CompSci 201, L4: Interfaces and Implementations, ArrayList

Logistics, Coming up

- Today, Wednesday, 1/25
  - APT 1 due (need to do 4 for full credit)
- This Friday, 1/27
  - Discussion 2
- Next Monday 1/30
  - Prjoect 0: Person201 due (warmup project)
- Next Wednesday 2/1
  - APT 2 due

Reminder: Java4Python Resource

Might find the [Java4Python] extended intro to Java for Python programmers helpful for translating.

Contents:

OOP (Object-Oriented Programming) Wrapup

Public vs. Private

- **Public** – Can be accessed by code *outside* of the class.
- **Private** – Can *only* be accessed by code *inside* of the class.

Record.java > Record

```java
public class Record {
    public String displayName;
    private int uniqueID;

    public Record(String name, int id) {
        displayName = name;
        uniqueID = id;
    }

```

PublicPrivate.java > ...

```java
public class PublicPrivate {
    Run | Debug
    public static void main (String[] args) {
        Record rec = new Record("Fain", 12345);
        System.out.println(rec.displayName);
        System.out.println(rec.uniqueID);
    }
}
```

Can access this **public** instance variable

Cannot access this **private** instance variable

(Im)mutability

- An object is **immutable** if you cannot change it after creation. Methods that change objects are called **mutators.**

- Java Strings are immutable, even though you can "append" to them. Creates a new String and copies all characters every time!

```
String s = "Hello";
s += " World";
```

More like

```
String sOld = "Hello";
String sNew = "" + sOld + " World";
```

(and then get rid of `sOld`)

Static belongs to the class

- Regular instance variables and methods are called on an object.
- Static methods are called on the class, do not use any instance variables. Often utility “functions”

StaticExample.java > ...

```java
public class StaticExample {
    Run | Debug
    public static void main(String[] args) {
        String s = "Hello World!";
        System.out.println(s.split(" ")[0]);

        System.out.println(Math.sqrt(4.0));
    }
}
```

Note that `split` is called on a String object

Whereas `sqrt` is called on the Math class

APT and OOP, making a PSVM method

Suppose you're working on the SandwichBar APT.

```
public class SandwichBar {
        public int whichOrder(String[] available, String[] orders){
            // fill in code here
            return 0;
        }
    }
```

Remember what you know about Java OOP:

- whichOrder is a regular method, need to call on an *object* of the SandwichBar class.
- whichOrder has parameters, need to supply those.
- All java programs must begin in a PSVM method.

APT and OOP, making a PSVM method

```java
public class SandwichBar {
        public int whichOrder(String[] available, String[] orders){
            // fill in code here
            return 0;
        }

        Run | Debug
        public static void main(String[] args) {
            String[] testAvailable = { "ham", "cheese", "mustard" };
            String[] testOrders = { "ham cheese" };
            SandwichBar testInstance = new SandwichBar();
            int testResult = testInstance.whichOrder(testAvailable, testOrders);
            System.out.println(testResult);
        }
    }
```

PSVM method can be in the same class or in a separate “driver” class in the same directory.

Creating test parameters, using example from APT site.

Make a SandwichBar object

Call the method

Interfaces and Implementations

Abstract Data Type (ADT)

- **ADT** specifies **what** a data structure does (functionality) but not **how** it does it (implementation).

