Photo credit: Andrew Kennedy

JAVA GENERICS

Lecture 22

CS2110 – Spring 2019

Announcements

Midnight tonight. Deadline for A6.

Late ones until Sunday night.

We tell you soon whether your A6 can be used in A7.

We make A7 available and demo it.

Material on generics

JavaHyperText entry

generics

Look at lecture notes page of course website, row for this lecture, and download demo code.

Java Collections

Early versions of Java lacked generics…

```
interface Collection {
    /** Return true iff the collection contains ob */
    boolean contains(Object ob);

   /** Add ob to the collection; return true iff
     * the collection is changed. */
   boolean add(Object ob);

   /** Remove ob from the collection; return true iff
    * the collection is changed. */
   boolean remove(Object ob);
  ...
}
```

Java Collections

Lack of generics was painful because programmers had to manually cast.

```
Collection c = ...
c.add("Hello")
c.add("World");
...
for (Object ob : c) {
  String s= (String) ob;
  System.out.println(s + " : " + s.length());
}
```

… and it was too easy to make mistakes!

Using Java Collections

Limitation seemed especially awkward because built-in arrays do not have the same problem!

```
String[] a = ...
a[0]= ("Hello")
a[1]= ("World");
...
for (String s : a) {
  System.out.println(s);
}
```

In late 1990s, Sun Microsystems initiated a design process to add generics to the language ...

Arrays → Generics

Array of Strings, ArrayList of strings ---same concept with a different syntax

We should be able to do the same thing with object types generated by classes!

```
Object[] oa= ...              // array of Objects
String[] sa=  ...             // array of Strings
ArrayList<Object> oA= ... // ArrayList of Objects
ArrayList<String> oA= ... // ArrayList of Strings
```

Proposals for adding Generics to Java

Andrew Meyers

Turing Award winner Barbara Liskov

Nate Foster

PolyJ

Pizza/GJ

LOOJ

…all based on *parametric polymorphism*.

Winner:

Gilad Bracha David Stoutamire Phil Wadler Martin Odersky

Reason: Proposal did not require changes to the Java Virtual Machine.

CL.java → Compiler → CL.class

Why not? Their proposal uses *type erasure*. All notions of type are erased from the program. (It could look like a Python program, which doesn't have types.) Of course, there are checks for improper casting and such.

Generic Collections

With generics, the Collection interface becomes...

```
interface Collection<T> {
  /** Return true iff the collection contains x */
  boolean contains(Object x);

  /** Add x to the collection; return true iff
    * the collection is changed. */
  boolean add(T x);

  /** Remove x from the collection; return true iff
    * the collection is changed. */
  boolean remove(T x);
  ...
}
```

Generic Collections

Can be a lot more complicated

```
interface Iterable<T> {
   default void forEach(Consumer<? super T > action)
}


class Arrays {
   /** Sort b according to the natural ordering. */
   static <T extends Comparable<? super T>> void
         parallelSort(T[] b)

         WOW! Who can understand THAT!!

}
```

Using Java Collections

With generics, no casts are needed...

```
Collection<String> c= ...
c.add("Hello")
c.add("World");
...
for (String s : c) {
  System.out.println(s + " : " + s.length());
}
```

… and mistakes (usually) get caught!

Type checking (at compile time)

The compiler can automatically detect uses of collections with incorrect types...

```
// This is Demo0
Collection<String> c= ...
c.add("Hello")  /* Okay */
c.add(1979);    /* Illegal: syntax error! */
```

Generally speaking,

<!-- -->Collection<String>

behaves like the parameterized type

Collection<T>

where all occurrences of T have been replaced by String.

Subtyping

Subtyping extends naturally to generic types.

```
interface Collection<T> { ... }
interface List<T> extends Collection<T> { ... }
class LinkedList<T> implements List<T> { ... }
class ArrayList<T> implements List<T> { ... }


/* The following statements are all legal. */
List<String> l= new LinkedList<String>();
ArrayList<String> a= new ArrayList<String>();
Collection<String> c= a;
l= a
c= l;
```

Array Subtyping

Java's type system allows the analogous rule for arrays:

```
// This is Demo1
String[] as= new String[10];
Object[] ao= new Object[10];

ao= as;             //Type-checks: considered outdated design
ao[0]= 2110;        //Type-checks: Integer subtype Object
String s= as[0];    //Type-checks: as is a String array
```

What happens when this code is run? TRY IT OUT!

