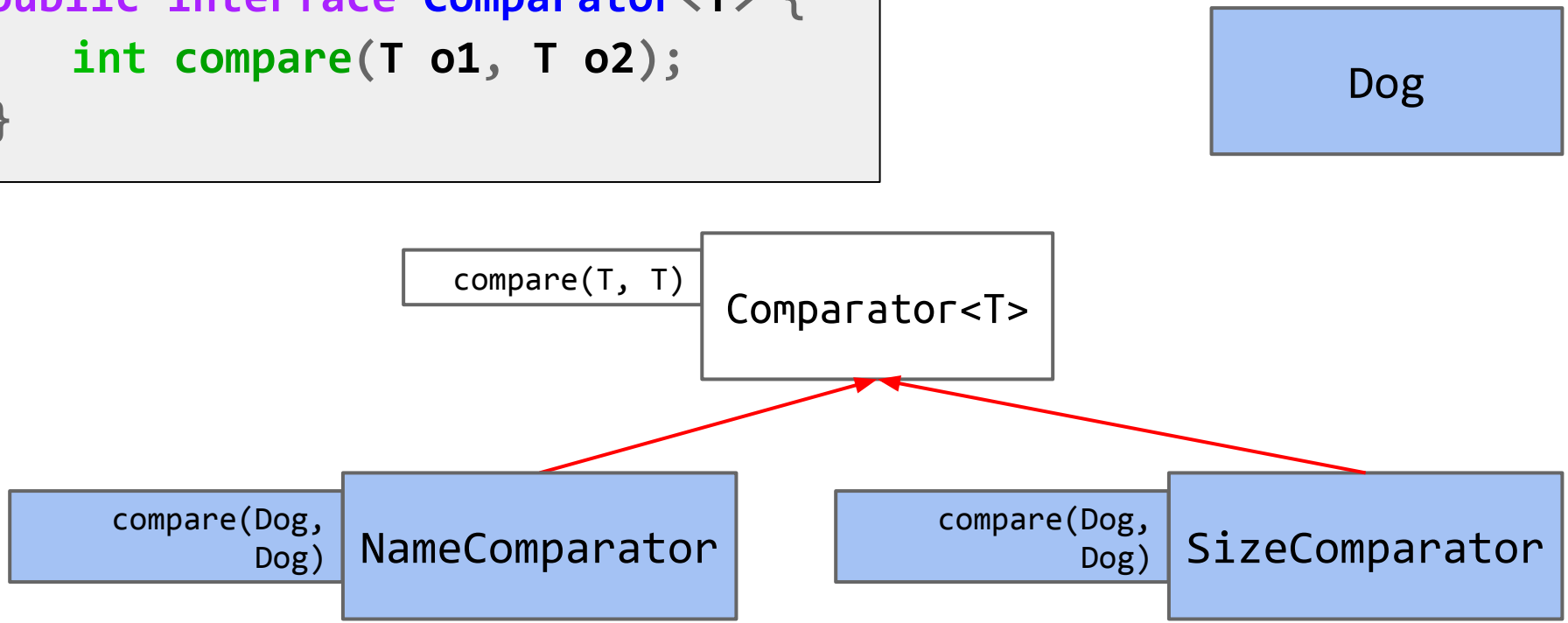
- Requires methods that also take Comparator arguments (see project 1B).

```
public interface Comparator<T> {
    int compare(T o1, T o2);
}
```

Dogs and Comparators

```
public interface Comparator<T> {
    int compare(T o1, T o2);
}
```

Dog not related by inheritance to any of the classes below.



Example: NameComparator

```
public class Dog implements Comparable<Dog> {
  private String name;
  private int size;

  public static class NameComparator implements Comparator<Dog> {
    public int compare(Dog d1, Dog d2) {
      return d1.name.compareTo(d2.name);
    }
  }
  ...
}
```

```
Comparator<Dog> cd = new Dog.NameComparator();
if (cd.compare(d1, d3) > 0) {
    d1.bark();
} else {
    d3.bark();
}
```

Result: If d1 has a name that comes later in the alphabet than d3, d1 barks.

Comparable and Comparator Summary

Interfaces provide us with the ability to make ***callbacks:***

- Sometimes a function needs the help of another function that might not have been written yet.
  - Example: max needs compareTo
  - The helping function is sometimes called a “callback”.
- Some languages handle this using explicit function passing.
- In Java, we do this by wrapping up the needed function in an interface (e.g. `Arrays.sort` needs `compare` which lives inside the `comparator` interface)
- `Arrays.sort` “calls back” whenever it needs a comparison.
  - Similar to giving your number to someone if they need information.
  - See Project 1B to explore how to write code that uses comparators.