CS 5004: OBJECT ORIENTED DESIGN AND ANALYSIS

SPRING 2024

LECTURE 4

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ADMINISTRIVIA

AGENDA

- Review
  - Inheritance
  - Interfaces
  - Abstract classes
- Enumerations
- Client vs. Implementer View
- Abstract Data Type (ADT)
- Arrays in Java
- Lists in Java
- Java Collections Framework
  - Stacks
  - Queues
  - Deques
  - Sets

REVIEW

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REVIEW: COMPOSITION

- Composition - set of classes connected by an ‘has-a’ relationships
- ‘Has-a’ relationship – a relationship where one class can use the functionality of another class by using an instance of that class
- Example 1:
  - Every person has a name
  - Every person has a date of birth
- Example 2:
  - Every vehicle has a make
  - Every vehicle has a model
  - Every vehicle has a manufacturing year

REVIEW: INHERITANCE AND "IS A" RELATIONSHIP

- Inheritance - set of classes connected by an 'is-a' relationships
- 'Is-a' relationship - hierarchical connection where one category can be treated as a specialized version of another
  - Example 1:
    - Every student is a person
    - Every ALIGN student is a student
  - Example 2:
    - Every pepper is a vegetable
    - Every bell pepper is a pepper
    - Every banana pepper is a pepper

REVIEW: EVERYTHING IS AN OBJECT IN JAVA

- `public class Object` - the root of the class hierarchy
  - Every class has Object as a superclass
  - All objects inherit public methods of `Object`

`protected Object clone()`	Creates and returns a copy of this object.
`Boolean equals (Object obj)`	Indicates whether some other object is "equal to" this one.
`protected void finalize()`	Called by the garbage collector on an object when garbage collection determines that there are no more references to the object.
`Class<?> getClass()`	Returns the runtime class of this Object.
`int hashCode()`	Returns a hash code value for the object.
`void notify()`	Wakes up a single thread that is waiting on this object's monitor.
`String toString()`	Returns a string representation of the object.

REVIEW: WHAT IS AN INTERFACE?

A set of ***method declarations***—a template for what a class can do

- Cannot be *instantiated* – no constructor
- Does not actually implement the methods it declares
- All methods are **public** by default
- Can contain only static fields

Classes can ***implement*** interfaces

- Classes fill in the implementation details of methods declared in an interface
- One class can implement multiple interfaces
  - …but *extend* only one super class.

REVIEW: WHEN IS AN INTERFACE USEFUL?

- Whenever you can imagine a “category” of classes that must have some common behavior
- AND implementation of common behavior needs to look different for each some/each of the classes

REVIEW: CONCRETE VS. ABSTRACT CLASSES

Concrete classes

- **Fully** implemented
- If implementing an interface, **must** implement all interface methods!
- Instantiated directly

Abstract classes

- **Partially** implemented
- If implementing an interface, **don't have to** implement all interface methods.
- Can't be instantiated directly.

REVIEW: WHEN TO USE AN ABSTRACT CLASS?

Instead of (or as well as) as an interface:

- When you want to provide *some* implementation details common to multiple potential subclasses.

Instead of a concrete class:

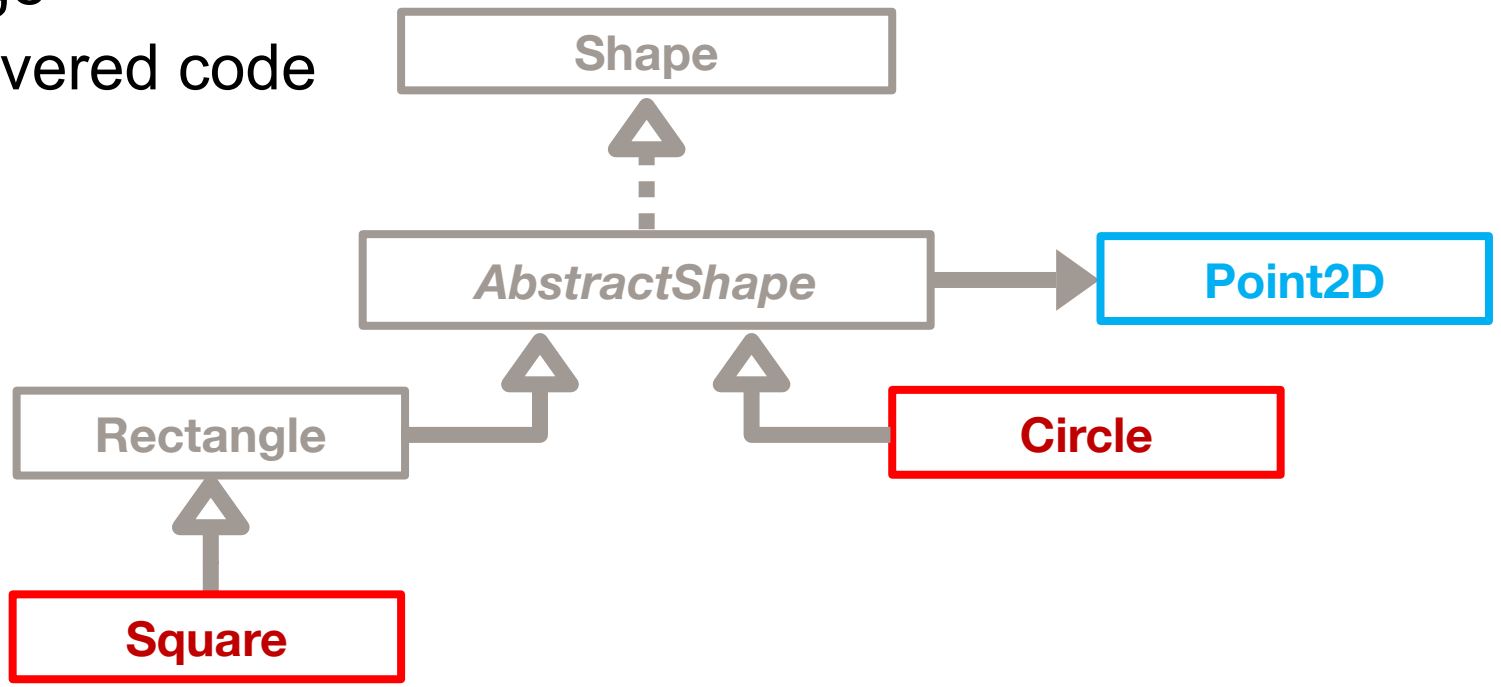
- When you don't want users to instantiate the class directly.

SOME CLARIFICATIONS

- Question 1: do we always need to have abstract classes and interfaces?
  - No, only if they're useful
  - But if in doubt, feel free to include them – you can't have too much of the good stuff ☺

SOME CLARIFICATIONS

- Question 2: how do we test abstract classes?
  - Write tests for concrete classes that don't have subclasses (including inherited methods)
  - Check Jacoco coverage
  - Add tests for any uncovered code



If `SquareTest` covers `Shape` methods `draw()`, `area()`, `resize()`, these methods will not have to be tested for parent classes

ENUMERATIONS

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REPRESENTING DATA THAT HAVE FINITE, SPECIFIC VALUES

- Example: we designed a class `Book`, and now we want to add information about the format in which we can buy it (hardcover, paperback, kindle)

- Question: how to represent this information in the Book class?

- Answer: let's use enumerated types

```
public enum TypeOfBook{HARDCOVER, PAPERBACK, KINDLE}
```

WHAT IS AN ENUMERATION?

- Enumeration - a way to represent a set of finite constants
- Represented as an `enum` data type
- What should be an **`enum`**?
  - Days of the week
  - Directions (N, S, E, W)

- **What shouldn't be an `enum`:**
  - Anything that is not finite
  - Anything that could be described as a "type of" something else
  - Anything that has properties/behaviors associated with it

BASIC ENUM STRUCTURE

- `Enum` data types are created in their own files (like a class), with keyword `enum`
- Each field is named in ALL CAPS (because they're always constant)
- Fields are separated by commas, and they don't have data types
- Fields are also not set to equal anything

```
public  enum DayOfWeek
{
MONDAY, TUESDAY,
WEDNESDAY, THURSDAY,
FRIDAY, SATURDAY,
SUNDAY
}
```

USING AN ENUM

- Variables can have an enum data type
- We set the value of an enum variable using:

```
<EnumType>  varName = <EnumType>.<Field>
```

```
DayOfWeek mon = DayOfWeek.MONDAY;
```

THE SWITCH STATEMENT

- An alternative to if-else if-else
- Neater (less typing)
- Only works with enums and a handful of other data types (incl. String)

```
switch(id) {
  case value-one: //is id==value-one?
     [do something 1]
     break;
  case value-two: //is id==value-two?
     [do something 2]
     break;
  ...
  default: //none of the above
     [do something-none-of-the-above]
 }
```

GOOD OOD PRACTICES

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HOW DO WE REPRESENT ..X..?

- When X is something descriptive, e.g., color, animal species, day of week?

- Do I make X:
  - a `String` field in a class?
  - an `enum` field in a class?
  - a class with its own properties and methods?

HOW DO WE REPRESENT ..X..?

- When X is something descriptive, e.g., color, animal species, day of week?
- Do I make X:
  - a `String` field in a class?
  - an `enum` field in a class?
  - a class with its own properties and methods?

- Factors to consider:
  - Is there a finite and fairly small set of possible values?
  - Is X for information only?
  - ...or are their additional properties/behaviors dependent on the value of X?

IS THERE A FINITE SMALL SET OF POSSIBLE VALUES?

NO - e.g., a person's name, a book title → Use a String field in another class

```
public class  Name {
   private String firstName;
   private String lastName ;

   public Name (String firstName,  String lastName) { ...}
}
```

IS THERE A FINITE SMALL SET OF POSSIBLE VALUES?

YES – e.g., vehicle color, pet species, day of week

→ String field is not a great choice (error prone)
→ Maybe an enum field (if set is fairly small)
→ Maybe a class

More information needed!

- Is X for information only?
- ...or are their additional properties/behaviors dependent on the value of X?

ARE PROPERTIES/BEHAVIORS DEPENDENT ON THE VALUE OF X?

- Might depend on specific situation
  - NO – e.g., vehicle color, day of week (much of the time)
  - An enum field is possibly acceptable

  - YES – e.g., pet species
  - An enum field is NOT the OOD choice
  - A class (or sub class) is usually the most appropriate OOD choice

WOULD YOU DESCRIBE X AS A TYPE OF SOMETHING?

If yes, X should be a class, not a String or an enum!

CLIENT VS. IMPLEMENTER VIEW

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CLIENT AND IMPLEMENTER

Client

- A piece of *code* (class, method) that relies on **public** elements of some other class *K*

Implementer

- The code inside *K* that has access to **private** information in *K*.

CLIENT AND IMPLEMENTER

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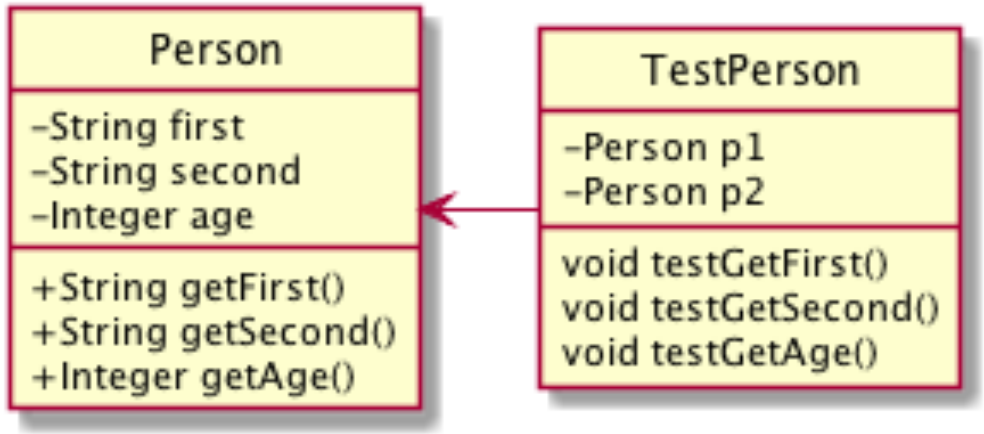
- A piece of code (class, method) that relies on **public** elements of some other class *K*

Implementer

- The code inside *K* that has access to **private** information in *K*.

CLIENT AND IMPLEMENTER

- So, what is a client and what is an implementor?



- `Person` is the implementation of the concept of a person
- `PersonTest` is a client of `Person`

CLIENT AND IMPLEMENTER

So far, you've written client code and implementer code at the same time.

