CS61B: 2021

Lecture 11: The End of Java

- Lists and Sets
- Exceptions
- Iteration
- toString and Equals

Lists and Sets in Java

Lists

In lecture, we've build two types of lists: ALists and SLLists.

- Similar to Python lists.

```
List61B<Integer> L = new AList<>();
L.addLast(5);
L.addLast(10);
L.addLast(15);
L.print();
```

```
L = []
L.append(3)
L.append(4)
L.append(5)
print(L)
```

```
$ java ListExample
3 4 5
$ python list_example.py
[3 4 5]
```

Note: We saw this in an earlier lecture, but repeated here for narrative flow.

Lists in Real Java Code

We built a list from scratch, but Java provides a built-in `List` interface and several implementations, e.g. `ArrayList`.

```
List61B<Integer> L = new AList<>();
L.addLast(5);
L.addLast(10);
L.addLast(15);
L.print();
```

```
java.util.List<Integer> L = new java.util.ArrayList<>();
L.add(5);
L.add(10);
L.add(15);
System.out.println(L);
```

Lists in Real Java Code

By including “import java.util.List” and “import java.util.ArrayList” at the top of the file, we can make our code more compact.

```
import java.util.List;
import java.util.ArrayList;

public class SimpleBuiltInListExample {
  public static void main(String[] args) {
    List<Integer> L = new ArrayList<>();
    L.add(5);
    L.add(10);
    L.add(15);
    System.out.println(L);
  }
}
```

If we import, we can use the “simple name” (ArrayList) as opposed to the longer “canonical name” (java.util.ArrayList).

Sets in Java and Python

Another handy data structure is the set.

- Stores a set of values with no duplicates. Has no sense of order.

```java
Set<String> S = new HashSet<>();
S.add("Tokyo");
S.add("Beijing");
S.add("Lagos");
S.add("São Paulo");
System.out.println(S.contains("Tokyo"));
```

```python
s = set()
s.add("Tokyo")
s.add("Beijing")
s.add("Lagos")
s.add("São Paulo")
print("Tokyo" in s)
```

```
$ java SetExample
true
$ python set_example.py
True
```

ArraySet

Today we're going to write our own Set called ArraySet.

- Won't be implementing any specific interface (for now).

```
ArraySet<String> S = new ArraySet<>();
S.add("Tokyo");
S.add("Beijing");
S.add("Lagos");
S.add("São Paulo");
System.out.println(S.contains("Tokyo"));
System.out.println(S.size());
```

Goals

Goal 1: Create a class ArraySet with the following methods:

- add(value): Add the value to the ArraySet if it is not already present.
- contains(value): Checks to see if ArraySet contains the key.
- size(): Returns number of values.

Ok to ignore resizing for this exercise.

- In lecture, I'll just give away the answer, but you might find implementing it useful. See DIY folder in the lectureCode repo for starter code.

ArraySet (Basic Implementation)

```
public class ArraySet<T> {
  private T[] items;
  private int size;

  public ArraySet() {
    items = (T[]) new Object[100];
    size = 0;
  }
  ...
}
```

Array implementation of a Set:

- Use an array as the core data structure.
- `contains(x)`: Checks to see if x is in the underlying array.
- `add(x)`: Checks to see if x is in the underlying array, and if not, adds it.

ArraySet (Basic Implementation)

```
public boolean contains(T x) {
  for (int i = 0; i < size; i += 1) {
    if (items[i].equals(x)) {
      return true;
    }
  }
  return false;
}
```

```
public void add(T x) {
  if (!contains(x)) {
    items[size] = x;
    size += 1;
  }
}
```

Using An ArraySet

Generic type variables

```
public class ArraySet<T> {
  private T[] items;
  private int size;

  public ArraySet() {
    items = (T[]) new Object[100];
    size = 0;
  }
  ...
}
```

Actual type arguments

```
ArraySet<String> S = new ArraySet<>();
S.add("horse");
S.add("fish");
```

Exceptions

Exceptions

Basic idea:

- When something goes really wrong, break the normal flow of control.
- So far, we've only seen implicit exceptions, like the one below.

```
public static void main(String[] args) {
    ArraySet<String> s = new ArraySet<>();
    s.add(null);
    s.add("horse");
}
```

```
$ java ExceptionDemo
Exception in thread "main"
java.lang.NullPointerException
    at ArraySet.contains(ArraySet.java:16)
    at ArraySet.add(ArraySet.java:26)
    at ArraySet.main(ArraySet.java:40)
```

Explicit Exceptions

We can also throw our own exceptions using the **`throw`** keyword.

