4.3 Subtype Polymorphism vs. HOFs

joshhug.gitbooks.io/hug61b/content/chap4/chap43.html

Subtype Polymorphism

We've seen how inheritance lets us reuse existing code in a superclass while implementing small modifications by overriding a superclass's methods or writing brand new methods in the subclass. Inheritance also makes it possible to design general data structures and methods using *polymorphism*.

Polymorphism, at its core, means 'many forms'. In Java, polymorphism refers to how objects can have many forms or types. In object-oriented programming, polymorphism relates to how an object can be regarded as an instance of its own class, an instance of its superclass, an instance of its superclass's superclass, and so on.

Consider a variable `deque` of static type Deque. A call to `deque.addFirst()` will be determined at the time of execution, depending on the run-time type, or dynamic type, of `deque` when `addFirst` is called. As we saw in the last chapter, Java picks which method to call using dynamic method selection.

Suppose we want to write a python program that prints a string representation of the larger of two objects. There are two approaches to this.

1. Explicit HoF Approach

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

1. Subtype Polymorphism Approach

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

Using the explicit higher order function approach, you have a common way to print out the larger of two objects. In contrast, in the subtype polymorphism approach, the object *itself* makes the choices. The `largerFunction` that is called is dependent on what x and y actually are.

Max Function

Say we want to write a `max` function which takes in any array - regardless of type - and returns the maximum item in the array.

Exercise 4.3.1. Your task is to determine how many compilation errors there are in the code below.

```
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];
}

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();
}
```

In the code above, there was only 1 error, found at this line:

```
if (items[i] > items[maxDex]) {
```

The reason why this results in a compilation error is because this line assumes that the `>` operator works with arbitrary Object types, when in fact it does not.

Instead, one thing we could is define a `maxDog` function in the Dog class, and give up on writing a "one true max function" that could take in an array of any arbitrary type. We might define something like this:

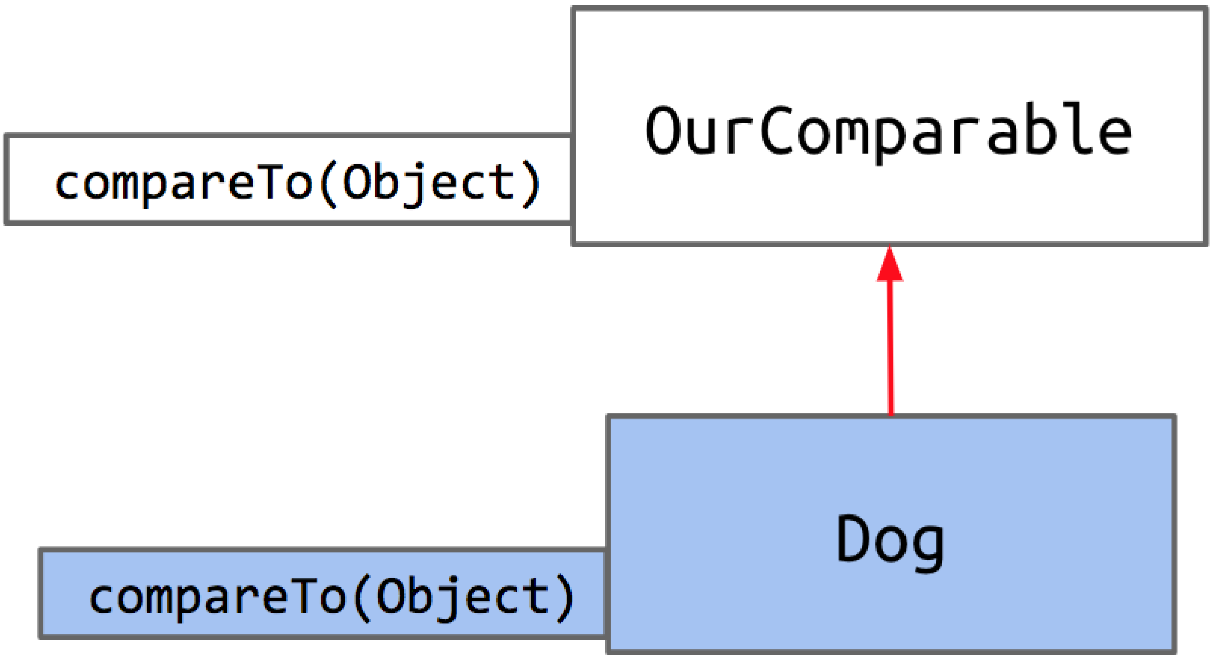
```
public static Dog maxDog(Dog[] dogs) {
    if (dogs == null || dogs.length == 0) {
        return null;
    }
    Dog maxDog = dogs[0];
    for (Dog d : dogs) {
        if (d.size > maxDog.size) {
            maxDog = d;
        }
    }
    return maxDog;
}
```