In the real world

- Client code may be written by someone else
- At a later date
- For some specific purpose you don't know about yet

DESIGNING WITH FUTURE CLIENTS IN MIND

- Use interfaces to ensure consistency
- Try to anticipate future clients' needs:
  - What functionality should your code provide?
- Make use of **abstract data types**

ABSTRACT DATA TYPE

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EXAMPLE: ARE THESE CLASSES THE SAME?

```
public class Point1 {
   private Float x;
   private Float y;
}
```

```
public class Point2 {
   private Float r;
   private Float theta;
}
```

- How are these classes different and similar?
  - Different: cannot replace one with the other in the program
  - Same: both classes implement a concept of a 2D point
- Goal of the ADT methodology is to express the sameness
  - Clients depend only on the concept of 2D point

ABSTRACT DATA TYPE (ADT)

- Model that describes data by specifying the operations that we can perform on them

- ADTs are written from the view of the client
  - We need to capture the clients' expectations in terms of the operations on the ADT

- For each operation, we need to describe:
  - The expected inputs, and any conditions that need to hold for our inputs and/or our ADT
  - The expected outputs and any conditions that need to hold for our output and/or our ADT
  - Invariants about our ADT

DATA TYPES VS. ABSTRACT DATA TYPES

Data type

- A set of values
- A set of operations on those values

Abstract data type

- Special data type
- Internal representation of data is hidden from clients

USING AN ADT: THE API

The ways a client can interact with an ADT are specified in an **Application Programming Interface (API)**

- An API = ”contract” between the ADT and the client
- Guarantees the type of data and operations the ADT will support
- *Does not reveal implementation details*

EXAMPLE: STRING ADT

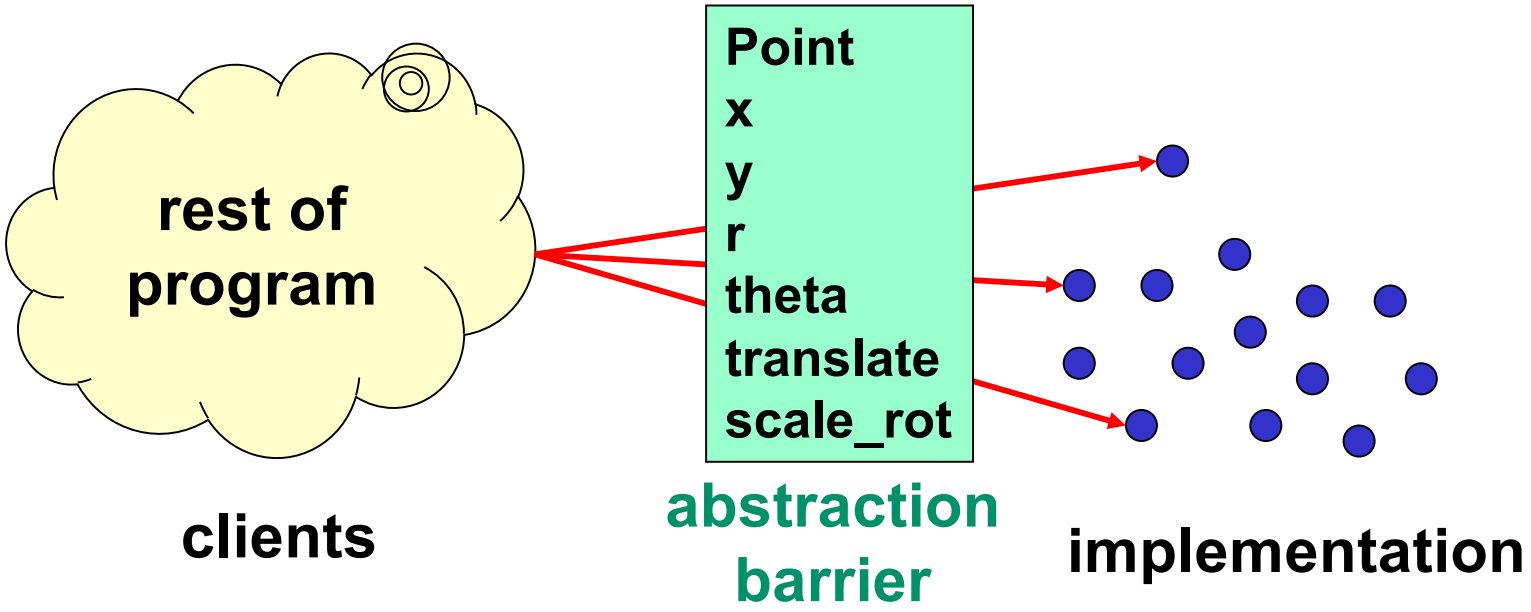
The docs (API):
https://docs.oracle.com/en/java/javase/11/docs/api/java.base/java/lang/String.html
(Google “Java 11 String”)

Key: The details of the underlying data structure are not revealed.

CREATING ADTS IN JAVA

- Use classes
- Separate specification in an interface and/or abstract class
  - Not required but usually a good idea
- Design:
  - How data will be organized
  - What client operations will be permitted

ADT = OBJECT + OPERATIONS



- Implementation is hidden
- The only operations on objects of the type are those provided by the abstraction

SPECIFYING A DATA ABSTRACTION

Purpose of a specification:

- Planning
- Documenting
- *No implementation just yet*

SPECIFYING A DATA ABSTRACTION

- A collection of procedural abstractions
  - Not a collection of procedures

- An abstract state
  - Not the (concrete) representation in terms of fields, objects, …
  - "Does not exists", but used to specify operations
  - Concrete state, not part of the specification, implements the abstract state

- Each operation described in terms of "creating", "observing", "producing" or "mutating"
  - No operations other than those in the specification

SPECIFYING AN ADT

Specification must include:

- **Overview**
- Abstract state
- Operation specifications

A description of what the class is for. Also specify whether it's mutable / immutable.

SPECIFYING AN ADT

Specification must include:

- Overview
- **Abstract state**
- Operation specifications

Describe key fields without implementation details. E.g. a “Person has a first and last name.”

SPECIFYING AN ADT

Specification must include:

- Overview
- Abstract state
- **Operation specifications**

Specifications of every operation (i.e. method) to be supported by the ADT.

SPECIFYING AN ADT

Operations are categorized into:

- Creators
- Observers
- Producers
- Mutators

SPECIFYING AN ADT

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Methods that create a new object i.e. constructors

SPECIFYING AN ADT

Operations are categorized into:

- Creators
- **Observers**
- Producers
- Mutators

Methods that return values or information about an object *without changing any values*. E.g. getters.

SPECIFYING AN ADT

Operations are categorized into:

- Creators
- Observers
- **Producers**
- Mutators

Methods that create and return a new object of the ADT. Mostly for *immutable* ADTs.

SPECIFYING AN ADT

Operations are categorized into:

- Creators
- Observers
- Producers
- **Mutators**

Methods that change the value of a field or otherwise modify an ADT object. E.g. setters. *Mutable ADTs only!*

CONCEPT OF A 2D POINT AS AN ADT

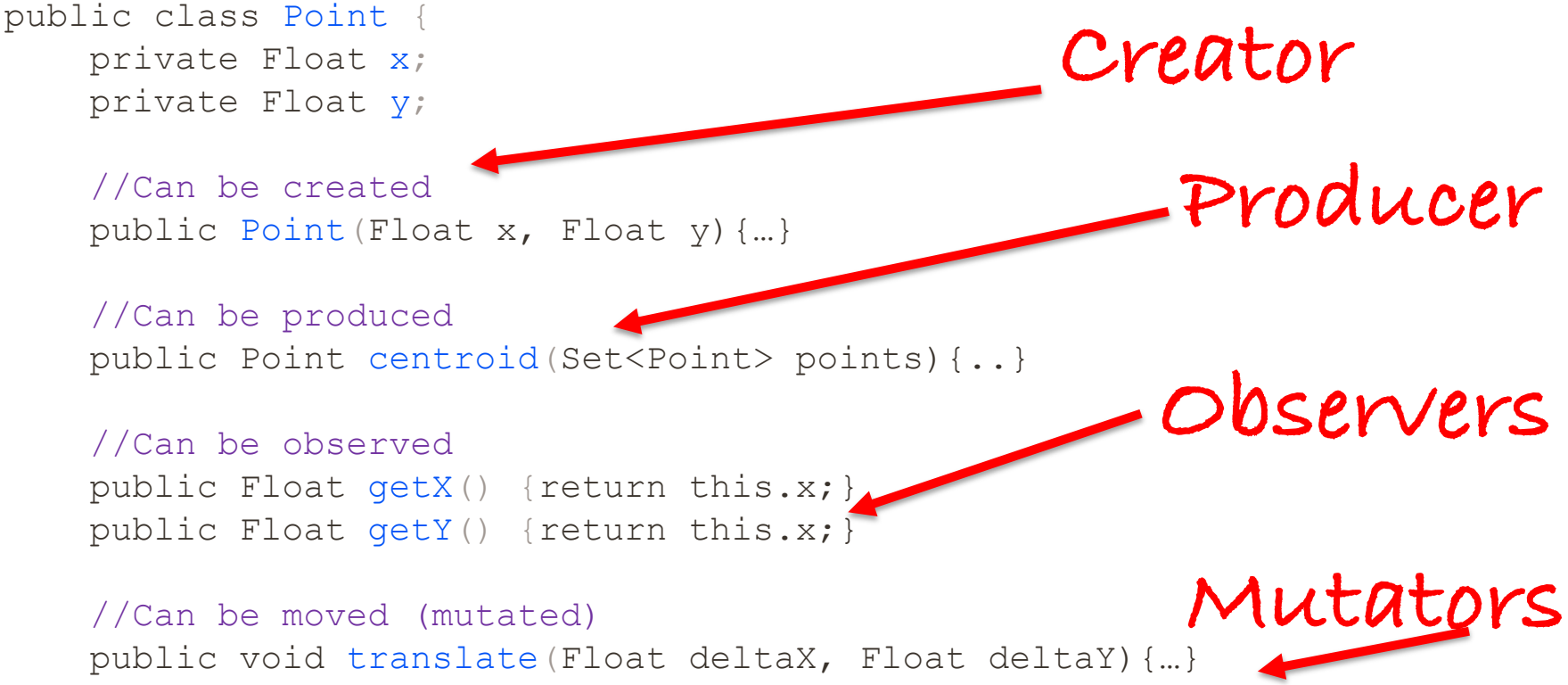
```
public class Point {
    private Float x;
    private Float y;

    //Can be created
    public Point(Float x, Float y){…}

    //Can be produced
    public Point centroid(Set<Point> points){..}

    //Can be observed
    public Float getX() {return this.x;}
    public Float getY() {return this.x;}

    //Can be moved (mutated)
    public void translate(Float deltaX, Float deltaY){…}
    public void scaleAndRotate(Float deltaX, Float deltaY){…}
}
```



WHY DO WE NEED ADTS?

- Organizing and manipulating data is pervasive
  - Inventing and describing algorithms is less common
- Start your design by designing data structures
  - How will relevant data be organized?
  - What operations will clients be permitted to do on the data?
- Potential problems with choosing data abstraction:
  - Decisions about data structures often made too early
  - Duplication of effort in creating derived data
  - Very hard to change key data structures (modularity!)

BENEFITS OF ADT

- If clients “respect” (are “forced to respect”) data abstractions:
  - We can delay decisions on how ADT is implemented
  - We can fix bugs by changing how ADT is implemented
  - We can change algorithms:
    - For performance
    - For security
    - In general or in specialized situations

- We talk about “abstraction barrier”
  - A good thing to have, and not to cross

ABSTRACT DATA TYPE - SUMMARY

- Abstract Data Type (ADT) - model that describes data by specifying the operations that we can perform on them

- Clients care about the ADT
- Developers care about the data structure (it's memory consumption, speed, correctness) and how the inner workings of the data structure faithfully implement the ADT

IMPLEMENTAING AN ADT IN JAVA

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IMPLEMENTING AN ADT

When the ADT is a ***collection*** of some sort:

- Choose an underlying data structure:
  - An array
  - Something else…
- Write an interface if appropriate
  - Useful if there may be multiple different implementations

ARRAYS IN JAVA

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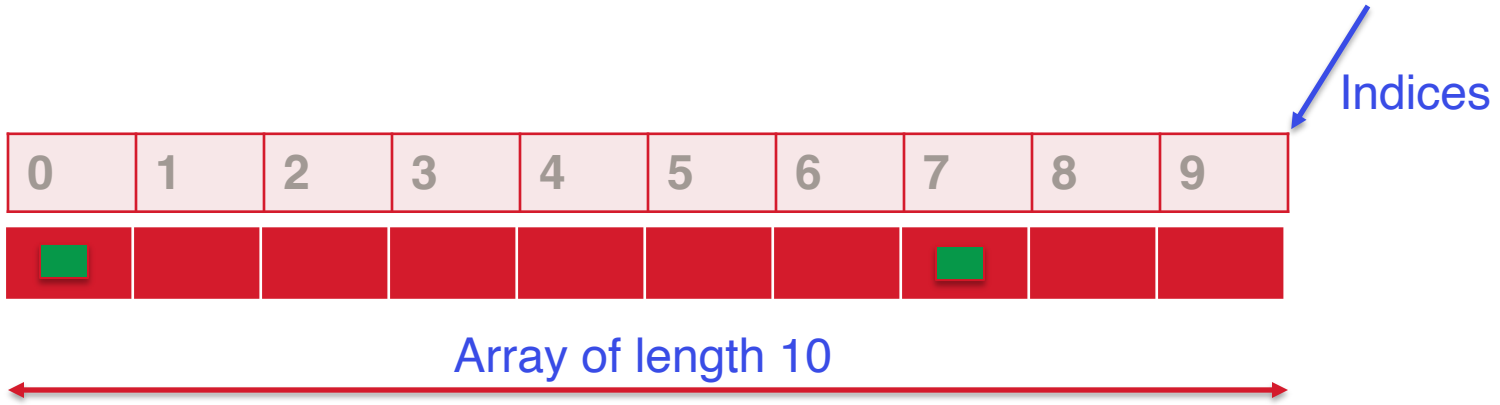
ARRAYS IN JAVA

- Array - container object that holds a fixed number of values of a single type
  - The length of an array is established when the array is created, and it is fixed after creation
  - Items in an array are called elements, and each element is accessed by its numerical index



ARRAYS OF OBJECTS

- An array of objects is created just like an array of primitive type data items

- Example:

```
Dancer[] dancers = new Dancer[5]; //Dancer is a user-defined class
```

- `Dancers` contains five memory spaces in which the address of five `Dancer` objects can be stored
- The `Dancer` objects have to be instantiated using the constructor of the Dancer class, and their references should be assigned to the array elements

MULTIDIMENSIONAL ARRAYS

- Multidimensional arrays (jagged arrays) - arrays of arrays where each element of an array holds a reference to another array
- Created by appending one set of square brackets ([]) per dimension