- Can provide more informative message to a user.
- Can provide more information to code that "catches" the exception.

More on "catching" at end of the course.

```
public void add(T x) {
  if (x == null) {
    throw new IllegalArgumentException("Cannot add null!");
  }
  ...
}
```

```
$ java ExceptionDemo
Exception in thread "main"
java.lang.IllegalArgumentException: Cannot add null!
    at ArraySet.add(ArraySet.java:27)
    at ArraySet.main(ArraySet.java:42)
```

Explicit Exceptions

Arguably this is a bad exception.

- Our code now crashes when someone tries to add a null.
- Other fixes:
  - Ignore nulls.
  - Fix contains so that it doesn't crash if items[i] is null.

```
public void add(T x) {
  if (x == null) {
    throw new IllegalArgumentException("Cannot add null!");
  }
  ...
}
```

Iteration

The Enhanced For Loop

Java allows us to iterate through Lists and Sets using a convenient shorthand syntax sometimes called the “foreach” or “enhanced for” loop.

```
Set<Integer> javaset = new HashSet<>();
javaset.add(5);
javaset.add(23);
javaset.add(42);
for (int i : javaset) {
    System.out.println(i);
}
```

The Enhanced For Loop

Java allows us to iterate through Lists and Sets using a convenient shorthand syntax sometimes called the “foreach” or “enhanced for” loop.

- This doesn’t work with our ArraySet.
- Let’s strip away the magic so we can build our own classes that support this.

```
ArraySet<Integer> aset = new ArraySet<>();
aset.add(5);
aset.add(23);
aset.add(42);
for (int i : aset) {
    System.out.printl
}
```

```
$ javac IterationDemo
error: for-each not applicable to expression type
        for (int i : S) {
                     ^
  required: array or java.lang.Iterable
  found:    ArraySet<Integer>
```

How Iteration Really Works

An alternate, uglier way to iterate through a List is to use the iterator() method.

Set.java:

```
public Iterator<E> iterator();
```

```
Set<Integer> javaset =
  new HashSet<Integer>();
...
for (int x : javaset) {
   System.out.println(x);
}
```

"Nice" iteration.

```
Set<Integer> javaset =
  new HashSet<Integer>();
...
Iterator<Integer> seer
    = javaset.iterator();

while (seer.hasNext()) {
  System.out.println(seer.next());
}
```

"Ugly" iteration.

How Iterators Work

An alternate, uglier way to iterate through a List is to use the iterator() method.


```
Iterator<Integer> seer
    = javaset.iterator();
while (seer.hasNext()) {
  System.out.println(seer.next());
}
```

How Iterators Work

An alternate, uglier way to iterate through a List is to use the iterator() method.

javaset:	5	23	42

```
$ java IteratorDemo.java
```

```
Iterator<Integer> seer
    = javaset.iterator();
while (seer.hasNext()) {
  System.out.println(seer.next());
}
```

How Iterators Work

An alternate, uglier way to iterate through a List is to use the iterator() method.

javaset:

5	23	42

```
$ java IteratorDemo.java
```

```
Iterator<Integer> seer
    = javaset.iterator();
while (seer.hasNext()) {
  System.out.println(seer.next());
}
```

How Iterators Work

An alternate, uglier way to iterate through a List is to use the iterator() method.

javaset:

5	23	42

```
$ java IteratorDemo.java
5
```

```
Iterator<Integer> seer
    = javaset.iterator();
while (seer.hasNext()) {
  System.out.println(seer.next());
}
```

How Iterators Work

An alternate, uglier way to iterate through a List is to use the iterator() method.

javaset:

5	23	42

```
$ java IteratorDemo.java
5
```

```
Iterator<Integer> seer
    = javaset.iterator();
while (seer.hasNext()) {
  System.out.println(seer.next());
}
```

How Iterators Work

An alternate, uglier way to iterate through a List is to use the iterator() method.

javaset:	5	23	42

```
$ java IteratorDemo.java
5
23
```

```
Iterator<Integer> seer
    = javaset.iterator();
while (seer.hasNext()) {
  System.out.println(seer.next());
}
```

How Iterators Work

An alternate, uglier way to iterate through a List is to use the iterator() method.

javaset:	5	23	42

```
$ java IteratorDemo.java
5
23
```

```
Iterator<Integer> seer
    = javaset.iterator();
while (seer.hasNext()) {
  System.out.println(seer.next());
}
```