It throws an ArrayStoreException! Because arrays are built into Java right from beginning, it could be defined to detect such errors

Array Subtyping

Java's type system allows the analogous rule for arrays:

```java
// This is Demo1
String[] as= new String[10];
Object[] ao= new Object[10];

ao= as;
ao[0]= 2110;
String s= as[0];
```

Is this legal? TRY IT OUT!

Subtyping

String[] is a subtype of Object[]

...is ArrayList<String> a subtype of ArrayList<Object>?

```
// This is Demo1
ArrayList<String> ls= new ArrayList<String>();
ArrayList<Object> lo= new ArrayList<Object>();

lo= ls;                    //Suppose this is legal
lo.add(2110);              //Type-checks: Integer subtype Object
String s = ls.get(0);      //Type-checks: ls is a List<String>
```

TRY IT OUT!

The answer is NO. ArrayList<String> is NOT a subtype of ArrayList<Object>

A type parameter for a method


```
Demo 2
/** Replace all values x in list by y. */
public void replaceAll(List<Double> ts, Double x, Double y) {
  for (int i= 0; i < ts.size(); i= i+1)
     if (Objects.equals(ts.get(i), x))
        ts.set(i, y);
}
```

We would like to rewrite the parameter declarations so this method can be used for ANY list, no matter the type of its elements.

A type parameter for a method

Try replacing Double by some “Type parameter” T, and Java will still complain that type T is unknown.

```
/** Replace all values x in list ts by y. */
                                          T                  T              T
public void replaceAll(List<Double> ts, Double x, Double y) {
  for (int i= 0; i < ts.size(); i= i+1)
      if (Objects.equals(ts.get(i), x))
          ts.set(i, y);
}
```

Somehow, Java must be told that T is a type parameter and not a real type. Next slide says how to do this

A type parameter for a method

Placing <T> after the access modifier indicates that T is to be considered as a type parameter, to be replaced when the method is called.

```
/** Replace all values x in list ts by y. */
public <T> void replaceAll(List<T> ts, T x, T y) {
  for (int i= 0; i < ts.size(); i= i+1)
     if (Objects.equals(ts.get(i), x))
        ts.set(i, y);
}
```

Printing Collections

Suppose we want to write a method to print every value in a Collection<T>.

```
void print(Collection<Object> c) {
  for (Object x : c) {
    System.out.println(x);
  }
}
...
Collection<Integer> c= ...
c.add(42);
print(c);  /* Illegal: Collection<Integer> is not a
            * subtype of Collection<Object>! */
```

Wildcards

To get around this problem, *wildcards* were added

```
void print(Collection<?> c) {
  for (Object x : c) {
    System.out.println(x);
  }
}
...
Collection<Integer> c= ...
c.add(42);
print(c);   /* Legal! */
```

One can think of Collection<?> as a "Collection of *some* unknown type of values".

Wildcards

We can't add values to collections whose types are wildcards ...

```
void doIt(Collection<?> c) {
  c.add(42); /* Illegal! */
}
...
Collection<String> c= ...
doIt(c);   /* Legal! */
```

42 can be added to

- Collection<Integer>
- Collection<Number>
- Collection<Object>

but c could be Collection of anything, not just supertypes of Integer

Object

Number

Integer

How to say that ? can be a supertype of Integer?