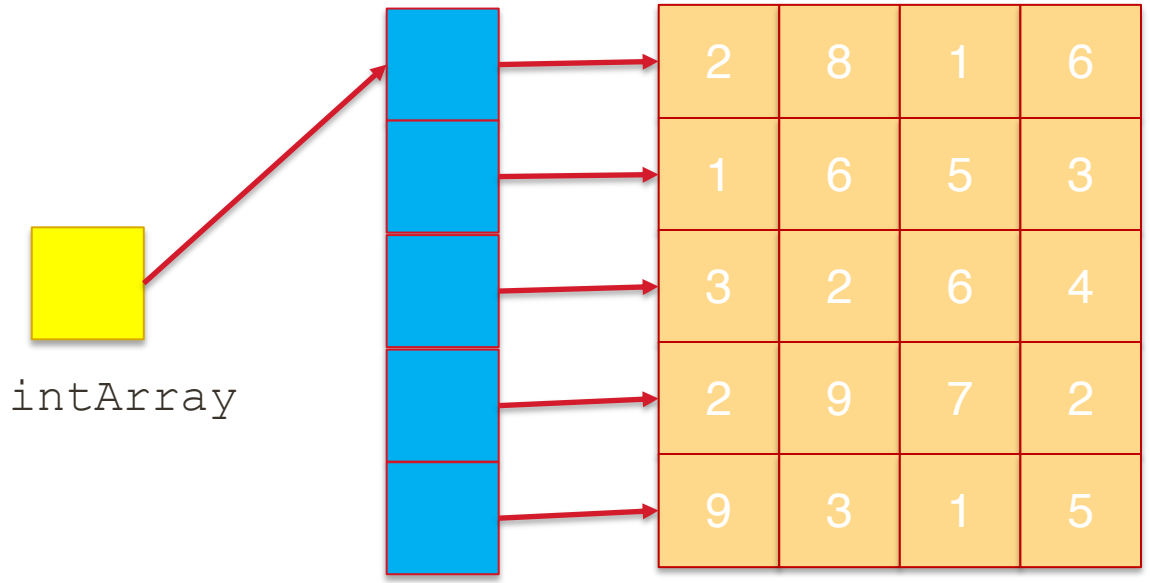
```
int[][] intArray = new int[10][20]; //a 2D array
or matrix

int[][][] intArray = new int[10][20][10]; //a 3D
array
```

MULTIDIMENSIONAL ARRAYS

- Multidimensional arrays (jagged arrays) - arrays of arrays where each element of an array holds a reference to another array

```
int[][] intArray = new int[5][4]; //a 2D array or
matrix
```



MULTIDIMENSIONAL ARRAYS

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```
int[][] intArray = new int[5][4]; //a 2D array or
matrix
```

The above is really equivalent to a 3-step process:

```
// create the single reference intArray (yellow square)
int [][] intArray;

// create the array of references (blue squares)
intArray = new int[5][];

// create the second level of arrays (red squares)
for (int i=0; i < 5 ; i++)
   intArray[i] = new int[4]; // create arrays of integers
```

IMPLEMENTING A COLLECTION ADT WITH AN ARRAY

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IMPLEMENTING A COLLECTION ADT WITH AN ARRAY

Considerations:

- Arrays must have a specified size → how big should it be?
- What happens if the array is bigger than the number of items in the collection?
- What happens if the array fills up?

IMPLEMENTING A COLLECTION ADT WITH AN ARRAY

```
public class SomeCollection implements ISomeCollection {
  private DataType[] items;
  private int size;
  private int NUM_SLOTS = 10;

  public SomeCollection() {
    this.items = new DataType[NUM_SLOTS];
    this.size = 0;
  }

  // Implement ADT methods here...
}
```

IMPLEMENTING A COLLECTION ADT WITH AN ARRAY

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    this.size = 0;
  }

  // Implement ADT methods here...
}
```

An array to store the items in the collection.

- Replace `DataType` with the appropriate data type...

IMPLEMENTING A COLLECTION ADT WITH AN ARRAY

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  private DataType[] items;
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  public SomeCollection() {
    this.items = new DataType[NUM_SLOTS];
    this.size = 0;
  }

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}
```

The number of items in the collection

- Not necessarily the same as `items.length`

IMPLEMENTING A COLLECTION ADT WITH AN ARRAY

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  public SomeCollection() {
    this.items = new DataType[NUM_SLOTS];
    this.size = 0;
  }

  // Implement ADT methods here...
}
```

The initial length of the `items` array

- Also used when resizing

LISTOFSTRINGS WITH AN ARRAY: INSTANTIATING

```
ListOfStrings list = new ListOfStrings();
```

Underlying data structure:

- String array, length 5

Client view:

- An empty list
  - No items
  - Size 0

LISTOFSTRINGS WITH AN ARRAY: ADDING

E.g., `list.add("A");`

Underlying data structure:

- String array, length 5

Client view:

- In the list: "A"
- Size 1

Check that `this.size < this.items.length`
→ `this.items[this.size] = newItem`
→ `this.size++` (`this.size` is now 1)

LISTOFSTRINGS WITH AN ARRAY: ADDING

E.g., `list.add("B");`

Underlying data structure:

- String array, length 5

Client view:

- In the list: "A", "B"
- Size 2

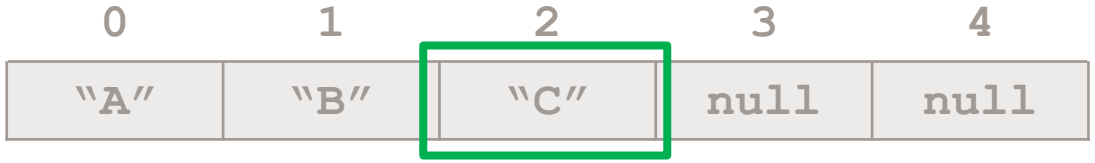
Check that `this.size < this.items.length`
→ `this.items[this.size] = newItem`
→ `this.size++` (`this.size` is now 2)

LISTOFSTRINGS WITH AN ARRAY: ADDING

E.g., `list.add("C");`

Underlying data structure:

- String array, length 5



Client view:

- In the list: "A", "B", "C"
- Size 3

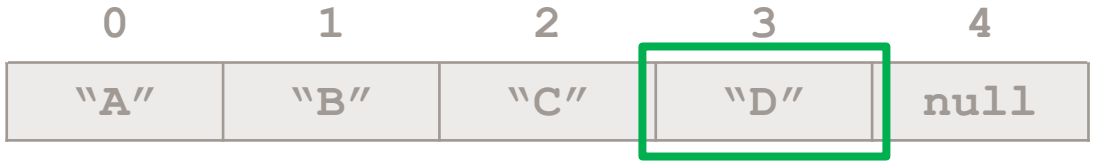
Check that `this.size < this.items.length`
→ `this.items[this.size] = newItem`
→ `this.size++` (`this.size` is now 3)

LISTOFSTRINGS WITH AN ARRAY: ADDING

E.g., `list.add("D");`

Underlying data structure:

- String array, length 5



Client view:

- In the list: "A", "B", "C", "D"
- Size 4

Check that `this.size < this.items.length`

→ `this.items[this.size] = newItem`

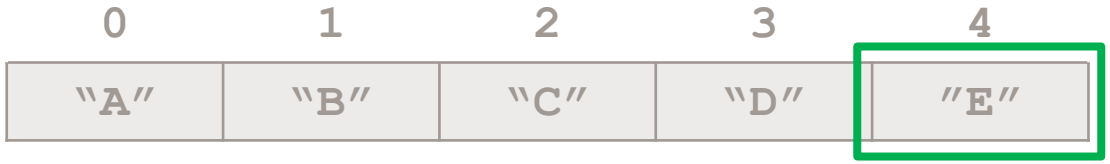
→ `this.size++` (`this.size` is now 4)

LISTOFSTRINGS WITH AN ARRAY: ADDING

E.g., `list.add("E");`

Underlying data structure:

- String array, length 5



Client view:

- In the list: "A", "B", "C", "D", "E"
- Size 5

Check that `this.size < this.items.length`
→ `this.items[this.size] = newItem`
→ `this.size++` (`this.size` is now 5)

LISTOFSTRINGS WITH AN ARRAY: ADDING

E.g., `list.add("F");`

Underlying data structure:

- String array, length 5

Client view:

- In the list: "A", "B", "C", "D", "E"
- Size 5

Check that `this.size < this.items.length` → false

LISTOFSTRINGS WITH AN ARRAY: ADDING

E.g., `list.add("F");`

Underlying data structure:

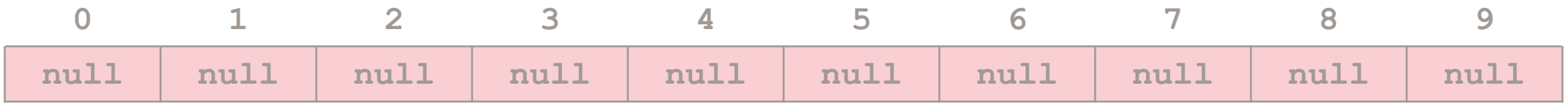
- String array, length 5

Client view:

- In the list: "A", "B", "C", "D", "E"
- Size 5

Check that `this.size < this.items.length` → false

- Make a new array of size `this.size + NUM_SLOTS`



LISTOFSTRINGS WITH AN ARRAY: ADDING

E.g., `list.add("F");`

Underlying data structure:

- String array, length 10

Client view:

- In the list: "A", "B", "C", "D", "E"
- Size 5

- Check that `this.size < this.items.length` → false
- Make a new array of size `this.size + NUM_SLOTS`

- Copy the contents of `this.items`, set `this.items` to the new array

LISTOFSTRINGS WITH AN ARRAY: ADDING

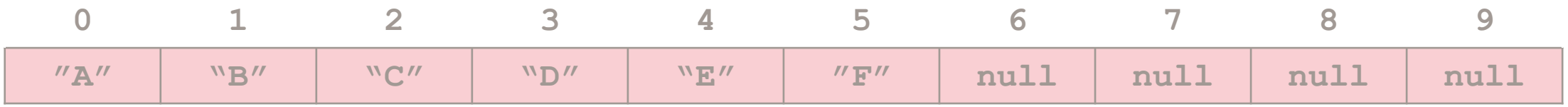
E.g., `list.add("F");`

Underlying data structure:

- String array, length 10

Client view:

- "A", "B", "C", "D", "E", "F"
- Size 6



ASIDE: CHOOSING THE UNDERLYING ARRAY SIZE

```
private int NUM_SLOTS = 10;
...
this.items = new String[NUM_SLOTS];
```

Tradeoff:

- Arrays with a lot of empty slots waste space.
- When the array fills, resizing takes time and space.

LISTOFSTRINGS WITH AN ARRAY: GET AN ITEM

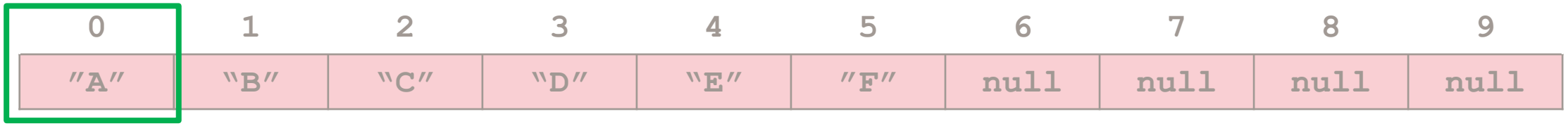
E.g., `list.get(0);`

Underlying data structure:

- String array, length 10

Client view:

- "A", "B", "C", "D", "E", "F"
- Index 0 should return "A"



Check that `index >= 0 && index < this.size`

→ `return this.items[index]`

LISTOFSTRINGS WITH AN ARRAY: GET AN ITEM

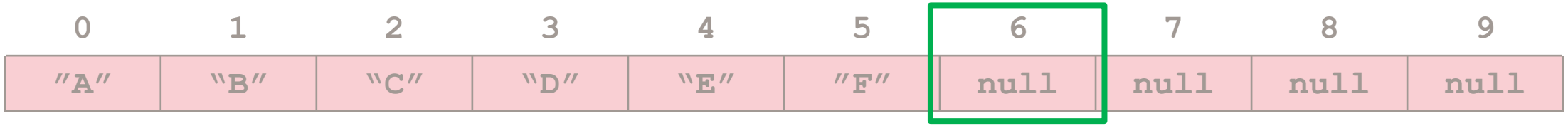
E.g., `list.get(6);`

Underlying data structure:

- String array, length 10

Client view:

- "A", "B", "C", "D", "E", "F"
- Index 6 is out of bounds

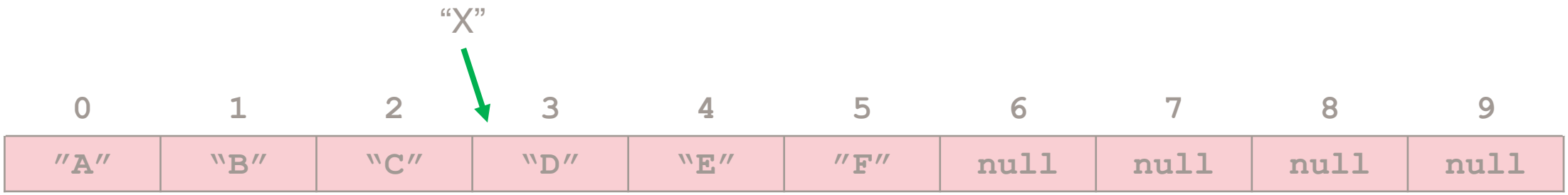


Check that `index >= 0 && index < this.size`

→ `false` so `throw new IndexOutOfBoundsException()`

LISTOFSTRINGS WITH AN ARRAY: INSERT AT INDEX

E.g., `list.insert("X", 3)`



Create a new array with the same* length (or resize if too small)