While this would work for now, if we give up on our dream of making a generalized `max` function and let the Dog class define its own `max` function, then we'd have to do the same for any class we define later. We'd need to write a `maxCat` function, a `maxPenguin` function, a `maxWhale` function, etc., resulting in unnecessary repeated work and a lot of redundant code.

The fundamental issue that gives rise to this is that Objects cannot be compared with `>`. This makes sense, as how could Java know whether it should use the String representation of the object, or the size, or another metric, to make the comparison? In

Python or C++, the way that the `>` operator works could be redefined to work in different ways when applied to different types. Unfortunately, Java does not have this capability. Instead, we turn to interface inheritance to help us out.

We can create an interface that guarantees that any implementing class, like Dog, contains a comparison method, which we'll call `compareTo`.



Let's write our interface. We'll specify one method `compareTo`.

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

We will define its behavior like so:

- Return -1 if `this` < o.
- Return 0 if `this` equals o.
- Return 1 if `this` > o.

Now that we've created the `OurComparable` interface, we can require that our Dog class implements the `compareTo` method. First, we change Dog's class header to include `implements OurComparable`, and then we write the `compareTo` method according to its defined behavior above.

Exercise 4.3.2. Implement the `compareTo` method for the Dog class.

We use the instance variable `size` to make our comparison.

```
public class Dog implements OurComparable {
    private String name;
    private int size;

    public Dog(String n, int s) {
        name = n;
        size = s;
    }

    public void bark() {
        System.out.println(name + " says: bark");
    }

    public int compareTo(Object o) {
        Dog uddaDog = (Dog) o;
        if (this.size < uddaDog.size) {
            return -1;
        } else if (this.size == uddaDog.size) {
            return 0;
        }
        return 1;
    }
}
```

Notice that since `compareTo` takes in any arbitrary Object o, we have to *cast* the input to a Dog to make our comparison using the `size` instance variable.

Now we can generalize the `max` function we defined in exercise 4.3.1 to, instead of taking in any arbitrary array of objects, takes in `OurComparable` objects - which we know for certain all have the `compareTo` method implemented.

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

Great! Now our `max` function can take in an array of any `OurComparable` type objects and return the maximum object in the array. Now, this code is admittedly quite long, so we can make it much more succinct by modifying our `compareTo` method's behavior:

- Return negative number if `this` < o.
- Return 0 if `this` equals o.
- Return positive number if `this` > o.

Now, we can just return the difference between the sizes. If my size is 2, and uddaDog's size is 5, `compareTo` would return -3, a negative number indicating that I am smaller.

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

Using inheritance, we were able to generalize our maximization function. What are the benefits to this approach?