Bounded Wildcards

Sometimes it is useful to have some information about a wildcard. Can do this by adding bounds...

```
void doIt(Collection<? super Integer> c) {
  c.add(42); /* Legal! */
}
...
Collection<Object> c= ...
doIt(c);   /* Legal! */
Collection<Float> c= ...
doIt(c);   /* Illegal! */
```

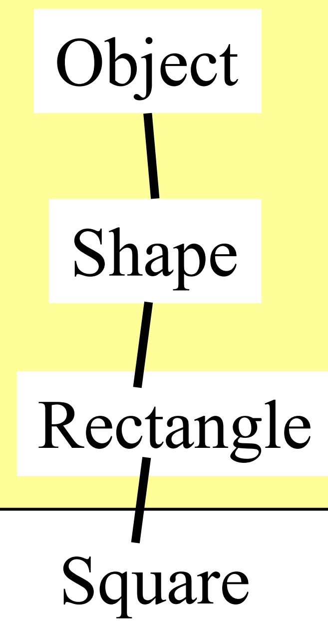
Now c can only be a Collection of Integer or some *supertype* of Integer, and 42 can be added to any such Collection

"? super" is useful when you are only *giving* values to the object, such as putting values into a Collection.

Bounded Wildcards

"? extends" is useful when you are only *receiving* values from the object, such as getting values out of a Collection.

```
void doIt(Collection<? extends Shape> c) {
  for (Shape s : c)
     s.draw();
}
...
Collection<Circle> c= ...
doIt(c);  /* Legal! */
Collection<Object> c= ...
doIt(c);  /* Illegal! */
```



Bounded Wildcards

Wildcards can be nested. The following *receives* Collections from an Iterable and then *gives* floats to those Collections.

```
void doIt(Iterable<? extends Collection<? super Float>> cs) {
  for(Collection<? super Float> c : cs)
    c.add(0.0f);
}
...
List<Set<Float>> l= ...
doIt(l);  /* Legal! */
Collection<List<Number>> c= ...
doIt(c);  /* Legal! */
Iterable<Iterable<Float>> i= ...
doIt(i);  /* Illegal! */
ArrayList<? extends Set<? super Number>> a= ...
doIt(a);  /* Legal! */
```

We skip over this in lecture. Far too intricate for everyone to understand. We won't quiz you on this.

Generic Methods

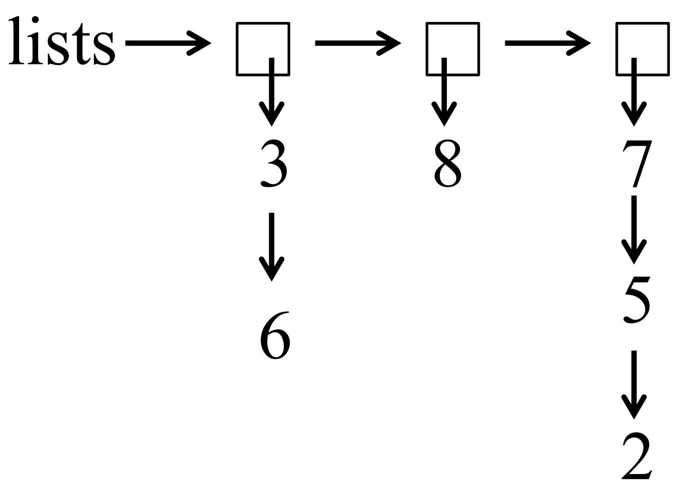
Here's the printing example again. Written with a method type-parameter.

```
<T> void print(Collection<T> c) {// T is a type parameter
  for (T x : c) {
    System.out.println(x);
  }
}
...
Collection<Integer> c= ...
c.add(42);
print(c);  /* More explicitly: this.<Integer>print(c) */
```

But wildcards are preferred when just as expressive.

Catenating Lists

Suppose we want to catenate a list of lists into one list. We want the return type to depend on what the input type is.



Return this list

$\rightarrow 3 \rightarrow 6 \rightarrow 8 \rightarrow 7 \rightarrow 5 \rightarrow 2$

Catenating Lists

The return type depends on what the input type is.

```
/** Return the flattened version of lists. */
<T> List<T> flatten(List<? extends List<T>> lists) {
  List<T> flat= new ArrayList<T>();
  for (List<T> l : lists)
     flat.addAll(l);
  return flat;
}
...
List<List<Integer>> is= ...
List<Integer> i= flatten(is);
List<List<String>> ss= ...
List<String> s= flatten(ss);
```

Interface Comparable

Interface Comparable<T> declares a method for comparing one object to another.

```
interface Comparable<T> {
   /* Return a negative number, 0, or positive number
    * depending on whether this is less than,
    * equal to, or greater than that */
  int compareTo(T that);
}
```

