Generics

IRS W-9 Form
Generics (universal polymorphism) is HUGE!

Computer science is about “bookkeeping.”
Syntax

Non-parametrized class:

<class declaration> ::= 
"class" <identifier> 
["extends" <type>]
["implements" <type list>]
"{" <class body> "}

Generic class

<class declaration> ::= 
"class" <identifier> [[]<type parameter list>]
["extends" <type>]
["implements" <type list>]
"{" <class body> "}"
Syntax

Non-parametrized method

<method declaration> ::=<type> <identifier>
"(" [<formal parameters list>] ")"
["throws" <qualified identifier list>]
"{" <method body> "}"

Generic method

<method declaration> ::=<type parameter list> [<type> <identifier>
"(" [<formal parameters list>] ")"
["throws" <qualified identifier list>]
"{" <method body> "}"
Syntax

Generic type parameters

```latex
\text{<type parameter list>} ::= \\
\quad "<" \text{<type parameter>} \{"," \text{<type parameter}>\} ">"

\text{<type parameter>} ::= \\
\quad \text{<identifier>} \ [ \ "extends" \ \text{<bound>} \ ]

\text{<bound>} ::= \text{<type>} \ \{ \ "&" \ \text{<type>} \ \}\n
\text{<type argument list>} ::= \\
\quad "<" \text{<type argument>} \{"," \text{<type argument}>\} ">"

\text{<type argument>} ::= \text{<type>}
\quad \text{<type>}
\quad \text{| } "?" \ [\ "extends" \ \text{<type>}] \\
\quad \text{| } "?" \ [\ "super" \ \text{<type>}]
```
Syntax

\[
\text{<type>} ::= \text{<identifier> \[<\text{type argument list}>]\}}
\{"." \text{<identifier> \[<\text{type argument list}>]\}}
\{"[" "]]"\}
/ \text{<primitive type>}
\]
Already we have used ArrayList and LinkedList.

```java
List<BigDecimal> list1 = new ArrayList<>();
list1.add(new BigDecimal("123"));
list1.add(new BigDecimal("4567"));
System.out.println(list1);

List<String> list2 = new LinkedList<String>();
list2.add("How");
list2.add("now");
list2.add("brown");
list2.add("cow");
System.out.println(list2);
```
Consider building a class to hold two values.

class Pair {
  int first, second;
}

Not very flexible. So we try using subtype polymorphism (object-oriented programming). We take advantage of the fact that every object is a subclass of `Object`.

```java
class Pair {
    Object first, second;
    void setFirst (Object first) {
        this.first = first;
    }
    Object getFirst () {
        return first;
    }
}
```

```java
Pair p = new Pair();
p.setFirst (new Object ());
p.setFirst ("hello");
p.setFirst (new Integer (5));
System.out.println(p.getFirst ());
```
Not very flexible. So we try using subtype polymorphism (object-oriented programming). We take advantage of the fact that every object is a subclass of Object.

class Pair {
    Object first, second;
    void setFirst (Object first) { this.first = first; }
    Object getFirst () { return first; }
}

Pair p = new Pair();
p.setFirst (new Object());
p.setFirst ("hello");
p.setFirst (new Integer (5));
System.out.println (p.getFirst());
Why Not Subtype?

Subtype polymorphism here is unsafe. The type of the objects is “laundered.” We can put it in; but we can’t take it out as the same type of thing we put in.

```java
class Pair {
    Object first, second;
    void setFirst (Object first) { this.first = first; }
    Object getFirst () { return first; }
}
```

```java
Pair p = new Pair();
p.setFirst("Hello, World!");
char leadingChar = p.getFirst().charAt(0);
// Error
```
Why Not Subtype?

Subtype polymorphism here is unsafe. The type of the objects is “laundered.” We can put it in; but we can’t take it out as the same type of thing we put in.

```java
class Pair {
    Object first, second;
    void setFirst (Object first) { this.first = first; }
    Object getFirst () { return first; }
}

Pair p = new Pair();
p.setFirst ("Hello, World!");
char leadingChar = p.getFirst().charAt(0); // Error
```
Why Not Subtype?