- No need for maximization code in every class(i.e. no `Dog.maxDog(Dog[])` function required
- We have code that operates on multiple types (mostly) gracefully

Interfaces Quiz

Exercise 4.3.3. Given the `Dog` class, `DogLauncher` class, `OurComparable` interface, and the `Maximizer` class, if we omit the compareTo() method from the Dog class, which file will fail to compile?

```
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;
        if (this.size < uddaDog.size) {
            return -1;
        } else if (this.size == uddaDog.size) {
            return 0;
        }
        return 1;
    }
    ...
}

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

In this case, the `Dog` class fails to compile. By declaring that it `implements OurComparable`, the Dog class makes a claim that it "is-an" OurComparable. As a result, the compiler checks that this claim is actually true, but sees that Dog doesn't implement `compareTo`.

What if we were to omit `implements OurComparable` from the Dog class header? This would cause a compile error in DogLauncher due to this line:

```
System.out.println(Maximizer.max(dogs));
```

If Dog does not implement the OurComparable interface, then trying to pass in an array of Dogs to Maximizer's `max` function wouldn't be approved by the compiler. `max` only accepts an array of OurComparable objects.

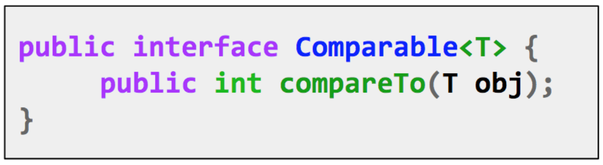
Comparables

The `OurComparable` interface that we just built works, but it's not perfect. Here are some issues with it:

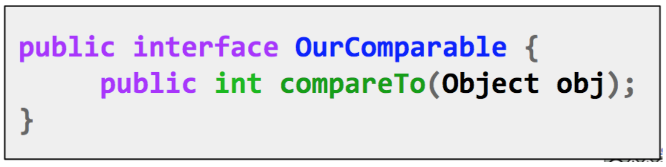
- Awkward casting to/from Objects
- We made it up.
    - No existing classes implement OurComparable (e.g. String, etc.)
    - No existing classes use OurComparable (e.g. no built-in max function that uses OurComparable)

The solution? We'll take advantage of an interface that already exists called `Comparable`. `Comparable` is already defined by Java and is used by countless libraries.

`Comparable` looks very similar to the OurComparable interface we made, but with one main difference. Can you spot it?



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



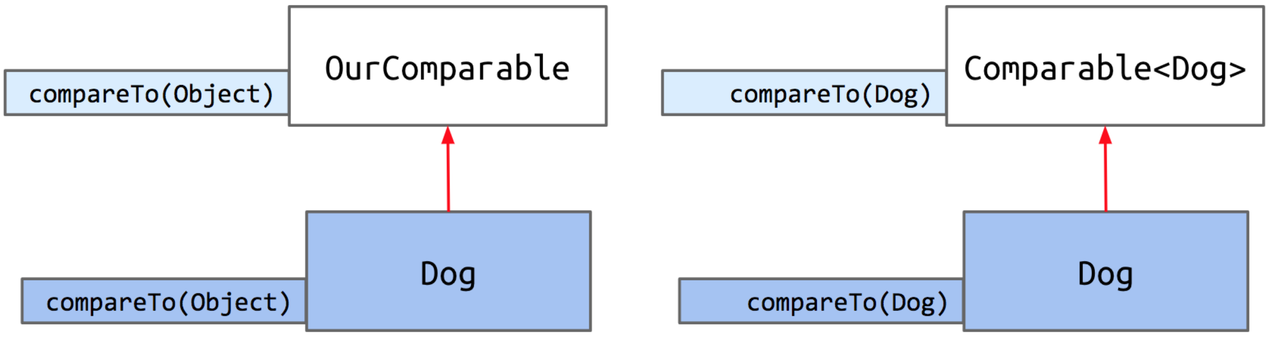
```
public interface OurComparable {
    public int compareTo(Object obj);
}
```

Notice that `Comparable<T>` means that it takes a generic type. This will help us avoid having to cast an object to a specific type! Now, we will rewrite the Dog class to implement the Comparable interface, being sure to update the generic type `T` to Dog:

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

Now all that's left is to change each instance of OurComparable in the Maximizer class to Comparable. Watch as the largest Dog says bark:

Instead of using our personally created interface `OurComparable`, we now use the real, built-in interface, `Comparable`. As a result, we can take advantage of all the libraries that already exist and use `Comparable`.



Comparator

We've just learned about the comparable interface, which imbeds into each Dog the ability to compare itself to another Dog. Now, we will introduce a new interface that looks very similar called `Comparator`.

Let's start off by defining some terminology.

> Natural order - used to refer to the ordering implied in the `compareTo` method of a particular class.

As an example, the natural ordering of Dogs, as we stated previously, is defined according to the value of size. What if we'd like to sort Dogs in a different way than their natural ordering, such as by alphabetical order of their name?

Java's way of doing this is by using `Comparator`'s. Since a comparator is an object, the way we'll use `Comparator` is by writing a nested class inside Dog that implements the `Comparator` interface.

But first, what's inside this interface?

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

This shows that the `Comparator` interface requires that any implementing class implements the `compare` method. The rule for `compare` is just like `compareTo`:

- Return negative number if o1 < o2.
- Return 0 if o1 equals o2.
- Return positive number if o1 > o2.

Let's give Dog a NameComparator. To do this, we can simply defer to `String`'s already defined `compareTo` method.