LISTOFSTRINGS WITH AN ARRAY: INSERT AT INDEX

E.g., `list.insert("X", 3)`

LISTOFSTRINGS WITH AN ARRAY: INSERT AT INDEX

E.g., `list.insert("X", 3)`

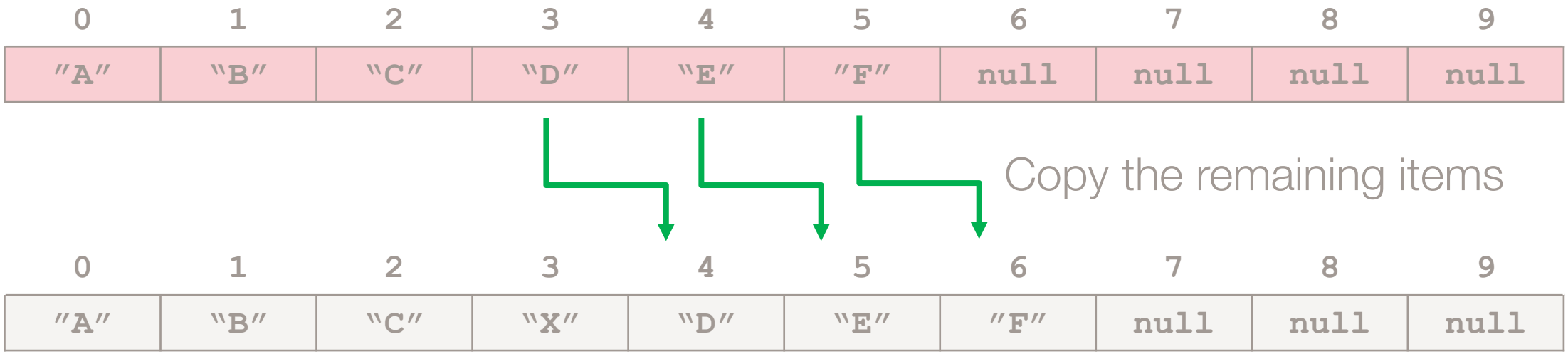
0	1	2	3	4	5	6	7	8	9
"A"	"B"	"C"	"D"	"E"	"F"	null	null	null	null

Add the new item at the given index

0	1	2	3	4	5	6	7	8	9
"A"	"B"	"C"	"X"	null	null	null	null	null	null

LISTOFSTRINGS WITH AN ARRAY: INSERT AT INDEX

E.g., `list.insert("X", 3)`



Don't forget to increase `this.size`!

IMPLEMENTING AN ADT

When the ADT is a ***collection*** of some sort:

- Choose an underlying data structure:
  - An array
  - **Something else…**
- Write an interface if appropriate
  - Useful if there may be multiple different implementations

COLLECTION ADT IMPLEMENTATION – UNDERLYING DATA STRUCTURE

Array

- Pro: Built-in data structure
- Con: Fixed size
  - What do we do when we run out of slots

Something else?

- A custom data structure
- …can we use something that doesn't need resizing?

INTRODUCING THE LINKED LIST

A collection of linked objects, each storing one element and one or more references to other elements.

INTRODUCING THE LINKED LIST

A collection of linked objects, each storing one element and one or more references to other elements.

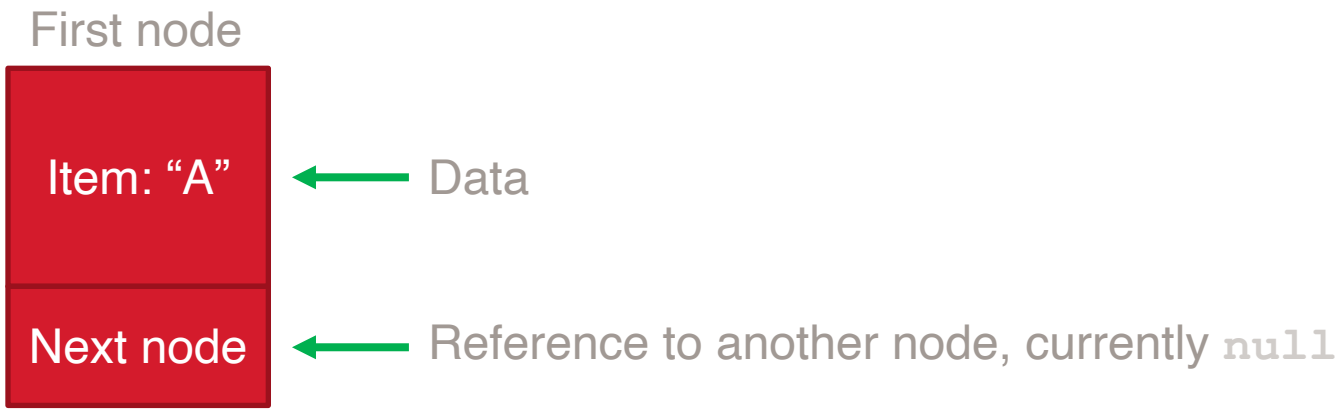
- Items in the list are commonly referred to as “nodes”

Two ways to implement:

- Sequential (today)
- Recursive (a couple of weeks)

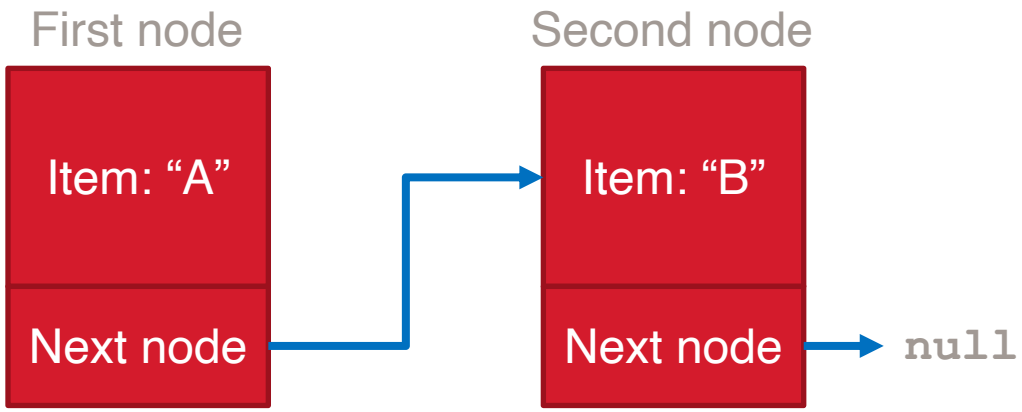
INTRODUCING THE LINKED LIST

We start with a single node, contains some data and a reference to another node.



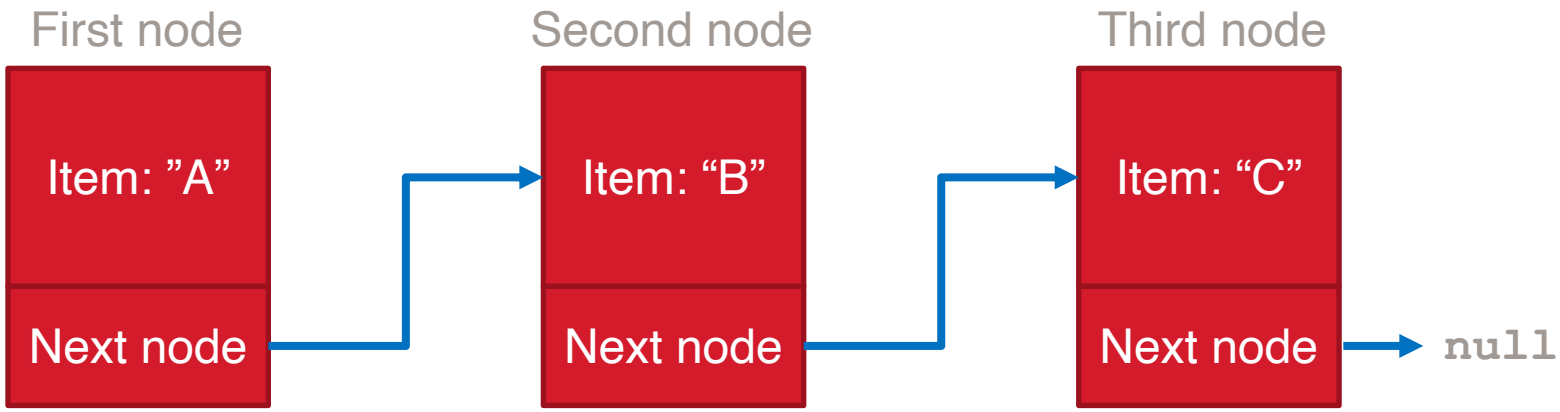
INTRODUCING THE LINKED LIST

Adding a second node…



INTRODUCING THE LINKED LIST

Adding a third node…



IMPLEMENTING A COLLECTION ADT WITH A LINKED LIST

```
public class Node {
  private DataType item;
  private Node nextNode;

  public Node(DataType item, Node nextNode) {
    this.item = item;
    this.nextNode = nextNode;
  }
  // Implement getters, setters, equals, hashCode, toString
}
```

IMPLEMENTING A COLLECTION ADT WITH A LINKED LIST

```
public class SomeCollection implements ISomeCollection {
  private Node head;
  private int numNodes;

  public SomeCollection() {
    this.head = null;
    this.numNodes = 0;
  }
  // Implement ADT methods here...
}
```

LISTOFSTRINGS WITH A LINKED LIST: INSTANTIATING

```
ListOfStrings list = new ListOfStrings();
```

Underlying data structure:

- `this.numNodes = 0;`
- `this.head = null;`

Client view:

- An empty list
  - No items
  - Size 0

LISTOFSTRINGS WITH A LINKED LIST: ADD ITEM

E.g., `list.add("A");`

Underlying data structure:

- `this.numNodes = 0;`

Client view:

- An empty list
  - No items
  - Size 0

- `this.head = null;`

If the head is null → make a new Node containing the item

```
Node newNode = new Node(item, null);
```

...and set `this.head` to be the new `Node`

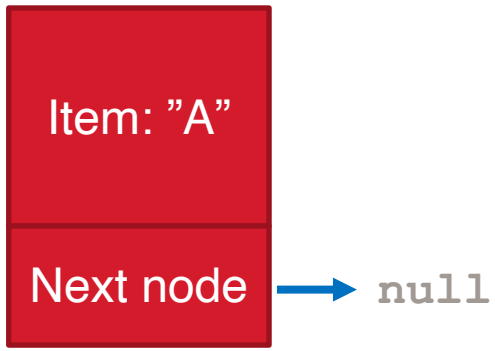
```
this.head = newNode;
```

LISTOFSTRINGS WITH A LINKED LIST: ADD ITEM

E.g., `list.add("A");`

Underlying data structure:

- `this.numNodes++;` (now 1)
- `this.head =`



Client view:

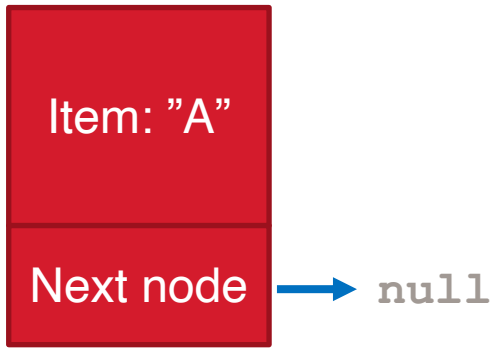
- List contents: "A"
- Size 1

LISTOFSTRINGS WITH A LINKED LIST: ADD ITEM

E.g., `list.add("B");`

Underlying data structure:

- `this.numNodes = 1;`
- `this.head =`



Client view:

- List contents: "A"
- Size 1

If the head is NOT null → make a new Node containing the item

- Starting from `this.head`, check each Node's `nextNode` until you find one that's `null`.
- Set the Node's `nextNode` to point to the new Node

LISTOFSTRINGS WITH A LINKED LIST: ADD ITEM

E.g., `list.add("B");`

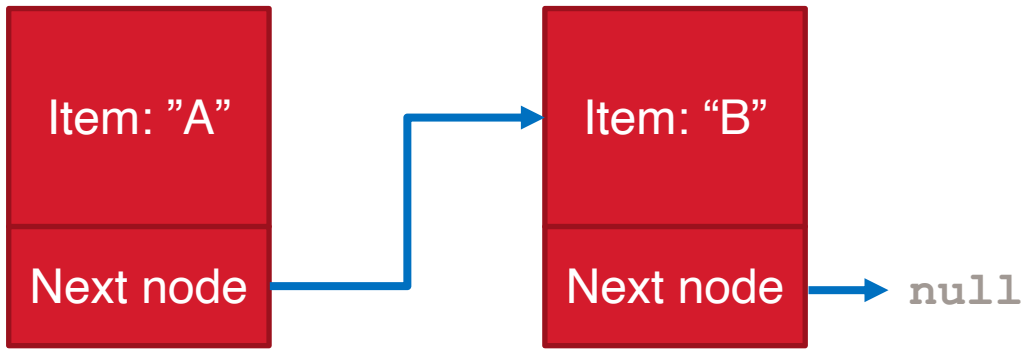
Underlying data structure:

- `this.numNodes++;` (now 2)

Client view:

- List contents: "A", "B"
- Size 2

- `this.head` =

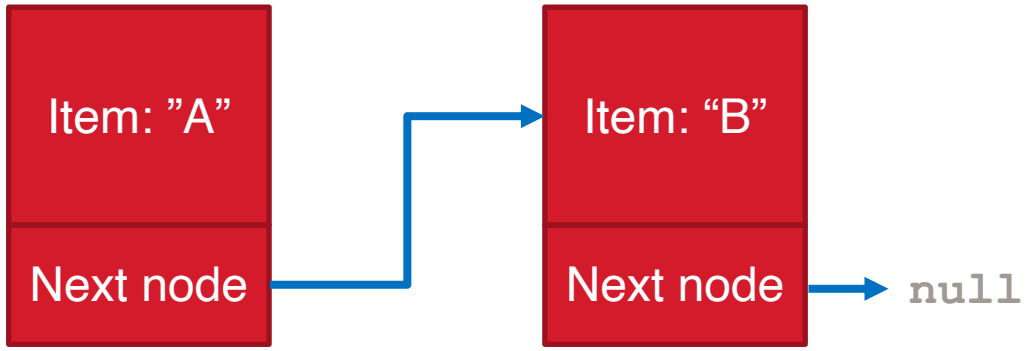


LISTOFSTRINGS WITH A LINKED LIST: GET ITEM

E.g., `list.get(0);`

Underlying data structure:

- `this.numNodes = 2;`
- `this.head =`



Client view:

- Expected return: “A”

LISTOFSTRINGS WITH A LINKED LIST: GET ITEM

E.g., `list.get(0);`

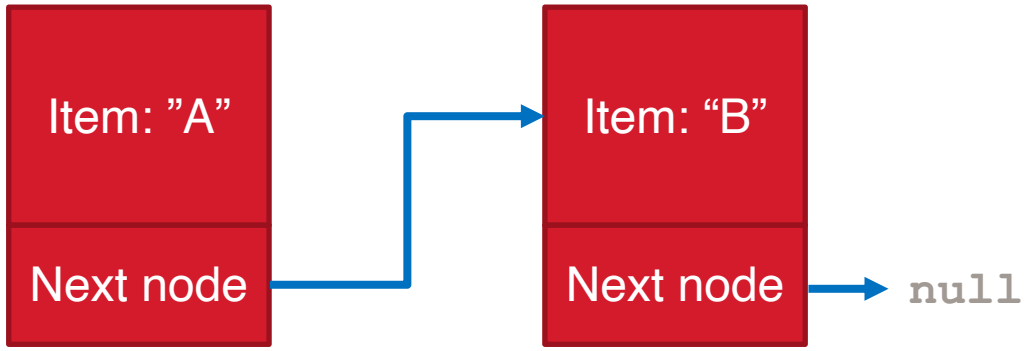
Underlying data structure:

- `this.numNodes = 2;`

Client view:

- Expected return: “A”

- `this.head =`



Check that `index >= 0 && index < this.numNodes`

→ Use a loop to step through each Node

LISTOFSTRINGS WITH A LINKED LIST: GET ITEM

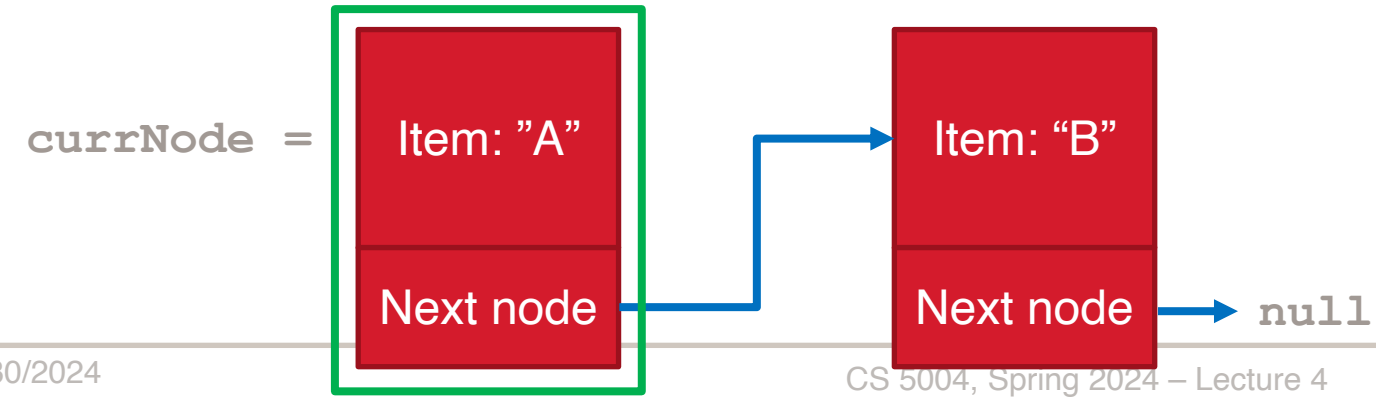
E.g., `list.get(0);`

```
Node currNode = this.head;
int i = 0;
while (i < index) {
    i++;
    currNode = currNode.getNextNode();
}
return currNode.getItem();
```

LISTOFSTRINGS WITH A LINKED LIST: GET ITEM

E.g., `list.get(0);`

```
Node currNode = this.head;
int i = 0;
while (i < index) {
    i++;
    currNode = currNode.getNextNode();
}
return currNode.getItem();
```

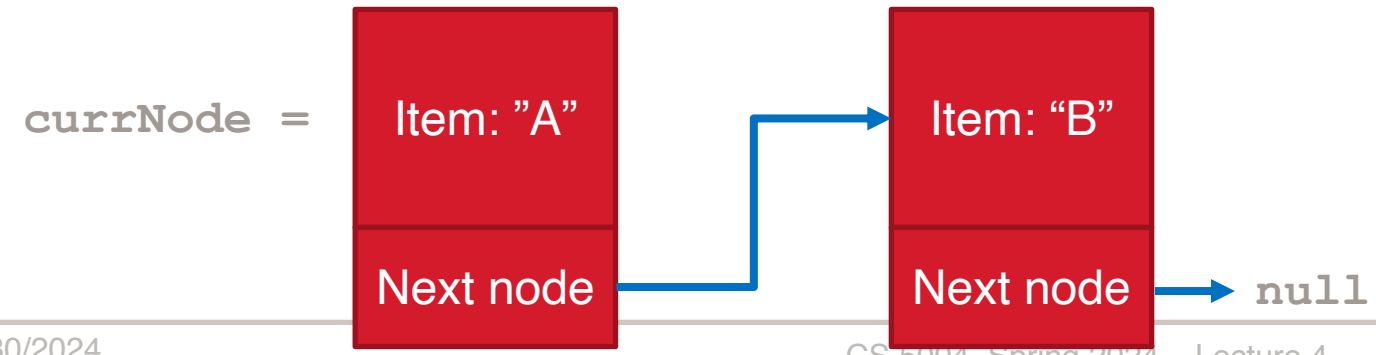


LISTOFSTRINGS WITH A LINKED LIST: GET ITEM

E.g., `list.get(0);`

```
Node currNode = this.head;
int i = 0;
while (i < index) {
    i++;
    currNode = currNode.getNextNode();
}
return currNode.getItem();
```

Because the index is 0, the while loop is skipped

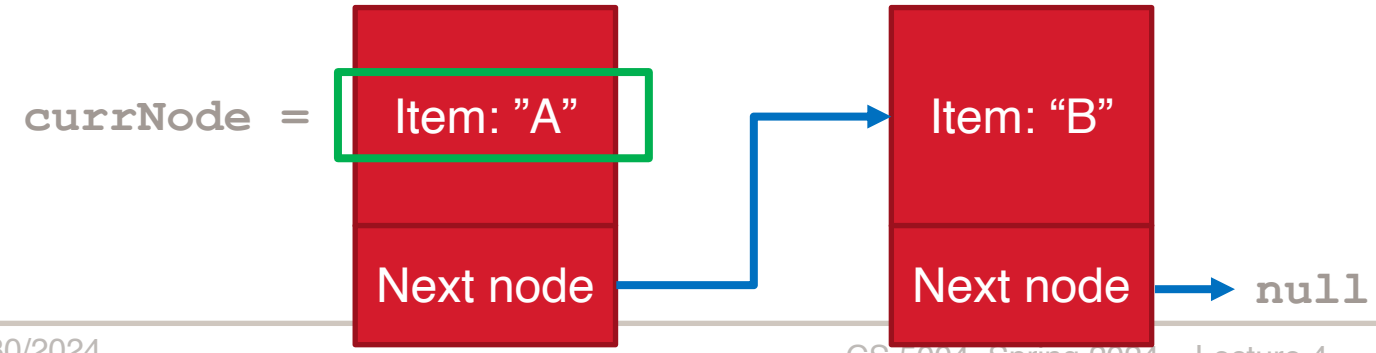


LISTOFSTRINGS WITH A LINKED LIST: GET ITEM

E.g., `list.get(0);`

```
Node currNode = this.head;
int i = 0;
while (i < index) {
    i++;
    currNode = currNode.getNextNode();
}
return currNode.getItem();
```

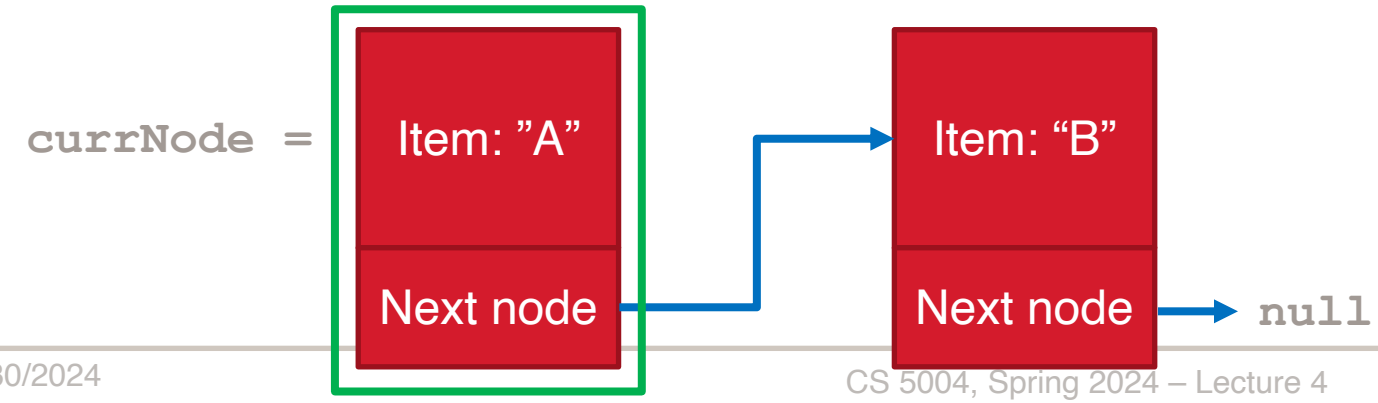
Return the item stored in the current node



LISTOFSTRINGS WITH A LINKED LIST: GET ITEM

E.g., `list.get(1);`

```
Node currNode = this.head;
int i = 0;
while (i < index) {
    i++;
    currNode = currNode.getNextNode();
}
return currNode.getItem();
```

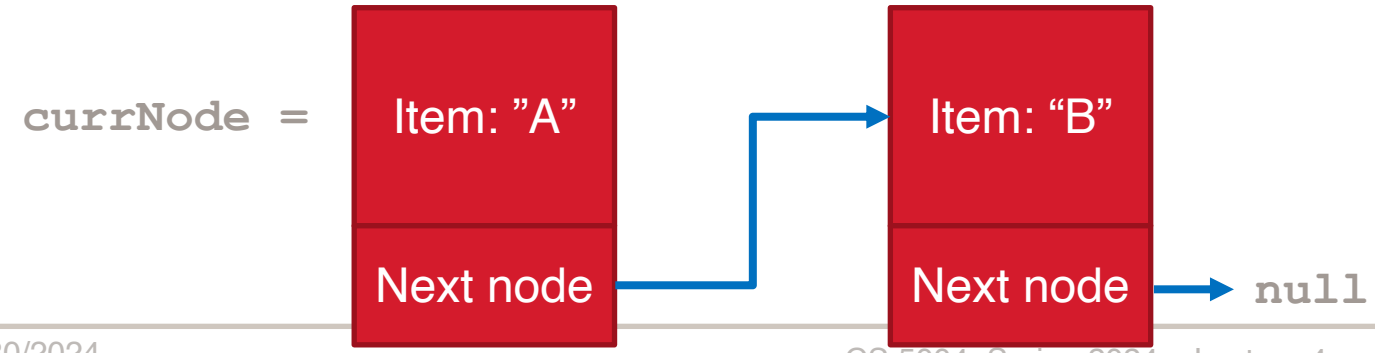


LISTOFSTRINGS WITH A LINKED LIST: GET ITEM

E.g., `list.get(1);`

```
Node currNode = this.head;
int i = 0;
while (i < index) {
    i++;
    currNode = currNode.getNextNode();
}
return currNode.getItem();
```

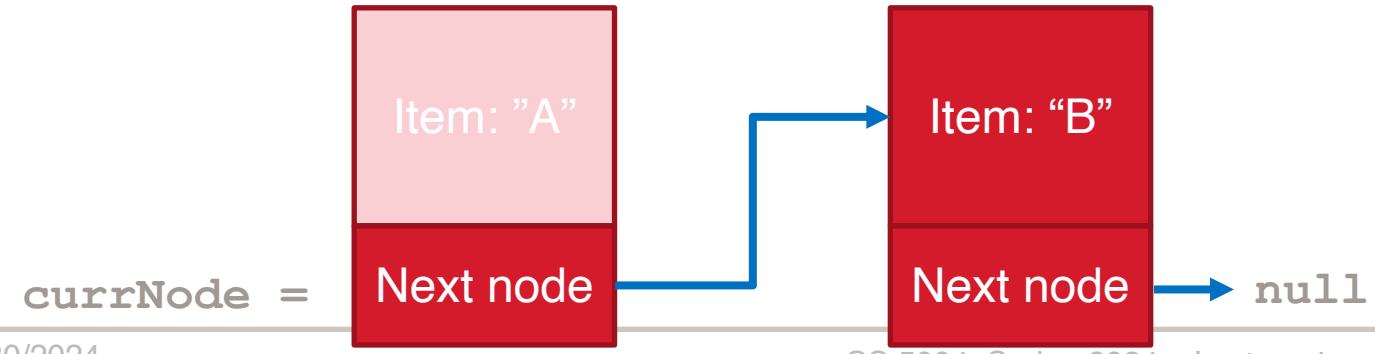
i < index →
Step into the while loop



LISTOFSTRINGS WITH A LINKED LIST: GET ITEM

E.g., `list.get(1);`

```
Node currNode = this.head;
int i = 0;
while (i < index) {
    i++;
    currNode = currNode.getNextNode();
}
return currNode.getItem();
```