Subtype polymorphism here is unsafe. The type of the objects is “laundered.” We can thwart the compiler, but this is not wise. The class can be abused and this is not discovered until runtime.

class Pair {
    Object first, second;
    void setFirst (Object first) {
        this.first = first;
    }
    Object getFirst () {
        return first;
    }
}

Pair p = new Pair();
p.setFirst (new Integer (5));

// Trust me!
Integer i = (Integer) p.getFirst();   // narrowing
**Why Generics?**

Generic classes (universal polymorphism) is the perfect solution. The compiler checks that the class is used correctly.

```java
class Pair <T> {
    public final T first, second;
    Pair (T first, T second) {
        this.first=first; this.second=second;
    }
    T getFirst () { return first; }
}
```
Pairs of integers, pairs of strings, pairs of pairs … there are possible and natural.

```java
Pair<Integer> p = new Pair<Integer>(new Integer(5), new Integer(8));
Integer i = p.getFirst();

Pair<String> q = new Pair<String>("abc","xyz");
String s = q.getFirst();

Pair<Pair<String>> r = new Pair<Pair<String>>(
    new Pair<String>("a","b"),
    new Pair<String>("c","d"));
```
Why Generics?

Generic classes (universal polymorphism) is the perfect solution. The compiler checks that the class is used correctly.

```java
record Pair<T> (T first, T second) {}

Pair<String> q = new Pair<String> ("abc","xyz");
String s = q.first();

Pair<Pair<String>> r = new Pair<Pair<String>>(
    new Pair<String>("a","b"),
    new Pair<String>("c","d")
);
String t = r.second().first();
```
Use the static factory method—not deprecated \texttt{new Integer(3)}

\texttt{Pair<Integer> p = new Pair<Integer>(Integer.valueOf(3), Integer.valueOf(8));}

Or better ...
Wrapper Classes

Generics class can be instantiated only with classes (not primitive types). However, Autoboxing and unboxing of primitive types make generics act as if they were applicable to primitive types. This is hugely useful.

The duplication of the type can be avoid by *type inference*

```java
Pair<Integer> p = new Pair<>(5, 8);
Pair<Character> q = new Pair<>('a', 'b');
int i = p.getFirst();
char c = q.getFirst();
```
```java
class Pair <T,U> {
    public final T first;
    public final U second;
    Pair (T first, U second) {
        this.first=first; this.second=second;
    }
    T getFirst () { return first; }
    U getSecond() { return second; }
}

Autoboxing and unboxing.
Pair<Integer,String> p = new Pair<>(5, "hello");
int i = p.getFirst();
String s = p.getSecond();
```
A method can be generic even if the class it is in is not generic.

```java
public <T> T pick (T... choices) {
    if (choices.length == 0) return null;
    final int i = new Random().nextInt(choices.length);
    return choices[i];
}
```
Generic method

This does not work:

```java
public <T> T max (T t1, T t2) {
    if (t1 > t2) {
        return t1;
    } else {
        return t2;
    }
}
```
Generic method

This does not work:

```java
public <T> T max (T t1, T t2) {
    if (t1 > t2) {
        return t1;
    } else {
        return t2;
    }
}
```

```java
public <T extends Comparable<T>> T max (T t1, T t2) {
    if (t1.compareTo(t2) > 0) {
        return t1;
    } else {
        return t2;
    }
}
```
Three important Java generic interfaces:

1. Iterator
2. Comparable
3. Comparator

are often used in conjunction with Java collections.

Also important is:

1. AutoCloseable
## Table 2-1. Important functional interfaces in Java

<table>
<thead>
<tr>
<th>Interface name</th>
<th>Arguments</th>
<th>Returns</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Predicate&lt;T&gt;</td>
<td>T</td>
<td>boolean</td>
<td>Has this album been released yet?</td>
</tr>
<tr>
<td>Consumer&lt;T&gt;</td>
<td>T</td>
<td>void</td>
<td>Printing out a value</td>
</tr>
<tr>
<td>Function&lt;T,R&gt;</td>
<td>T</td>
<td>R</td>
<td>Get the name from an Artist object</td>
</tr>
<tr>
<td>Supplier&lt;T&gt;</td>
<td>None</td>
<td>T</td>
<td>A factory method</td>
</tr>
<tr>
<td>UnaryOperator&lt;T&gt;</td>
<td>T</td>
<td>T</td>
<td>Logical not (!)</td>
</tr>
<tr>
<td>BinaryOperator&lt;T&gt;</td>
<td>(T, T)</td>
<td>T</td>
<td>Multiplying two numbers (*)</td>
</tr>
</tbody>
</table>
AutoCloseable

The try-with-resources statement is a try statement that declares one or more resources. A resource is an object that must be closed after the program is finished with it. The try-with-resources statement ensures that each resource is closed at the end of the statement. Any object that implements java.lang.AutoCloseable, which includes all objects which implement java.io.Closeable, can be used as a resource.