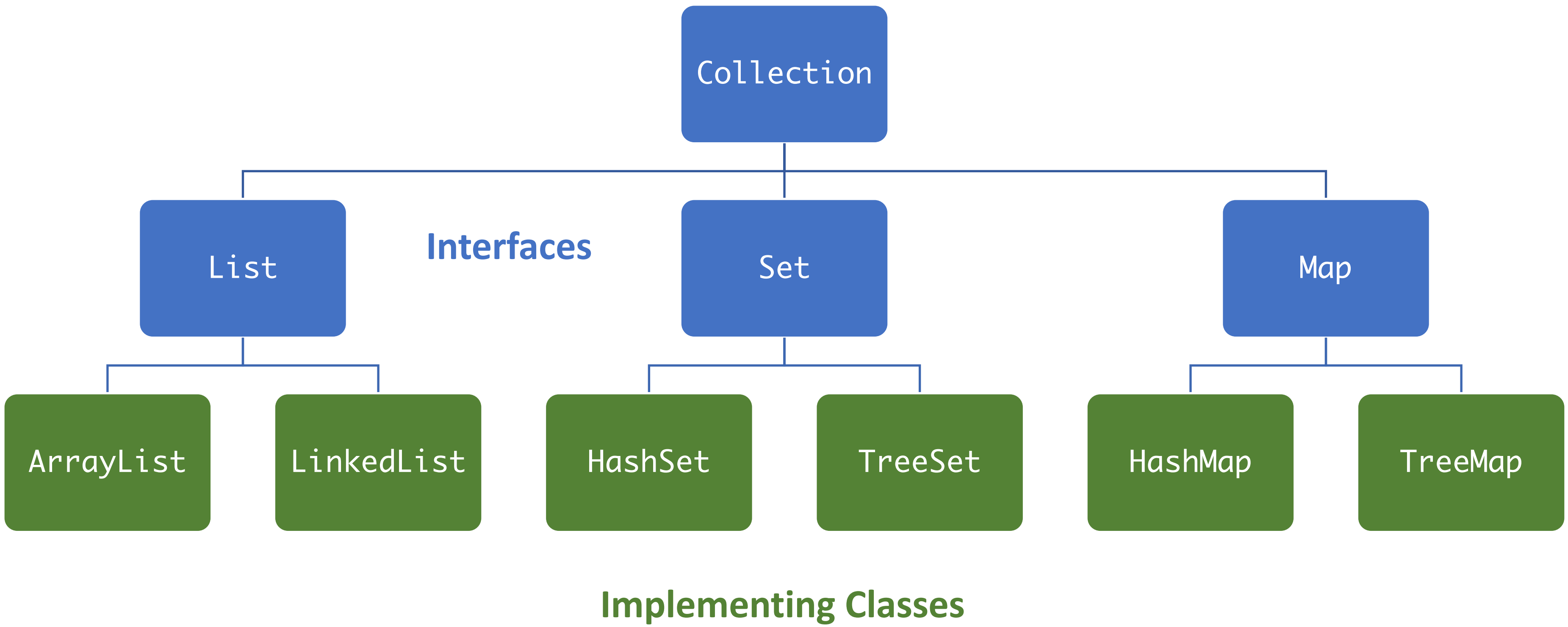
- **API** (Application Program Interface) perspective: What methods can I call on these objects, what inputs do they take, what outputs do they return?

- For example, An abstract List should…
  - Keep values in an order
  - Be able to add new values, grow
  - Be able to get the first value, or the last, etc.
  - Be able to get the size of the list

Java Interface

- One primary way Java formalizes ADTs is with **interfaces,** which "*specify a set of abstract methods that an implementing class must override and define*." – ZyBook
- 3 most important ADTs we study are all interfaces in Java!
  - `List`: An ordered sequence of values
  - `Set`: An unordered collection of *unique* elements
  - `Map`: A collection that associates keys and values

The Java Collection Hierarchy



What is a collection?

```
public interface Collection<E>
extends Iterable<E>
```

The root interface in the *collection hierarchy*. A collection represents a group of objects, known as its *elements*. Some collections allow duplicate elements and others do not. Some are ordered and others unordered. The JDK does not provide any *direct* implementations of this interface: it provides implementations of more specific subinterfaces like `Set` and `List`. This interface is typically used to pass collections around and manipulate them where maximum generality is desired.

- Java API data structures storing groups of objects likely based on the `Collection` interface.
- Lists, Sets, Maps, and more
- Useful static methods (such as sorting) in java.util.Collections (like Java.util.Arrays), see API documentation

Interface vs. Implementation

Interfaces need an *implementing class* specified at creation.

```java
public class InterfaceExample {
    Run | Debug
    public static void main(String[
        List<String> strList = new List<>();
    }
```

List cannot be resolved to a type Java(16777218)

View Problem   Quick Fix... (⌘.)

What is an implementation? Can have any instance variables. Must override and implement *all* methods.