How Iterators Work

An alternate, uglier way to iterate through a List is to use the iterator() method.


```
$ java IteratorDemo.java
5
23
42
```

javaset:

5	23	42

```
Iterator<Integer> seer
    = javaset.iterator();
while (seer.hasNext()) {
  System.out.println(seer.next());
}
```

How Iterators Work

An alternate, uglier way to iterate through a List is to use the iterator() method.


```
$ java IteratorDemo.java
5
23
42
```

javaset:

5	23	42

```
Iterator<Integer> seer
    = javaset.iterator();
while (seer.hasNext()) {
  System.out.println(seer.next());
}
```

The Secret of the Enhanced For Loop yellkey.com/art

The secret: The code on the left is just shorthand for the code on the right. For code on right to compile, which checks does the compiler need to do?

A. Does the Set interface have an iterator() method?
B. Does the Set interface have next/hasNext() methods?
C. Does the Iterator interface have an iterator method?
D. Does the Iterator interface have next/hasNext() methods?

```
Set<Integer> javaset = new HashSet<Integer>();
```

```
for (int x : javaset) {
   System.out.println(x);
}
```

```
Iterator<Integer> seer
    = javaset.iterator();

while (seer.hasNext()) {
  System.out.println(seer.next());
}
```

The Secret of the Enhanced For Loop

The secret: The code on the left is just shorthand for the code on the right. For code on right to compile, which checks does the compiler need to do?

A. Does the Set interface have an iterator() method?
B. Does the Set interface have next/hasNext() methods?
C. Does the Iterator interface have an iterator method?
D. Does the Iterator interface have next/hasNext() methods?

```
Set<Integer> javaset = new HashSet<Integer>();
```

```
for (int x : javaset) {
   System.out.println(x);
}
```

```
Iterator<Integer> seer
    = javaset.iterator();

while (seer.hasNext()) {
  System.out.println(seer.next());
}
```

Supporting Ugly Iteration in ArraySets

To support ugly iteration:

- Add an `iterator()` method to `ArraySet` that returns an `Iterator<T>`.
- The `Iterator<T>` that we return should have a useful `hasNext()` and `next()` method.

`Iterator<T>`

```
public interface Iterator<T> {
    boolean hasNext();
    T next();
}
```

```
Iterator<Integer> aseer
    = aset.iterator();

while (aseer.hasNext()) {
  System.out.println(aseer.next());
}
```

Completed ArraySet iterator Method

To support ugly iteration:

- Add an `iterator()` method to `ArraySet` that returns an `Iterator<T>`.
- The `Iterator<T>` that we return should have a useful `hasNext()` and `next()` method.

```
private class ArraySetIterator implements Iterator<T> {
    private int wizPos;
    public ArraySetIterator() { wizPos = 0; }
    public boolean hasNext() { return wizPos < size; }
    public T next() {
        T returnItem = items[wizPos];
        wizPos += 1;
        return returnItem;
    }
}
```

```
public Iterator<T> iterator() {
    return new ArraySetIterator();
}
```

The Enhanced For Loop

Our code now supports “ugly” iteration, but enhanced for loop still doesn’t work.

The problem: Java isn’t smart enough to realize that our `ArraySet` has an `iterator()` method.

- Luckily there’s an interface for that.

```
ArraySet<Integer> aset = new ArraySet<>();
aset.add(5);
aset.add(23);
aset.add(42);
for (int i : aset) {
    ...
}
```

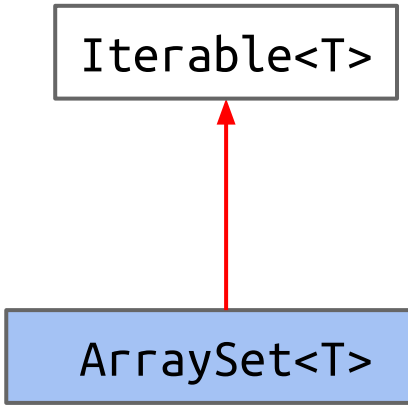
```
$ javac IterationDemo
error: for-each not applicable to expression type
        for (int i : aset) {
                     ^
  required: array or java.lang.Iterable
  found:    ArraySet<Integer>
```

For-each Iteration And ArraySets

To support the enhanced for loop, we need to make `ArraySet` implement the `Iterable` interface.