An object that may hold resources (such as file or socket handles) until it is closed. The close() method of an AutoCloseable object is called automatically when exiting a try-with-resources block for which the object has been declared in the resource specification header. This construction ensures prompt release, avoiding resource exhaustion exceptions and errors that may otherwise occur.
Iterator

The interface `java.lang.Iterator<E>` has methods (i.a.):

```java
boolean hasNext()
E next()
```

The interface `java.util.Collection` has method (i.a.):

```java
Iterator<E> iterator()
```

```java
public static void main (String[] args) {
    final List<Integer> list = new ArrayList<>();
    final Iterator<Integer> it = list.iterator();
    while (it.hasNext()) {
        // NB. auto unboxing, no narrowing
        final int x = it.next();
        // Do something with "x"
    }
}
```
I tend to use the for loop.

```java
public static void main (String[] args) {
    final List<Integer> list = new ArrayList<>();
    for (final Iterator<Integer> it = list.iterator();
        it.hasNext();
        /**/)
    {
        final int x = it.next(); // auto-unboxing
        // Do something with "x"
    }
}

(Interesting use of final in a for loop. Iterator is a mutable class.)
```
The “for each” loop is better:

```java
public static void main (String[] args) {
    final List<Integer> list = new ArrayList<>();
    for (final int x: list) {
        // Do something with "x"
    }
}
```

No narrowing necessary, and static type checking possible!
The interface `java.lang.Comparable<T>` has just one method.

```java
interface Comparable <T> {
    int compareTo (T other);
}
```

The interface is used to give a class a “natural” ordering — an ordering the Java API’s (especially the collection API’s) uses by default. It *should* be a total ordering consistent with equals: for every `e1` and `e2` of the class `T`, `e1.compareTo(e2)==0` iff `e1.equals(e2)`. 
// Give X a "natural" ordering
class X implements Comparable<X> {
    /* ... */
    int compareTo (X other) {
        /* compare 'this' and 'other' */
        if (/* 'this' is greater than 'other' */) {
            return +1;
        } else if (/* 'this' is less than 'other' */) {
            return -1;
        } else {
            /* Should be consistent with "equals()" */
            return 0;
        }
    }
}
class Person implements Comparable<Person> {
    final String name;
    final int idNumber;

    /* Warning: This method is *not* consistent with equals; use for sorting only and not hashing. */
    @java.lang.Override
    int compareTo (final Person other) {
        if (this.idNumber > other.idNumber) {
            return +1;
        } else if (this.idNumber < other.idNumber) {
            return -1;
        } else {
            return this.name.compareTo(other.name);
        }
    }
}
For example:

```java
abstract static class Coin implements Comparable<Coin> {
    abstract int value ();
    public int compareTo (final Coin other) {
        final int v=value (), w=other.value ();
        if (v<w) return -1;
        else if (v>w) return +1;
        else return 0;
    }
}
```
The interface `java.util.Comparator<T>` has two methods.

```java
interface Comparator <T> {
    int compare (T o1, T o2)
    boolean equals (Object obj); // equal comparing classes
}
```

(We rarely create more than one instance of a particular comparator, so equals is hardly ever overridden.)

A comparator allows us to describe an ordering of objects without a natural ordering, or with a completely different ordering. This ordering is completely independent from the class.
Comparator

An example program which compares 2D points in three ways. [Need a better example without double.] Main.java
Comparable

By implementing Comparable, you allow your class to interoperate with all of the many generic algorithms and collection implementations that depend on this interface. You gain a tremendous amount of power of a small amount of effort. Virtually all of the value classes [data structures] in the Java platform libraries, as well as all enum types, implement Comparable. If you are writing a value class with an obvious natural ordering, such as alphabetical order, numerical order, or chronological order, you should implement the Comparable interface:

```java
public interface Comparable<T>
    int compareTo(T t);
```

Comparator

The generic procedure reserveOrder() has some really advanced code ultimately relying on a unsafe cast to do the work. The code is something like this:

class Collections {
    // ...
    private static final class RevComp<T> implements Comparator<T> {
        private static final RevComp<Object> INSTANCE = new RevComp<Object>();

        public int compare (Comparable<Object> o1, T o2) {
            Comparable<T> c2 = (Comparable<T>) o2;
            return c2.compare(o1)
        }
    }
    public static <T> Comparator<T> reverseOrder() {
        return (Comparator<T>) RevComp.INSTANCE;
    }
}
Reverse the natural order.