DIYList.java > DIYList

```java
import java.util.List;
public class DIYList implements List {

}
```

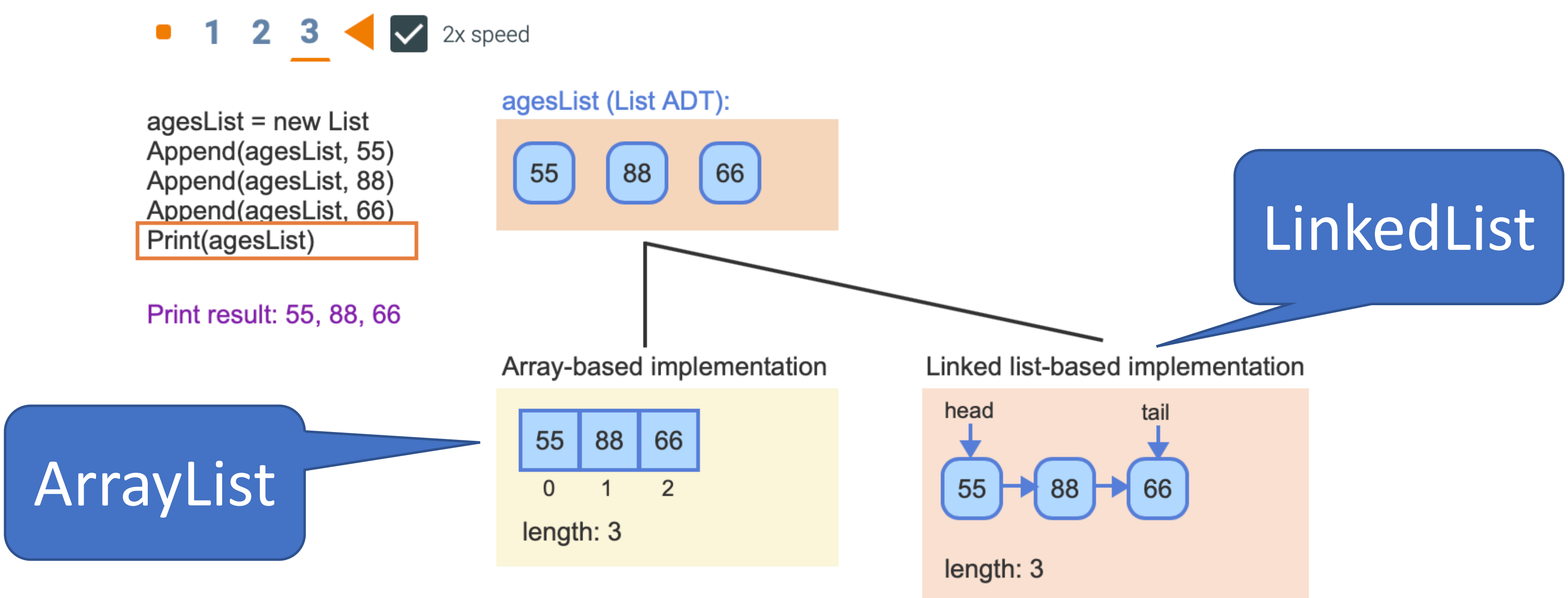
Add unimplemented methods

```java
public class DIYList implements List {

    @Override
    public int size() {
        // TODO Auto-generated method stub
        return 0;
    }
```

Multiple Implementations of the Same Interface

2.4.1: List ADT using array and linked lists data structures.



A list ADT is commonly implemented using array and linked list data structures. But, a programmer need not have knowledge of which data structure is used to use the list ADT.

Implementations all have (at least) the same methods as the Interface

Doesn't matter for correctness whether the argument Lists are ArrayList or LinkedList, because both implement `.contains()`.

```java
public static List<String> inBothLists(List<String> aList,
                                        List<String> bList) {
    List<String> retList = new ArrayList<>();
    for (String s : aList) {
        if (bList.contains(s)) {
            retList.add(s);
        }
    }
    return retList;
}
```

Method doesn't even "know" how `aList` and `bList` are implemented.

Since `retList` is an `ArrayList` which implements `List`, it is a valid return.