Integer, Double, Character, and String are all Comparable with themselves

Our binary search

Type parameter: anything T that implements Comparable<T>

```
/** Return h such that c[0..h] <= x < c[h+1..].
  * Precondition: c is sorted according to .. */
public static <T extends Comparable<T>>
                   int indexOf1(List<T> c, T x) {
   int h= -1;
   int t= c.size();
   // inv: h < t  &&  c[0..h] <= x < c[t..]
   while (h + 1 < t) {
      int e= (h + t) / 2;
      if (c.get(e).compareTo(x) <= 0) h= e;
      else t= e;
   }
   return h;
}
```

Those who fully grok generics write:

Type parameter: anything T that implements Comparable<T>

```
/** Return h such that c[0..h] <= x < c[h+1..].
  * Precondition: c is sorted according to .. */
public static <T extends Comparable<? super T>>
               int indexOf1(List<T> c, T x) {
   int h= -1;
   int t= c.size();
   // inv: h < t  &&  c[0..h] <= x < c[t..]
   while (h+1 < t) {
      int e= (h + t) / 2;
      if (c.get(e).compareTo(x) <= 0)
          h= e;
      else t= e;
    }
return h;
}
```

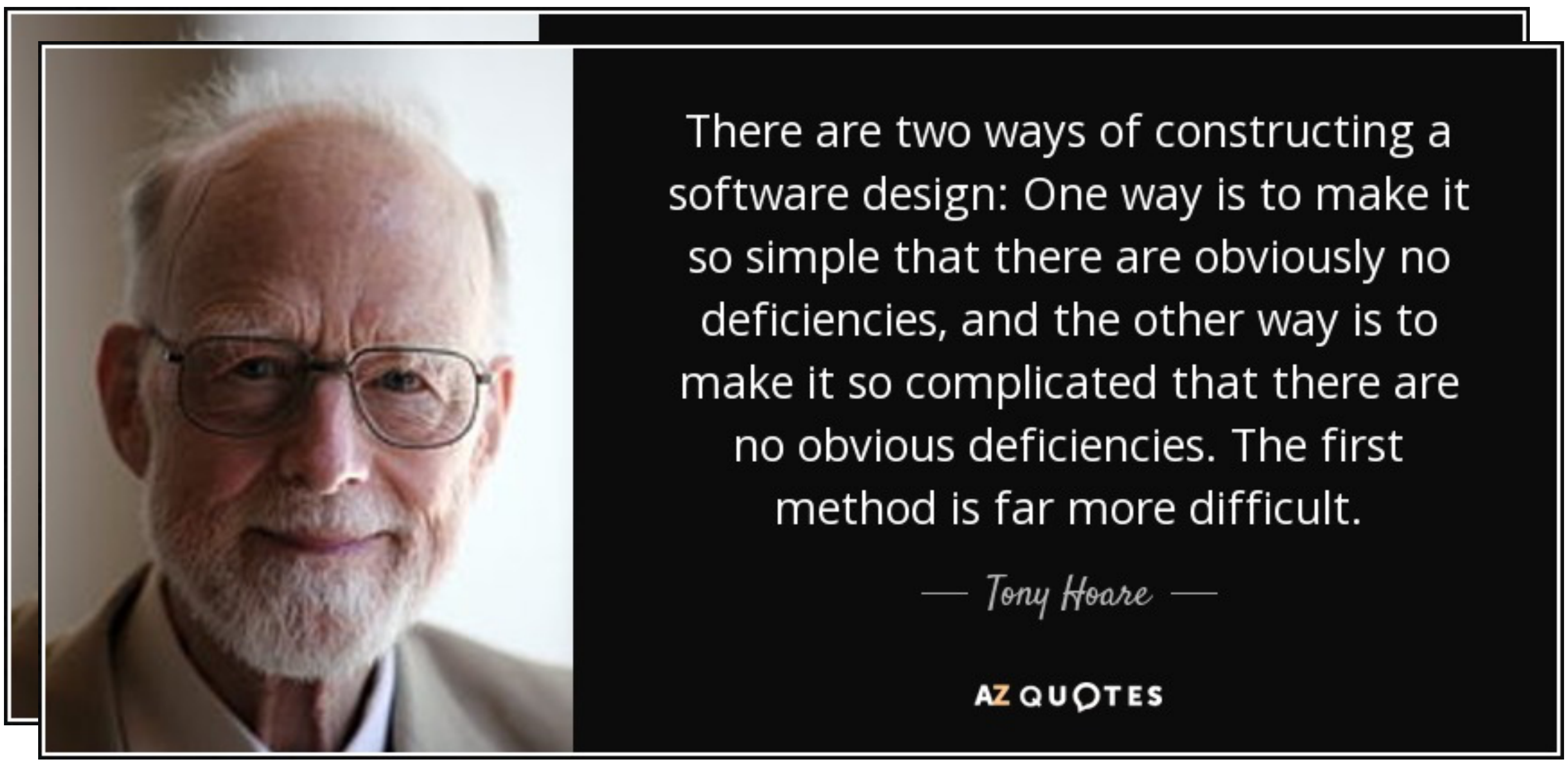
Anything that is a superclass of T.