- There are also some default methods in Iterable, not shown.

```
public interface Iterable<T> {
    Iterator<T> iterator();
}
```




```
public class ArraySet<T> implements Iterable<T> {
    ...
    public Iterator<T> iterator() { ... }
}
```

The Iterable Interface

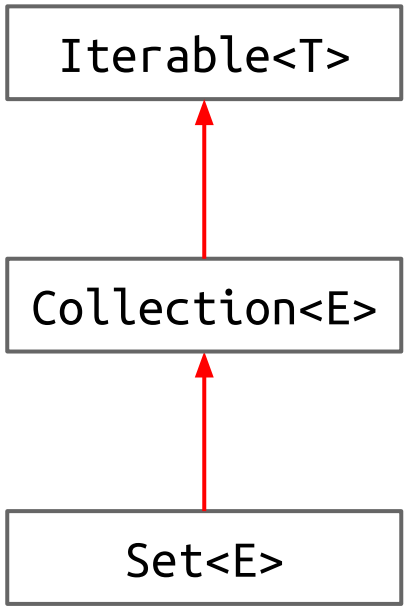
By the way, this is how `Set` works as well.

- Source code for Iterable: Link, Set: Link, Collection: Link.

```
public interface Iterable<T> {
    Iterator<T> iterator(); ...
}
```

```
public interface Collection<E> extends Iterable<E> {
    public Iterator<E> iterator();
}
```

```
public interface Set<E> extends Collection<E> {
    public Iterator<E> iterator();
}
```



Iteration Summary

To support the enhanced for loop:

- Add an `iterator()` method to your class that returns an `Iterator<T>`.
- The `Iterator<T>` returned should have a useful `hasNext()` and `next()` method.
- Add `implements Iterable<T>` to the line defining your class.

Part 5 of HW1 gives you a chance to try this out yourself.

Object Methods: Equals and toString()

Objects

All classes are hyponyms of `Object`.

- **`String toString()`**
- **`boolean equals(Object obj)`**
- `Class<?> getClass()`
- `int hashCode()`
- `protected Object clone()`
- `protected void finalize()`
- `void notify()`
- `void notifyAll()`
- `void wait()`
- `void wait(long timeout)`
- `void wait(long timeout, int nanos)`

Very important, but won't discuss for a few weeks.

Won't discuss or use in 61B.

toString()

The `toString()` method provides a string representation of an object.

- `System.out.println(Object x)` calls `x.toString()`
  - If you're curious: println calls String.valueOf which calls toString

```
Set<Integer> javaset = new HashSet<>();
javaset.add(5);
javaset.add(23);
javaset.add(42);

System.out.println(javaset);
```

```
$ java JavaSetPrintDemo
[5, 23, 42]
```

toString()

The `toString()` method provides a string representation of an object.

- `System.out.println(Object x)` calls `x.toString()`
- The implementation of toString() in Object is the the name of the class, then an @ sign, then the memory location of the object.
  - See 61C for what the "memory location" really means.

```
ArraySet<Integer> aset = new ArraySet<>();
aset.add(5);
aset.add(23);
aset.add(42);

System.out.println(aset);
```

```
$ java ArraySetPrintDemo
ArraySet@75412c2f
```

ArraySet toString

Let’s try implementing toString for ArraySet.

ArraySet toString

One approach is shown below.

- Warning: This code is slow. Intuition: Adding even a single character to a string creates an entirely new string. Will discuss why at end of course.

```
@Override
public String toString() {
    String returnString = "{";
    for (int i = 0; i < size; i += 1) {
        returnString += keys[i];
        returnString += ", ";
    }
    returnString += "}";
    return returnString;
}
```

Spoiler: It's because Strings are "immutable".

ArraySet toString

Much faster approach is shown below.

- Intuition: Append operation for a StringBuilder is fast.

```
@Override
public String toString() {
    StringBuilder returnSB = new StringBuilder("{");
    for (int i = 0; i < size; i += 1) {
        returnSB.append(items[i]);
        returnSB.append(", ");
    }
    returnSB.append("}");
    return returnSB.toString();
}
```

Objects

All classes are hyponyms of `Object`.

- `String toString()`
- **`boolean equals(Object obj)`**
- `Class<?> getClass()`
- `int hashCode()`
- `protected Object clone()`
- `protected void finalize()`
- `void notify()`
- `void notifyAll()`
- `void wait()`
- `void wait(long timeout)`
- `void wait(long timeout, int nanos)`

Very important, but won't discuss for a few weeks.

Won't discuss or use in 61B.