ArrayList Implementation

Algorithmic tradeoffs depend on the implementation

Often, we are interested in how the **efficiency** of operations on data structures depends on **scale**. For an **`ArrayList`** with N values how efficient is…

- **`get()`**. Direct lookup in an Array. "Constant time" – does not depend on size of the list.
- **`contains()`**. Loops through Array calling `.equals()` at each step. Takes longer as list grows.
- **`size()`**. Returns value of an instance variable tracking size, does not depend on size of the list.
- **`add()`.** Depends.

How does `ArrayList` `add` work?

Implements **`List`** (can grow) with **`Array`** (cannot grow). How?

Keep an Array with extra space at the end. Two cases when adding to end of ArrayList:

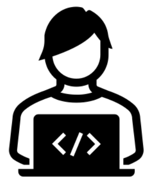
1. Space left – add to first open position.
2. No space left – Create a new (larger) array, copy everything, then add to first open position.

Array representing List

~~15~~	~~12~~	~~21~~

15	12	21	33		

DIY (do it yourself) ArrayList

Live Coding 

How efficient is `ArrayList` add?

For an **`ArrayList`** with N values, 2 cases:

1. Space left – One Array assignment statement, *constant time*, does not depend on list size.
2. No space left – Copy entire list! Takes N array assignments!

How often are we in the second slow case? Depends on *how much we increase the Array size by in case 2.*

ArrayList Growth

Starting with Array length 1, if you keep creating a new Array that…

Is twice as large (geometric growth)

- Must copy at sizes:
  - 1, 2, 4, 8, 16, 32, …
- Total values copied to add N values:
  - 1+2+4+8+16+…N

Has 100 more positions (arithmetic growth)

- Must copy at sizes:
  - 1, 101, 201, 301, …
- Total values copied to add N values:
  - 1+101+201+301+…+N

Algebra to our rescue!

ArrayList Growth and Algebra

Geometric growth

$$1 + 2 + 4 + \cdots + N$$

$$= \sum_{i=0}^{\approx \log_2 N} 2^i$$

$$\approx 2N$$

Geometric series formula:

$$\sum_{i=0}^{n} a\, r^i = a\left(\frac{1 - r^{n+1}}{1 - r}\right)$$

Arithmetic growth

$$1 + 101 + 201 + \cdots + N$$

$$= \sum_{i=0}^{\approx N/100} 1 + 100i$$

$$\approx \frac{N^2}{200}$$

Arithmetic series formula:

$$\sum_{i=1}^{n} a_i = \left(\frac{n}{2}\right)(a_1 + a_n)$$

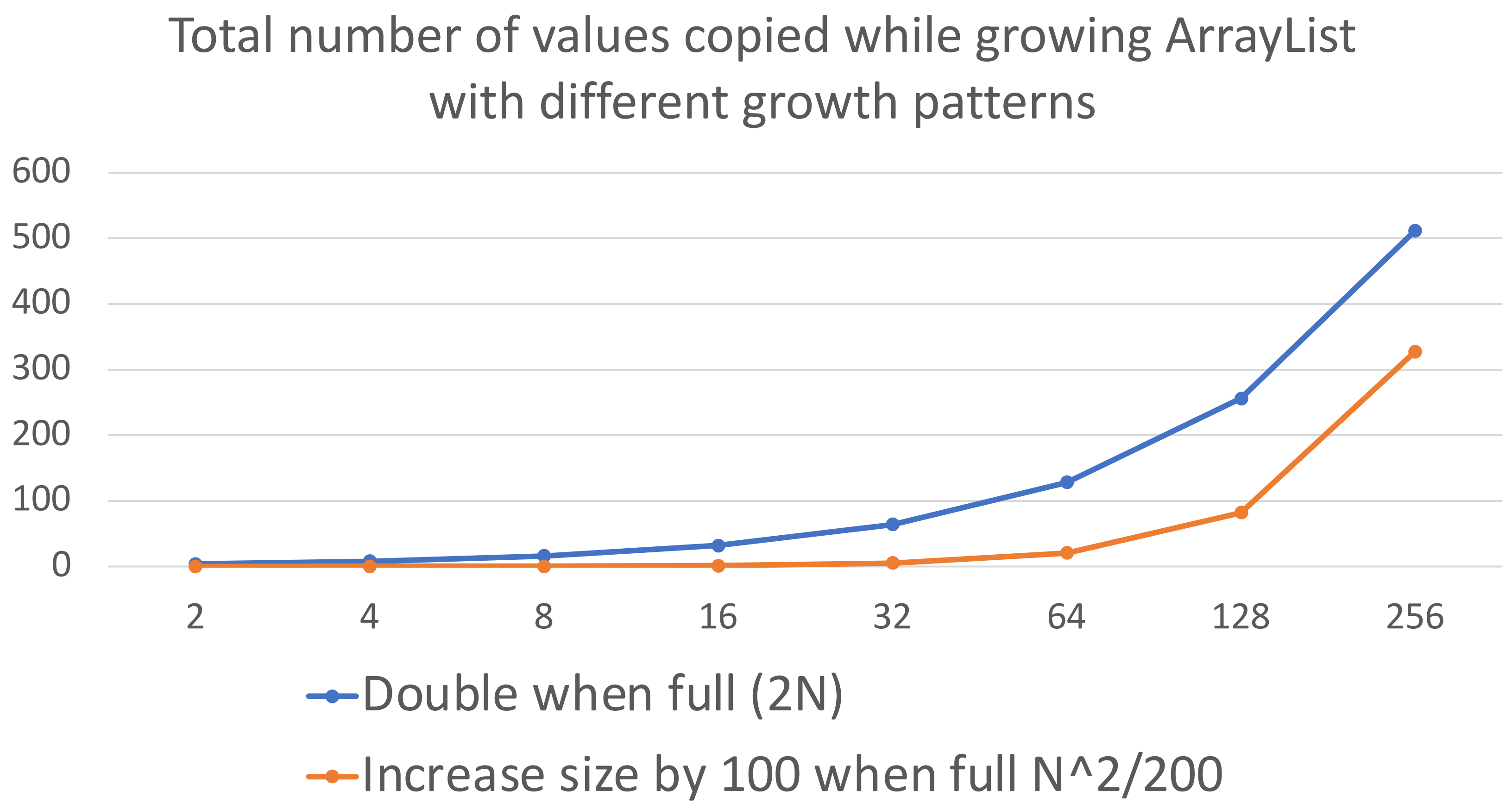
Math and Expectations in 201

- ***Do not*** expect you to formally derive closed form expressions / give proofs.
- ***Do*** expect you to recognize:
  - Geometric growth: $1 + 2 + 4 + \cdots + N$ is *linear,* $\approx 2N$.
  - Arithmetic growth: $1 + 101 + 201 + \cdots + N$ is *quadratic,* $\approx \frac{N^2}{200}$.
- Patterns like these show up again and again!