Don't be concerned with this! You don't have to fully understand this.

Sir Tony Hoare

Inside every large program is a small program struggling to get out.

The unavoidable price of reliability is simplicity.

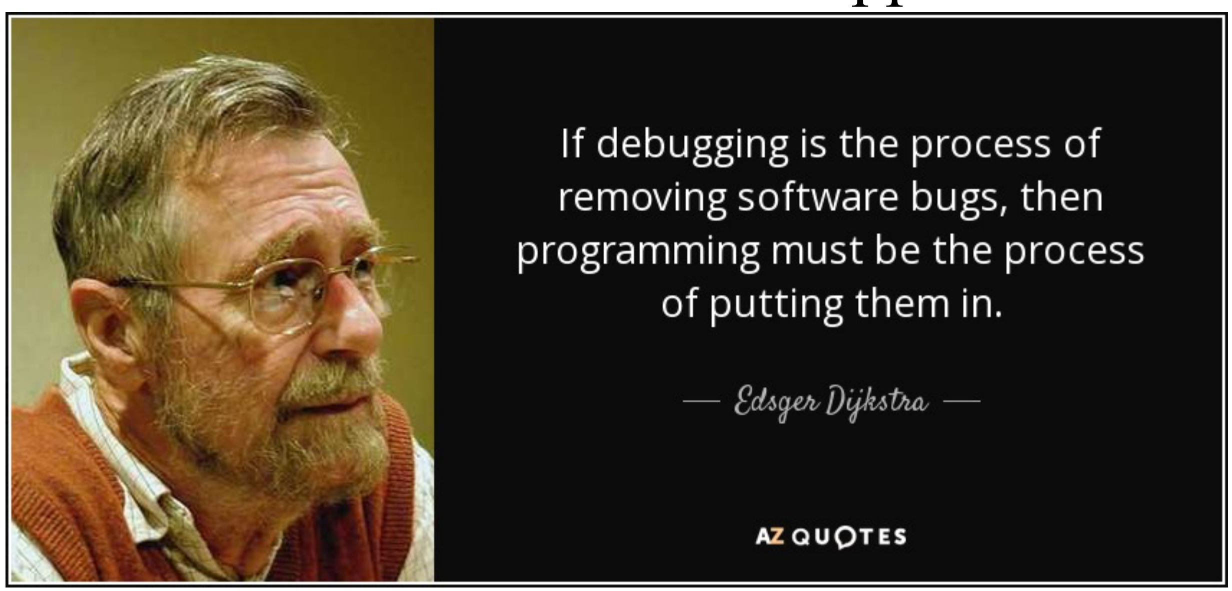


Edsger W. Dijkstra

Beauty is our business.

How do w convince people that in programming simplicity and clarity —in short, what mathematicians call elegance— are not a dispensable luxury but a crucial matter that decides between success and failure?

Simplicity and elegance are unpopular because they require hard work and discipline to achieve and education to be appreciated.



Donald Knuth

Programs are meant to be read by humans and only incidentally for computers to execute

Everyday life is like programming, I guess. If you love something you can put beauty into it.

The best practice is inspired by theory.