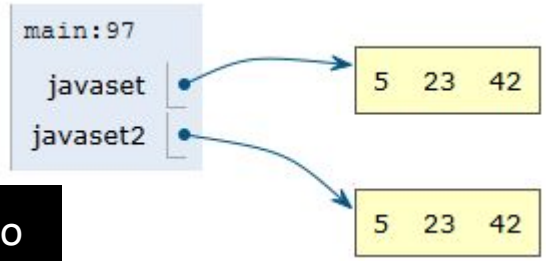
Equals vs. ==

As mentioned in an offhand manner previously, == and .equals() behave differently.

- == compares the bits. For references, == means “referencing the same object.”

```
Set<Integer> javaset = Set.of(5, 23, 42);
Set<Integer> javaset2 = Set.of(5, 23, 42);
System.out.println(javaset == javaset2);
```

```
$ java EqualsDemo
False
```



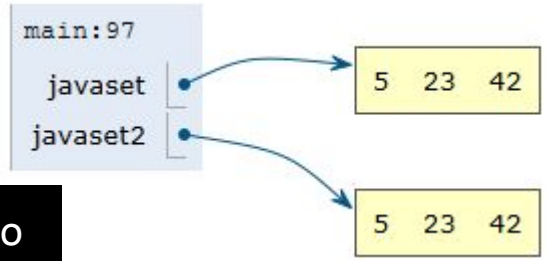
Equals vs. ==

As mentioned in an offhand manner previously, == and .equals() behave differently.

- == compares the bits. For references, == means “referencing the same object.”

```
Set<Integer> javaset = Set.of(5, 23, 42);
Set<Integer> javaset2 = Set.of(5, 23, 42);
System.out.println(javaset.equals(javaset2));
```

```
$ java EqualsDemo
True
```



To test equality in the sense we usually mean it, use:

- `.equals` for classes. Requires writing a `.equals` method for your classes.
  - Default implementation of `.equals` uses == (probably not what you want).
- BTW: Use `Arrays.equal` or `Arrays.deepEquals` for arrays.

The Default Implementation of Equals

```
ArraySet<Integer> aset = new ArraySet<>();
aset.add(5);
aset.add(23);
aset.add(42);

System.out.println(aset);

ArraySet<Integer> aset2 = new ArraySet<>();
aset2.add(5);
aset2.add(23);
aset2.add(42);

System.out.println(aset.equals(aset2));
```

```
$ java EqualsDemo
False
```

Returns false because the default implementation of equals just uses ==.

ArraySet equals

Let’s try implementing equals for ArraySet.

ArraySet equals

The implementation below is a good start, but fails if o is null or another class.

```
@Override
public boolean equals(Object o) {
  ArraySet<T> other = (ArraySet<T>) o;
  if (this.size() != other.size()) { return false; }
    for (T item : this) {
      if (!other.contains(item)) {
        return false;
      }
    }
  return true;
}
```

ArraySet equals

The implementation below is much better, but we can speed things up.

```
@Override
public boolean equals(Object o) {
  if (o == null) { return false; }
  if (this.getClass() != o.getClass()) { return false; }
  ArraySet<T> other = (ArraySet<T>) o;
  if (this.size() != other.size()) { return false; }
    for (T item : this) {
      if (!other.contains(item)) {
        return false;
      }
    }
  return true;
}
```

ArraySet equals

The code below is pretty close to what a standard equals method looks like.

```
@Override
public boolean equals(Object o) {
  if (o == null) { return false; }
  if (this == o) { return true; } // optimization
  if (this.getClass() != o.getClass()) { return false; }
  ArraySet<T> other = (ArraySet<T>) o;
  if (this.size() != other.size()) { return false; }
    for (T item : this) {
      if (!other.contains(item)) {
        return false;
      }
    }
  return true;
}
```

Summary

We built our own Array based Set implementation.

To make it more industrial strength we:

- Added an exception if a user tried to add null to the set.
  - There are other ways to deal with nulls. Our choice was arguably bad.
- Added support for “ugly” then “nice” iteration.
  - Ugly iteration: Creating a subclass with next and hasNext methods.
  - Nice iteration: Declaring that ArraySet implements Iterable.
- Added a toString() method.
  - Beware of String concatenation.
- Added an equals(Object) method.
  - Make sure to deal with null and non-ArraySet arguments!
  - Used getClass to check the class of the passed object. Use sparingly.

Even Better toString and ArraySet.of

(Extra)

Citations

Seer:
http://www.clipartoday.com/_thumbs/022/Fantasy/astrology_crystal_190660_tnb.png

Edge of the world:

https://www.flickr.com/photos/tochis/2947187311