```
import java.util.Comparator;

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

    private static class NameComparator implements Comparator<Dog> {
        public int compare(Dog a, Dog b) {
            return a.name.compareTo(b.name);
        }
    }

    public static Comparator<Dog> getNameComparator() {
        return new NameComparator();
    }
}
```

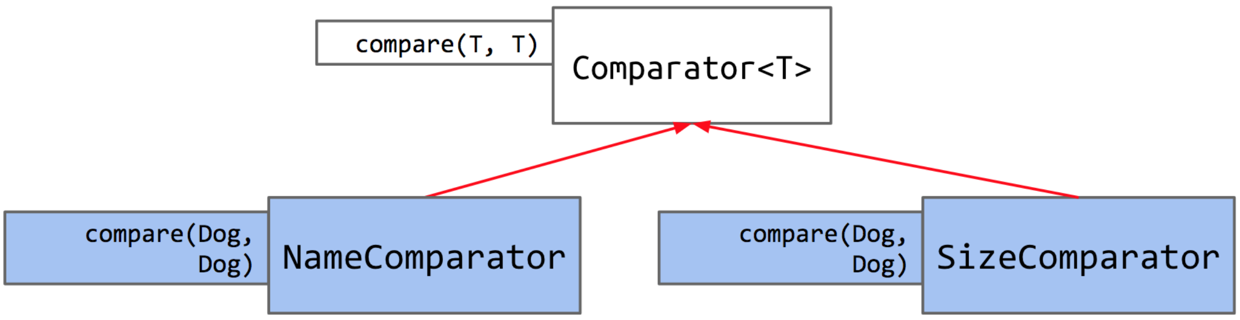
Note that we've declared NameComparator to be a static class. A minor difference, but we do so because we do not need to instantiate a Dog to get a NameComparator. Let's see how this Comparator works in action.

As you've seen, we can retrieve our NameComparator like so:

```
Comparator<Dog> nc = Dog.getNameComparator();
```

All in all, we have a Dog class that has a private NameComparator class and a method that returns a NameComparator we can use to compare dogs alphabetically by name.

Let's see how everything works in the inheritance hierarchy - we have a Comparator interface that's built-in to Java, which we can implement to define our own Comparators (`NameComparator` , `SizeComparator` , etc.) within Dog.



To summarize, interfaces in Java provide us with the ability to make **callbacks**. Sometimes, a function needs the help of another function that might not have been written yet (e.g. `max` needs `compareTo`). A callback function is the helping function (in the scenario, `compareTo`). In some languages, this is accomplished using explicit function passing; in Java, we wrap the needed function in an interface.

A Comparable says, "I want to compare myself to another object". It is imbedded within the object itself, and it defines the **natural ordering** of a type. A Comparator, on the other hand, is more like a third party machine that compares two objects to each other. Since there's only room for one `compareTo` method, if we want multiple ways to compare, we must turn to Comparator.