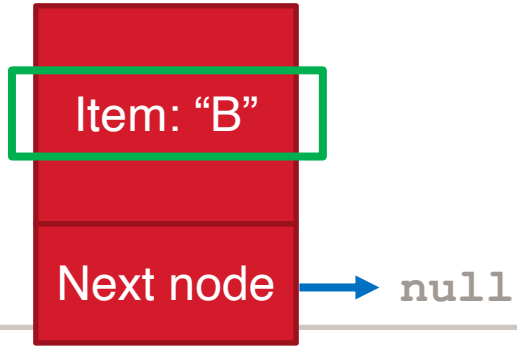


LISTOFSTRINGS WITH A LINKED LIST: GET ITEM

E.g., `list.get(1);`

```
Node currNode = this.head;
int i = 0;
while (i < index) {
    i++;
    currNode = currNode.getNextNode();
}
return currNode.getItem();
```

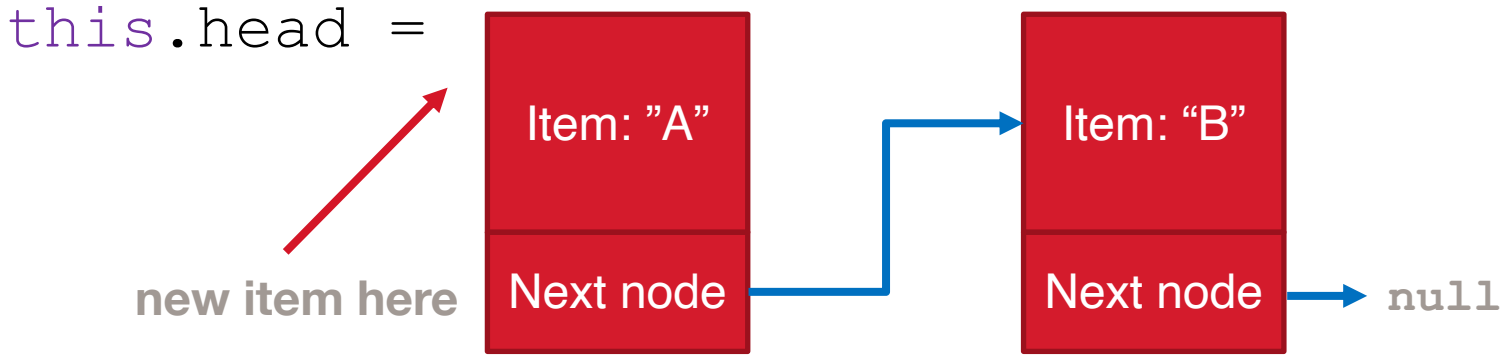
Return the item stored in the current node



currNode =

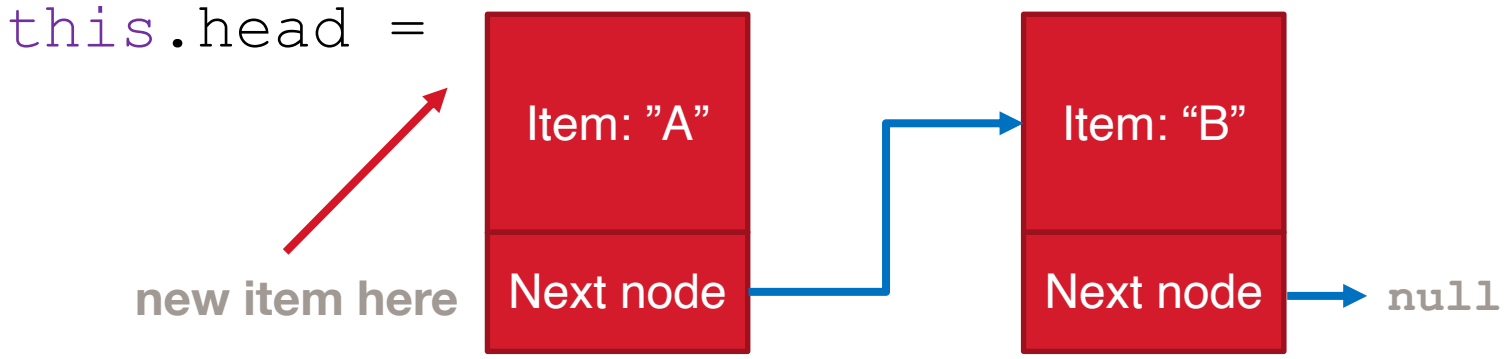
LISTOFSTRINGS WITH A LINKED LIST: INSERT ITEM

E.g., `list.insert("X", 0);`



LISTOFSTRINGS WITH A LINKED LIST: INSERT ITEM

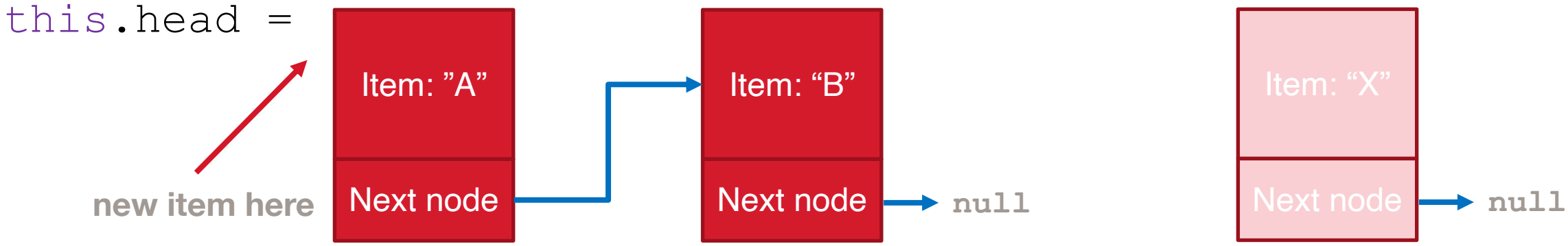
E.g., `list.insert("X", 0);`



Check that `index >= 0 && index < this.numNodes`

LISTOFSTRINGS WITH A LINKED LIST: INSERT ITEM

E.g., `list.insert("X", 0);`



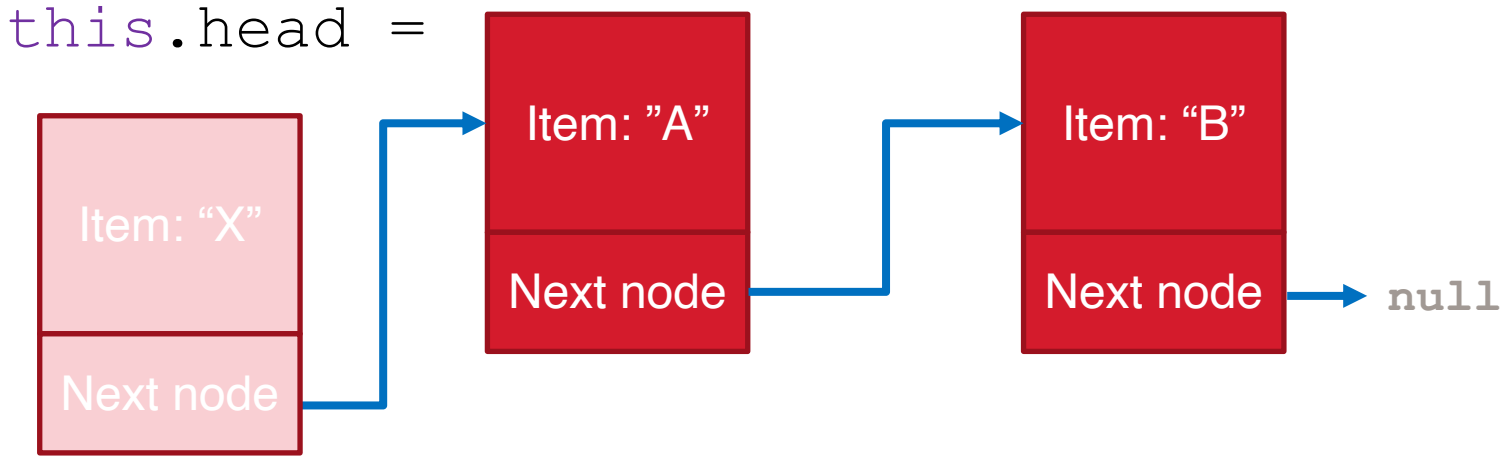
Check that `index >= 0 && index < this.numNodes`

→ Create a new Node containing the item:

```
Node newNode = new Node("X", null);
```

LISTOFSTRINGS WITH A LINKED LIST: INSERT ITEM

E.g., `list.insert("X", 0);`



If `index == 0`

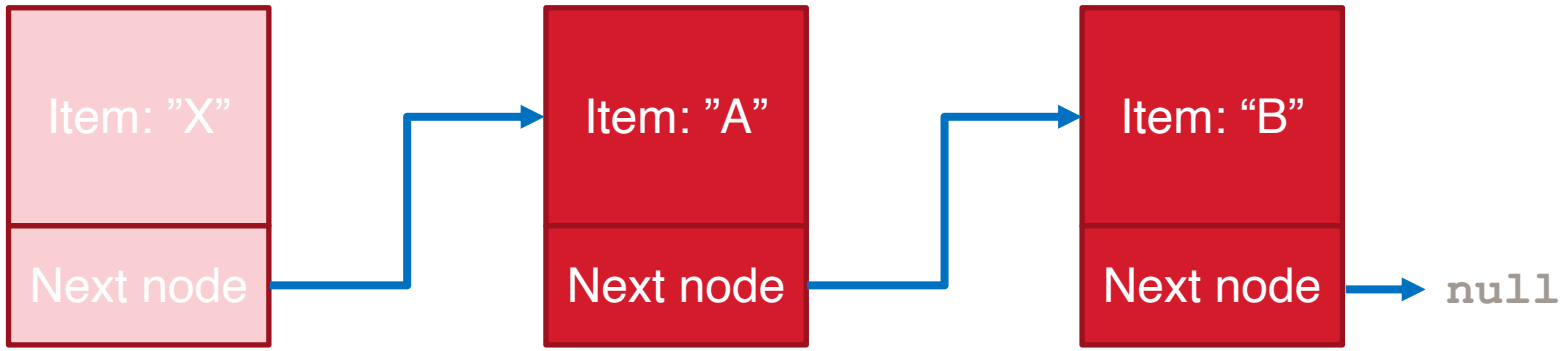
→ Set the new Node's **`nextNode`** to **`this.head`**;

```
newNode.setNextNode(this.head);
```

LISTOFSTRINGS WITH A LINKED LIST: INSERT ITEM

E.g., `list.insert("X", 0);`

`this.head =`



If `index == 0`

→ Set the new Node's **`nextNode`** to **`this.head`**;

```
newNode.setNextNode(this.head);
```

→ Set **`this.head`** to **`nextNode`**

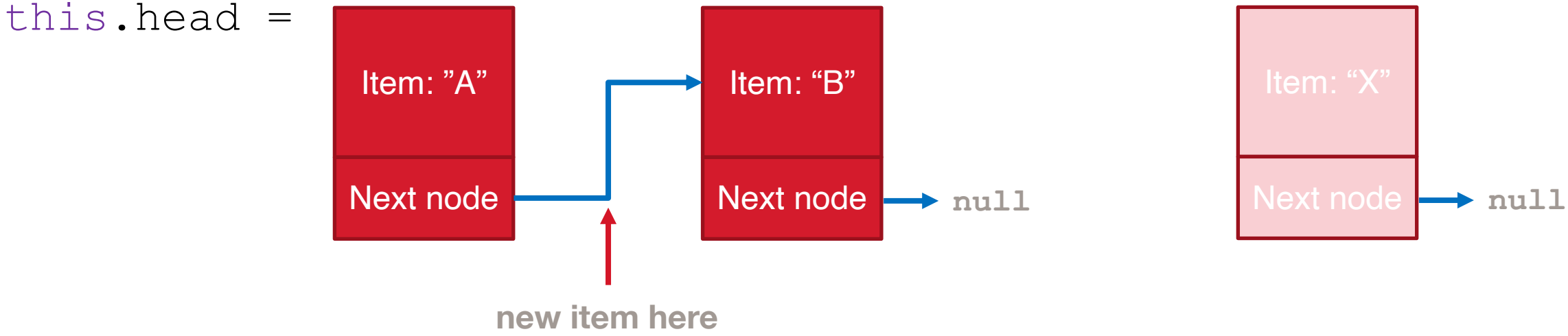
```
this.head = newNode;
```

LISTOFSTRINGS WITH A LINKED LIST: INSERT ITEM

```
//Inside the insert method (after validating index)
Node newNode = new Node(item, null);
if (index == 0) {
   newNode.setNextNode(this.head);
   this.head = newNode;
}
```

LISTOFSTRINGS WITH A LINKED LIST: INSERT ITEM

E.g., `list.insert("X", 1);`



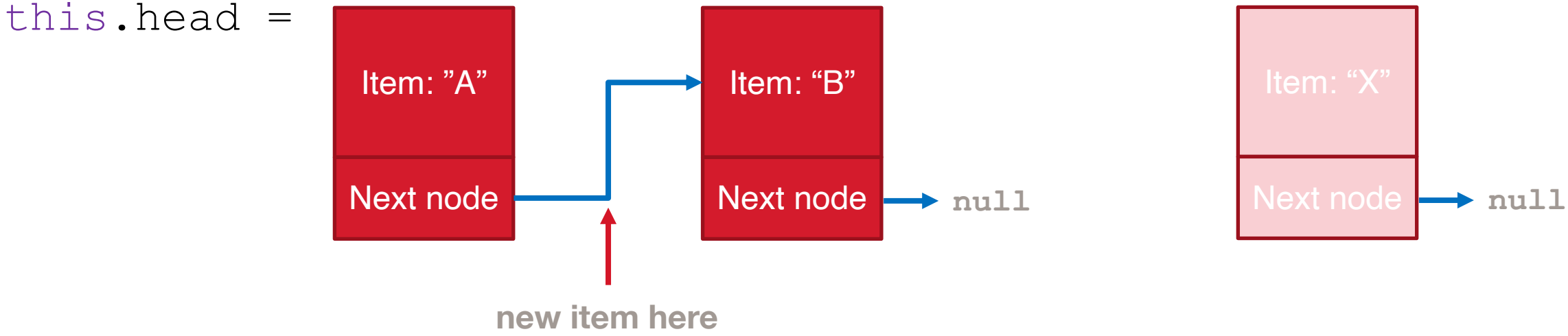
Check that `index >= 0 && index < this.numNodes`