List<Event> track = new LinkedList<Event>();
Collections.sort(track, Collections.reverseOrder());
Equality

Consistent with Equals.
Usually, we require that two objects are equal if and only if they compare as the same:
\[ x.equals(y) \text{ if and only if } x.compareTo(y) == 0 \]
It is recommended that when designing a class you choose a natural ordering that is consistent with equals.
hash sets and maps
Recursive type bound.

// WRONG. A collection of things S that implement Comparable<T> do not have to be things of type T.

```
<T> T max(Collection<Comparable<T>> coll)
```

```
<T extends Comparable<T>> T max(Collection<T> coll)
```

```
<T extends Comparable<? super T>> T max(Collection<? extends T> coll)
```

```
<T extends Object & Comparable<? super T>>
    T max(Collection<? extends T> coll)  // Multiple bounds For backward compatibility
```

See Fruity example by Naftalin and Wadler. Oranges and apples ordered by name (kind of fruit) and size.
Many predefined classes in Java are generic. Generics make these classes useful in more situations. The Java package `java.util` is filled with generic, “utility” classes — classes that are used to solve a wide variety of problems types.

Many of these classes are container or collection classes — classes the hold many individual sub-pieces (like arrays do). These classes are organized in a rich system known as the collection classes.

Collections classes share two important characteristics:

1. the individual items have arbitrary type
2. it is common to iterate over all the individual items of the collection
List

What is a list?
A list is an ordered collection of elements, like a chain.

There is a first element, a second element, and so on. There is a last element as well. Sometimes this structure is called a sequence. The same value may occur more than once (unlike a set).
List

What is a list? It is the first and simplest of the data structures. It is a polymorphic (generic), recursive structure with two constructors.

```haskell
data List a = Nil | Cons a (List a)
```
List Essence

Operations:
• Constructor of polymorphic empty list “nil”
• Constructor of non-empty list “cons”
•Recognizer “null?”
• Destructor of the non-empty list “head” and “tail”

Rules:
• head(cons(e, _)) = e
• tail(cons(_, l)) = l

Implementation and performance are other matters.
List versus Array

The advantage of an array is that it is fairly cheap to allocate a big fixed amount of storage at once. But it wastes storage if a lot of elements are requested, but few are needed. Also, removing an element in the middle of an array is expensive because one has to move a lot of elements.

A list allocates exactly what is needed as it is needed—no space is wasted. Removing an element in the middle can be cheaper than with an array. On the other hand, random access to all elements is lost and more bookkeeping is required. Access to the first and last elements of a list may be cheap.

ArrayList in an attempted compromise. How does it handle changes in the number of elements?
The Java API has already implemented the LinkedList class. Let us implement our own simple version.

Implementing our own lists:
- IntList.java
- GenericList.java

But first a mental picture of the approach:
???
List

See Sedwick and Wayne section 4.3 for a array-based stack, and a linked-list with header implementation.
Abstract List

Abstract representation of a list
Implementing our own lists:

- ImmutableList.java
- ImmutableLinkedList.java

Let us implement our own simple version of a linked list:
- IntList.java
- GenericList.java

The Java API has already implemented the LinkedList class, which like the ArrayList class, implements the generic List interface.
List Interface in the Collection Classes

interface java.util.List\<E\> implements Collection \<E\>

E get (int index)
E set (int index, E element) returns previous elem, if any
void add (int index, E element)
E remove (int index)

int size() number of elements in the list
void clear() removes all the elements

boolean contains (Object o) search
int indexOf (Object o) index of the first occurrence

Iterator\<E\> iterator ()
The Java API has two implementations of the list interface with different performance characteristics.
ArrayList in the Collection Classes

java.util.ArrayList<E> implements List<E>

ArrayList()
ArrayList (int initialCapacity)

void ensureCapacity (int minCapacity)
void trimToSize ()
java.util.LinkedList<E> implements List<E>, Dequeue<E>

LinkedList()

E getFirst () same as element()
E getLast ()
void addFirst () same as push()
void addLast ()
E removeFirst () same as pop(), remove()
E removeLast ()
If you have to save space, then use a linked list, If you have to have fast access (set/get) to random elements, then use a list implemented as an array. If you have to remove and add elements in the middle of the list, use a linked list. See the Josephus problem.
List methods: get  add  contains  next  remove(0)  iterator.remove