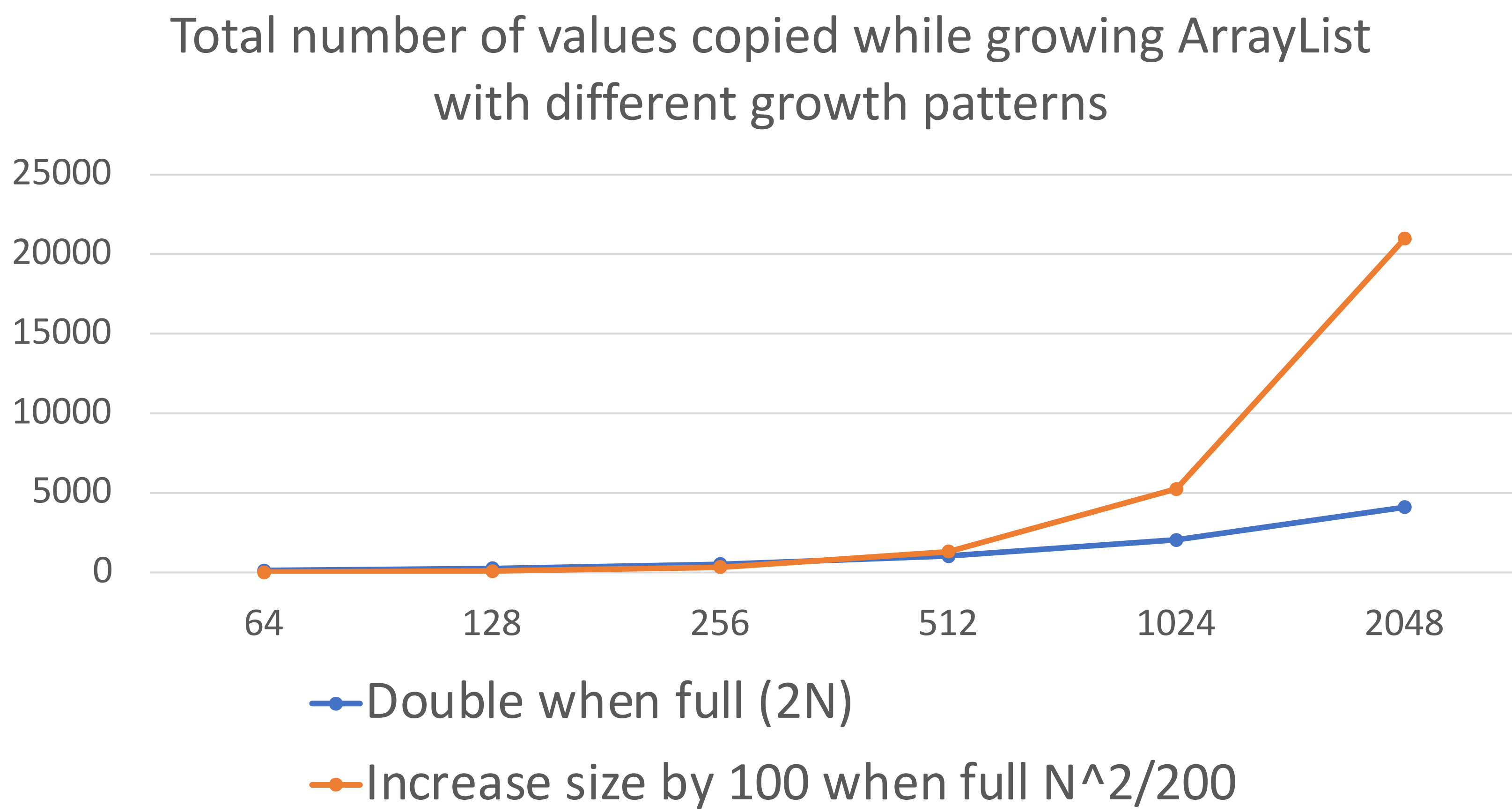
```java
int n = 100;
int numIterations = 0;
for (int i=0; i<n; i++) {
    for (int j=0; j<i; j++) {
        numIterations += 1;
    }
}
```

```
numIterations: 4950
n*(n-1)/2: 4950
```

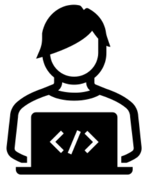
Which version is more efficient? Small N?



Which version is more efficient? Larger N?



Experiment to verify hypothesis

Live Coding 

`ArrayList` `add` (to end) is (amortized) efficient

According to the Java 17 API documentation:
"The add operation runs in *amortized constant time…*" – What does that mean?

- With geometric growth (e.g., double size of Array whenever out of space): Need $\approx 2N$ copies to `add` N elements to `ArrayList`.

- The *average* number of copies per add is thus $\frac{2N}{N} = 2$, a constant that does not depend on N.

`ArrayList` add to the front is not efficient

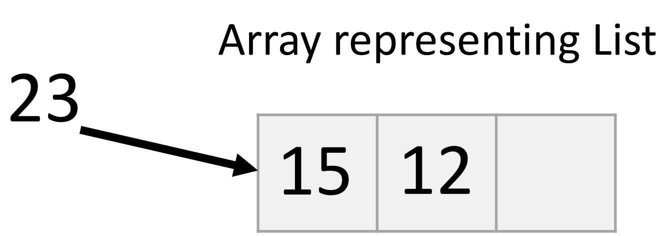
add

```
public void add(int index,
                E element)
```

[Java 17 API documentation of add]

Inserts the specified element at the specified position in this list. Shifts the element currently at that position (if any) and any subsequent elements to the right (adds one to their indices).

Always requires shifting the entire `Array`, even if there is space available.



`ArrayList` `contains` revisited

`contains` loops through the `Array` calling `.equals()` at each step. May check every element!

`list.contains(33)`