→ Create a new Node containing the item:

```
Node newNode = new Node("X", null);
```

LISTOFSTRINGS WITH A LINKED LIST: INSERT ITEM

E.g., `list.insert("X", 1);`

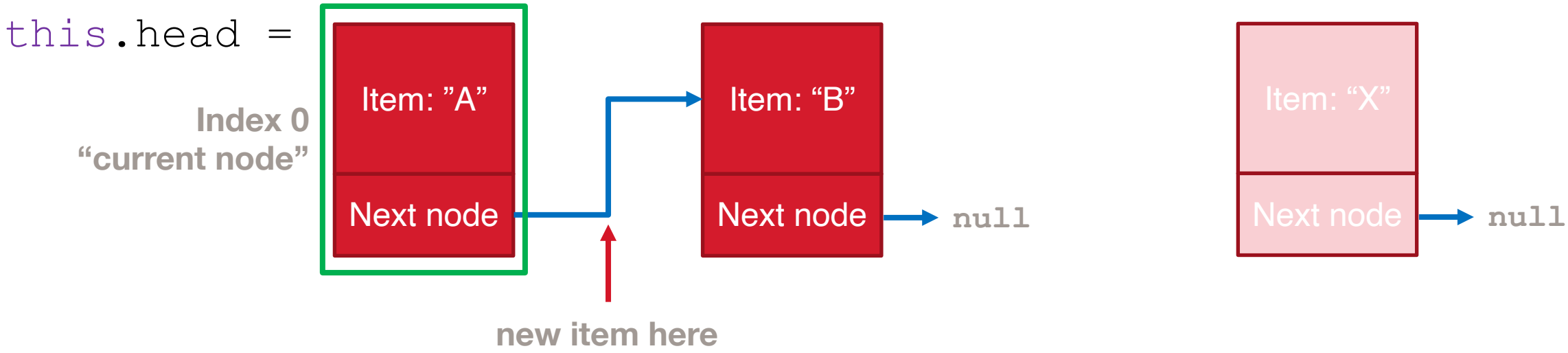


If `index > 0`

→ Starting from **`this.head`**, loop through the Nodes until get to the item at the index *before* where we want to insert

LISTOFSTRINGS WITH A LINKED LIST: INSERT ITEM

E.g., `list.insert("X", 1);`

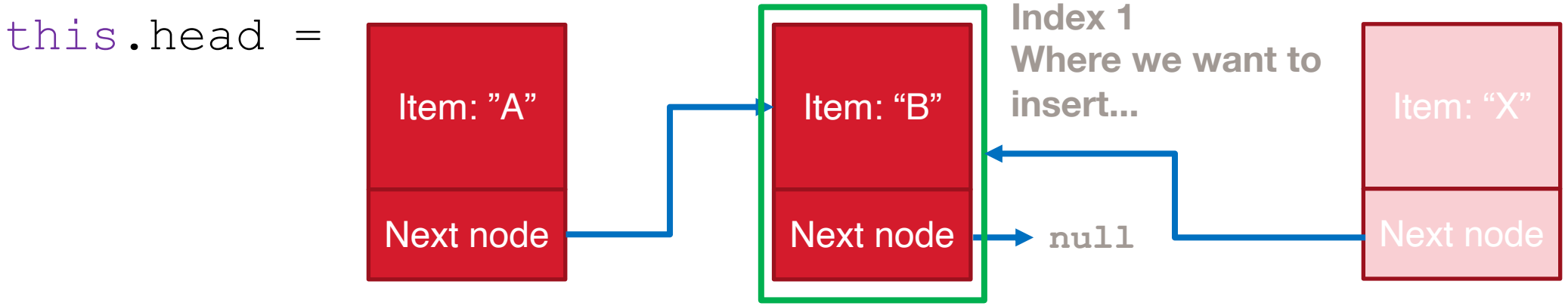


If `index > 0`

→ Starting from **`this.head`**, loop through the Nodes until get to the item at the index *before* where we want to insert

LISTOFSTRINGS WITH A LINKED LIST: INSERT ITEM

E.g., `list.insert("X", 1);`



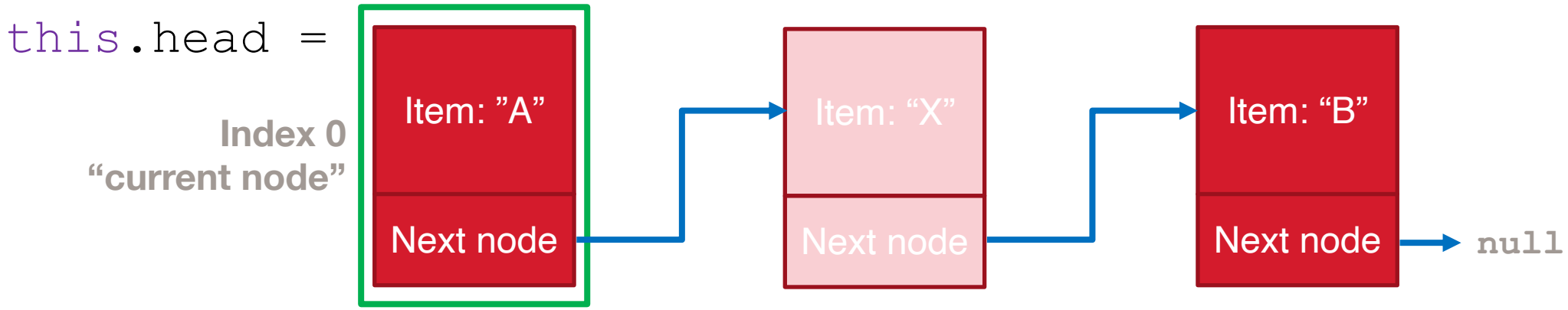
If `index > 0`

→ Starting from **`this.head`**, loop through the Nodes until get to the item at the index *before* where we want to insert

→ Set the new Node's **`nextNode`** to the *next* Node in the loop i.e. the Node currently occupying the index

LISTOFSTRINGS WITH A LINKED LIST: INSERT ITEM

E.g., `list.insert("X", 1);`



If `index > 0`

→ Starting from **`this.head`**, loop through the Nodes until get to the item at the index *before* where we want to insert

→ Set the new Node's **`nextNode`** to the next Node in the loop

→ Set the current Node's **`nextNode`** to the new Node

LISTOFSTRINGS WITH A LINKED LIST: INSERT ITEM

```
//Inside the insert method (after validating index)
Node newNode = new Node(item, null);
if (index == 0) {
  newNode.setNextNode(this.head);
  this.head = newNode;
}
else {
  int i = 0;
  Node currNode = this.head;
  while (i < index - 1) {
    i++;
    currNode = currNode.getNextNode();
  }
  newNode.setNextNode(currNode.getNextNode());
  currNode.setNextNode(newNode);
}
this.numNodes++;
```

Inserting at a *valid* index > 0

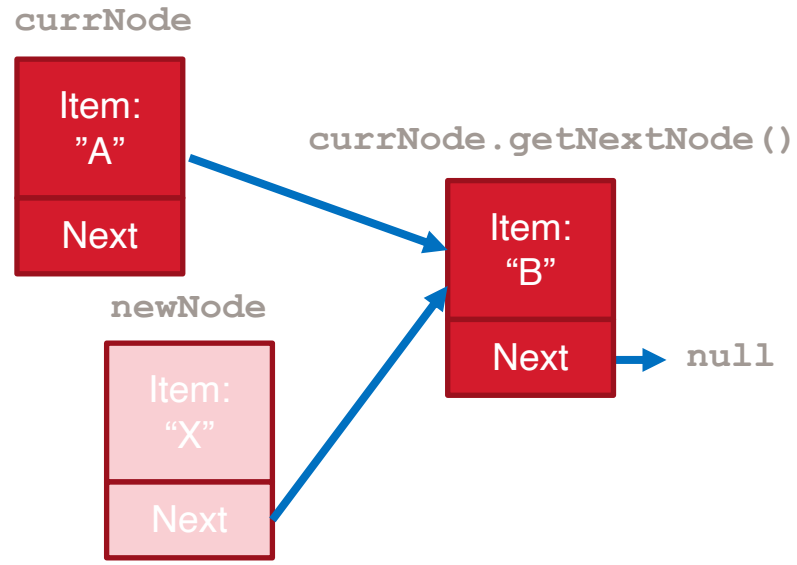
LISTOFSTRINGS WITH A LINKED LIST: INSERT ITEM

```
//Inside the insert method (after validating index)
Node newNode = new Node(item, null);
if (index == 0) {
  newNode.setNextNode(this.head);
  this.head = newNode;
}
else {
  int de curi = 0;
  NorNode = this.head;
  while (i < index - 1) {
    i++;
    currNode = currNode.getNextNode();
  }
  newNode.setNextNode(currNode.getNextNode());
  currNode.setNextNode(newNode);
}
this.numNodes++;
```

Iterate through the nodes until we get to the one before the insert

LISTOFSTRINGS WITH A LINKED LIST: INSERT ITEM

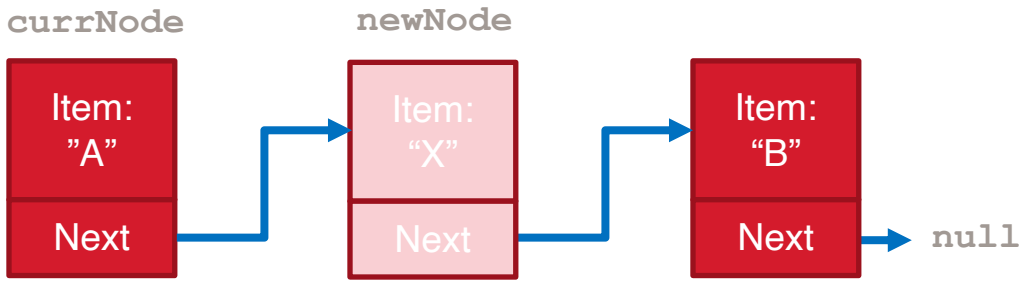
```
//Inside the insert method (after validating index)
Node newNode = new Node(item, null);
if (index == 0) {
  newNode.setNextNode(this.head);
  this.head = newNode;
}
else {
  int i = 0;
  Node currNode = this.head;
  while (i < index - 1) {
    i++;
    currNode = currNode.getNextNode();
  }
  newNode.setNextNode(currNode.getNextNode());
  currNode.setNextNode(newNode);
}
this.numNodes++;
```



Set the *new* Node's nextNode pointer to the node currently at `index`

LISTOFSTRINGS WITH A LINKED LIST: INSERT ITEM

```
//Inside the insert method (after validating index)
Node newNode = new Node(item, null);
if (index == 0) {
  newNode.setNextNode(this.head);
  this.head = newNode;
}
else {
  int i = 0;
  Node currNode = this.head;
  while (i < index - 1) {
    i++;
    currNode = currNode.getNextNode();
  }
  newNode.setNextNode(currNode.getNextNode());
  currNode.setNextNode(newNode);
}
this.numNodes++;
```



Set the *current* Node's nextNode pointer to the *new* Node

IMPLEMENTING OTHER COLLECTION ADTS

Still need to choose an underlying data structure, either:

- Built-in array
- Linked list (i.e., Node)
  - Encouraged

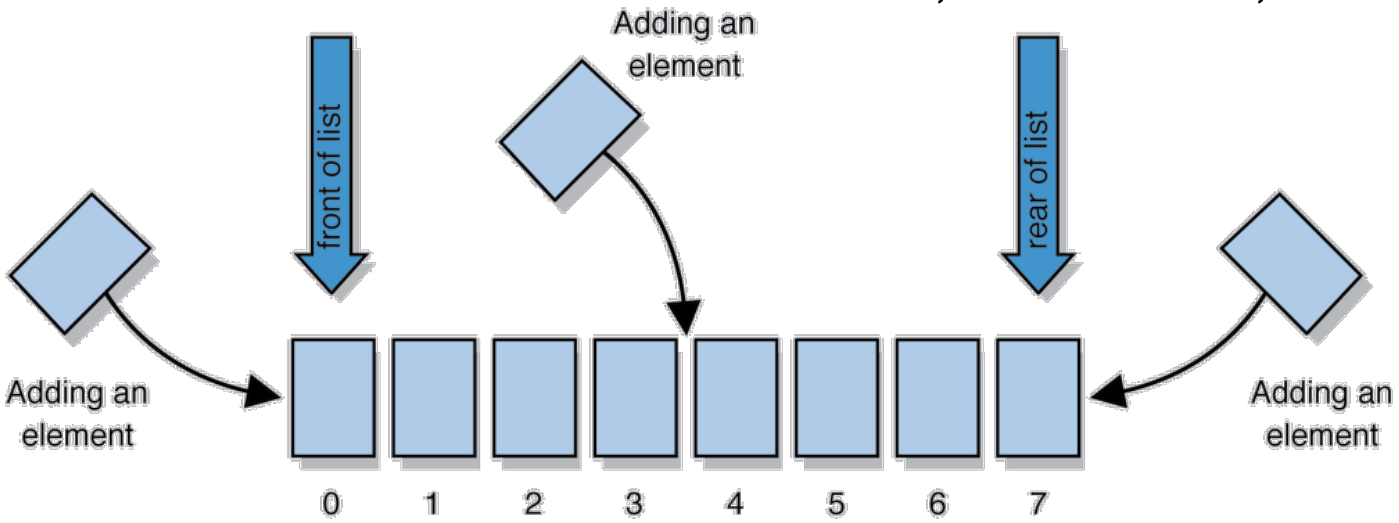
- Implementation of key methods will vary based on ADT specification