<table>
<thead>
<tr>
<th></th>
<th>get</th>
<th>add</th>
<th>contains</th>
<th>next</th>
<th>remove(0)</th>
<th>iterator.remove</th>
</tr>
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<td>ArrayList</td>
<td>O(1)</td>
<td>O(1)</td>
<td>O(n)</td>
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<td>O(n)</td>
<td>O(n)</td>
</tr>
<tr>
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</tr>
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</table>
Deque methods: get add contains next remove(0) iterator.remove

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</tr>
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<td>O(1)</td>
<td>O(1)</td>
</tr>
<tr>
<td>contains</td>
<td>O(n)</td>
<td>O(n)</td>
</tr>
<tr>
<td>next</td>
<td>O(1)</td>
<td>O(1)</td>
</tr>
<tr>
<td>remove(0)</td>
<td>O(n)</td>
<td>O(1)</td>
</tr>
<tr>
<td>iterator.remove</td>
<td>O(n)</td>
<td>O(1)</td>
</tr>
</tbody>
</table>
Collection Classes

Not be confused with the generic interface Collection<T> is the utility class

java.util.Collections

```java
static <T> int binarySearch(List<...> list, T key)
static <T> List<T> emptyList()
static <T> List<T> singletonList(T o)
static <T ...> T max (Collection<? extends T> coll)
static <T ...> T min (Collection<? extends T> coll)
static int frequency (Collection<??> coll, Object o)
static void shuffle (List<??> list)
static <T ...> void sort (List<T> list)
static <T> List<T> synchronizedList (List<T> list)
static <T> List<T> unmodifiableList (List<T> list)
```
Also Useful

Also in java.util.Arrays

```java
static <T> List<T> asList (T... a)
```

```java
List<Integer> list = Arrays.asList (1,2,3,4,5,6);
```

I never can remember where this very useful static method is found.
Avoid

Do not use StringBuffer, Stack, Vector, or Hashtable, unless you need synchronization.
Use StringBuilder, ArrayDeque, ArrayList, or HashMap, instead.
The class `java.util.Collections` has methods (i.a.):

```java
static void sort (List list);
static void sort (List list, Comparator c);
```

Notice the use of the interface `List`.

```java
class Main {
    // For some class X implementing Comparable<X>
    public static void main (String[] args) {
        final List<X> list = new ArrayList<X> ();
        add (new X());
        add (new X());
        Collections.sort (list);
        Collections.sort (list,
            Collections.<X>.reverseOrder());
    }
}
```
Stack, Queue, Deque

Linear lists in which insertions, deletions, and accesses to values occur almost always at the first or the last node are very frequently encountered, and we give them special names:

A stack is a linear list for which all insertions and deletions (and usually all accesses) are made at one end of the list.

A queue is a linear list for which all insertions are made at one end of the list; all deletions (and usually all accesses) are made at the other end.

A deque ("double-ended queue") is a linear list for which all insertions and deletions (and usually all accesses) are made at the ends of the list.

A deque is therefore more general than a stack or a queue; it has some properties in common with a deck of cards, and it is pronounced the same way. We also distinguish output-restricted or input-restricted deques, in which deletions or insertions, respectively, are allowed to take place at only one end.

From Knuth, volume I, page 235. The term deque was coined by E. J. Schweppe.
Stack, Queue, Deque

stack (LIFO): addFirst or push, removeFirst or pop
queue (FIFO): addLast (enqueue), removeFirst
deque: addFirst, addLast, removeFirst, removeLast
If you want a stack, a queue, or a deque in Java.

```java
Deque<Integer> stack = new ArrayDeque<Integer> ();
Deque<String> queue = new ArrayDeque<String> ();
Deque<Integer> deque = new ArrayDeque<Integer> ();
```

The LinkedList class also implements the interface Deque. It is preferred only when it that data is treated as an ordered sequence in which it is necessary to insert elements.
A set is more complicated data structure philosophically that a list, because it required a notion of equality.

Yet since is the common in mathematics, its “essence” is generally more familiar.

Concrete implementation in Java of the interface `Set` including the `HashSet` and the `TreeSet` which are fascinating implementations to be studied in data structures classes. Also to be mentioned is the class `BitSet`. One of many things there is not time to discuss presently.
Using (mutable!) sets are easy in Java.

Set<Integer> set = new HashSet<>();
Maps are key/value pairs. They are finite functions like arrays. So they have two type parameters: one for the type of keys and one for the type of values. Using (mutable!) maps are easy in Java.

```java
Map<Integer> set = new HashSet<>();
```
Maps/Dictionaries

One has the tools (the data structures) lists, sets, and map to solve many problems.

What is missing are the algorithms, the performance analyses, the implementation choices to solve problems efficiently.