LISTS IN JAVA

CS 5004, SPRING 2024 – LECTURE 4

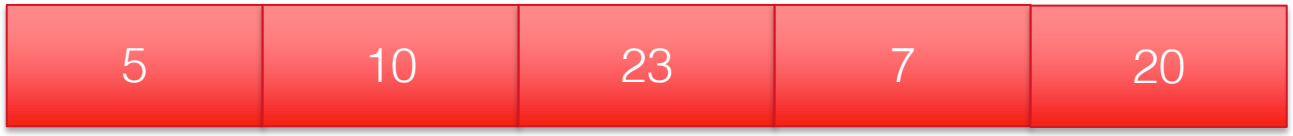
LISTS

- List – an ordered collection (also known as a sequence)
  - A user controls where in the list each element is inserted
  - A user can access elements by their integer index (position in the list), and search for elements in the list
- Size - the number of elements in the list
- List allows for elements to be added to the front, to the back, or arbitrary

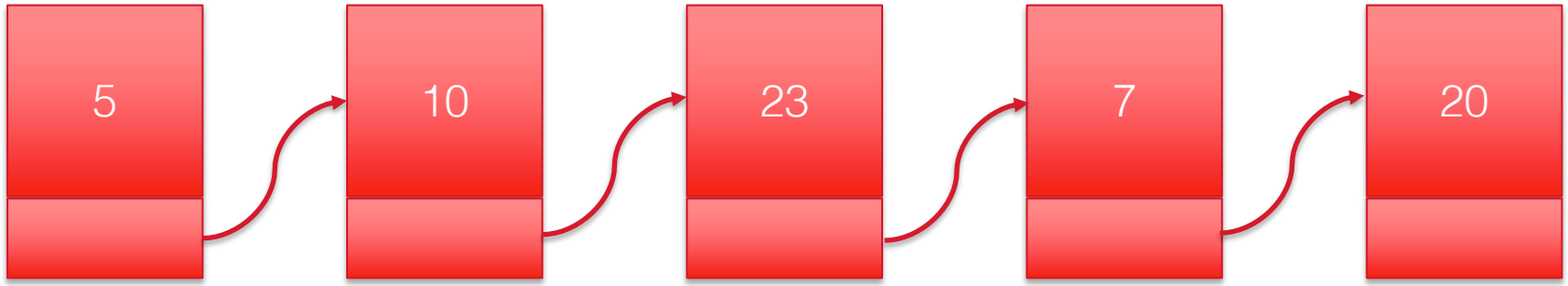


LISTS AND LINKED DATA STRUCTURES

- Lists use one of the following underlying structures:
  - An array of elements

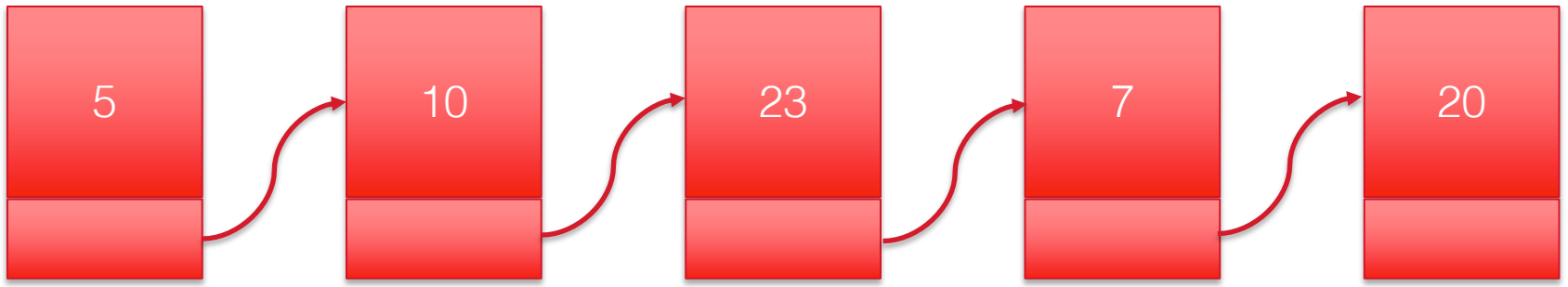


  - A collection of linked objects, each storing one element, and one or more references to other elements



LINKED LIST

- A collection of linked objects, each storing one element, and one or more references to other elements

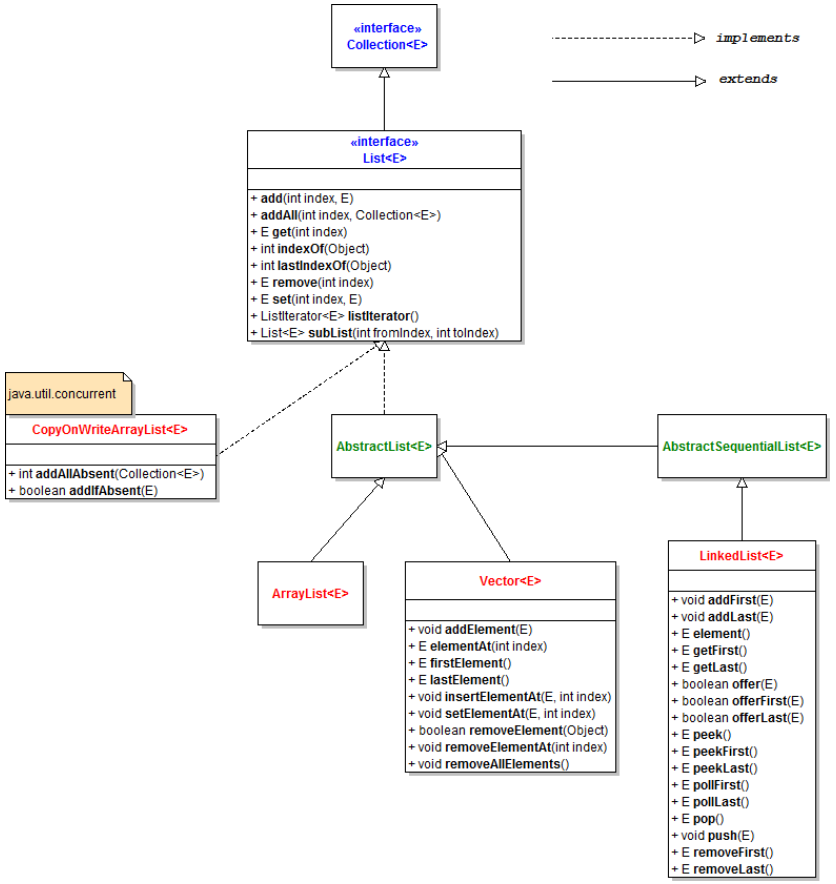


ARRAYLIST VS. LINKED LIS

- List - a collection of elements with 0-based indexes
  - Elements can be added to the front, back, or in the middle
  - Can be implemented as an ArrayList or as a LinkedList

  - What is the complexity of adding an element to the front of an:
    - ArrayList?
    - LinkedList?

JAVA LIST API



[Pictures credit: http://www.codejava.net]

- `List<E>` - the base interface
- Abstract subclasses:
  - `AbstractList<E>`
  - `AbstractSequentialList<E>`
- Concrete classes:
  - `ArrayList<E>`
  - `LinkedList<E>`
  - `Vector<E>` (legacy collection)
  - `CopyOnWriteArrayList<E>` (class under java.util.concurrent package)
- Main methods:
  - `E get(int index);`
  - `E set(int index, E newValue);`
  - `Void add(int index, E x);`
  - `Void remove(int index);`
  - `ListIterator<E> listIterator();`

JAVA LIST API

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- Concrete classes:
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JAVA COLLECTIONS FRAMEWORK

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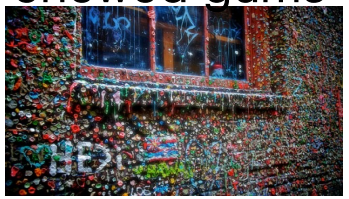
DATA COLLECTIONS

Collection of chewed gums



Collection of pens

Collection of cassette tapes

Collection of old radios

What is a data collection?

Shoes collection

Star wars collection

Cars collection

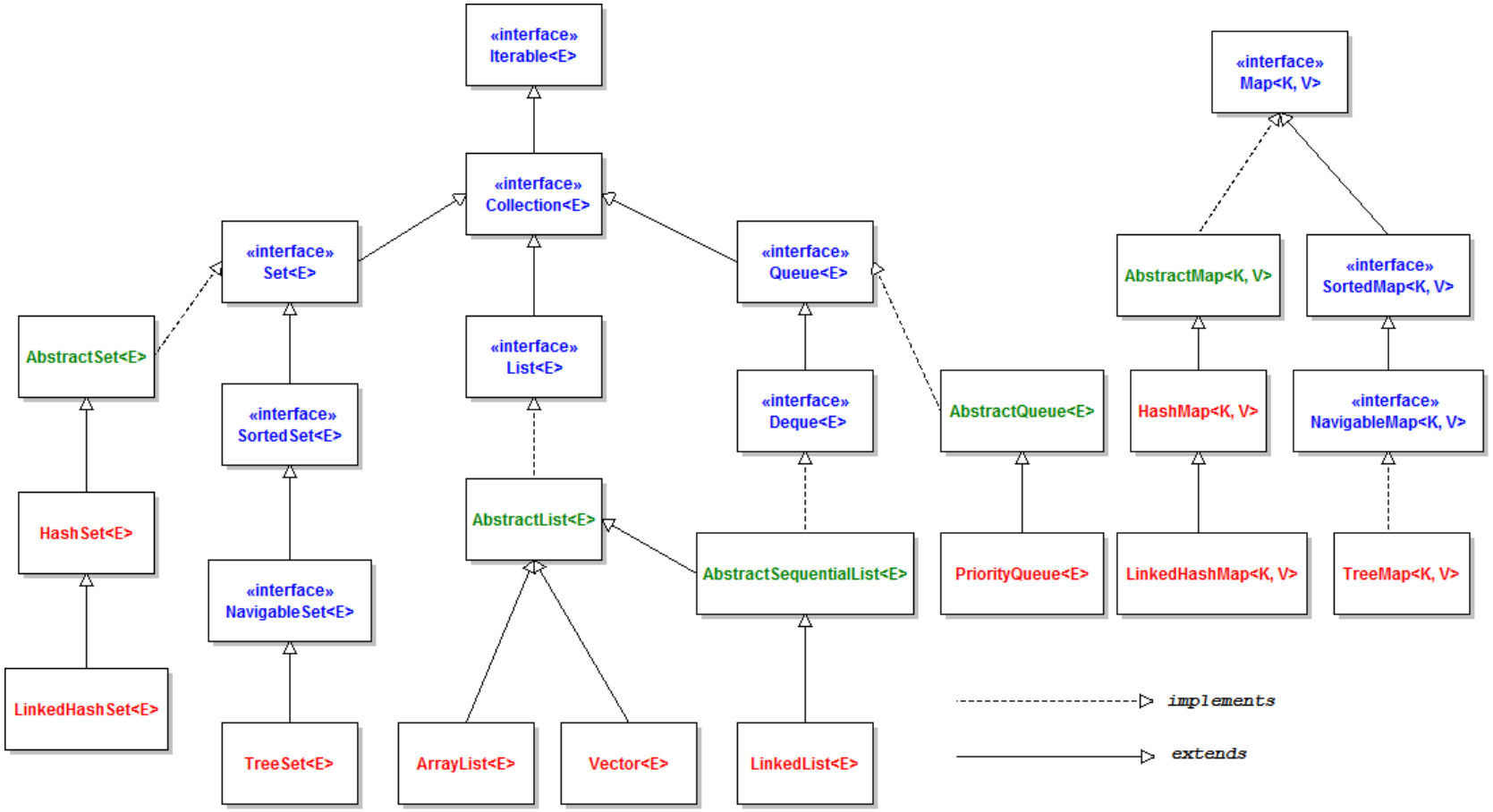
[Pictures credit: http://www.smosh.com/smosh-pit/articles/19-epic-collections-strange-things]

DATA COLLECTIONS?

- Data collection - an object used to store data (think data structures)
  - Stored objects called elements
  - Some typically operations:
    - `add()`
    - `remove()`
    - `clear()`
    - `size()`
    - `contains()`
- Some examples: ArrayList, LinkedList, Stack, Queue, Maps, Sets, Trees

Why do we need different data collections?

JAVA COLLECTIONS API



[Pictures credit: http://www.codejava.net]

JAVA COLLECTIONS FRAMEWORK

- Part of the `java.util` package

- Interface `Collection<E>`:
  - Root interface in the collection hierarchy
  - Extended by four interfaces:
    - `List<E>`
    - `Set<E>`
    - `Queue<E>`
    - `Map<K,V>`
  - Extends interface `Iterable<T>`

STACK ADT

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JAVA CLASS STACK

`Stack <E> ()`	Object constructor – constructs a new stack with elements of type E
`push(value)`	Places given value on top of the stack
`pop()`	Removes top value from the stack, and returns it. Throws `EmptyStackException` if the stack is empty.
`peek()`	Returns top value from the stack without removing it. Throws EmptyStackException if the stack is empty.
`size()`	Returns the number of elements on the stack.
`isEmpty()`	Returns true if the stack is empty.

- Example:

```
Stack<String> s = new Stack<String>();
s.push("Hello");
s.push("PDP");
S.push("Fall 2017"); //bottom ["Hello", "CS 5004", "Spring 2020"] top
System.out.println(s.pop()); //Spring 2020
```

QUEUE ADT

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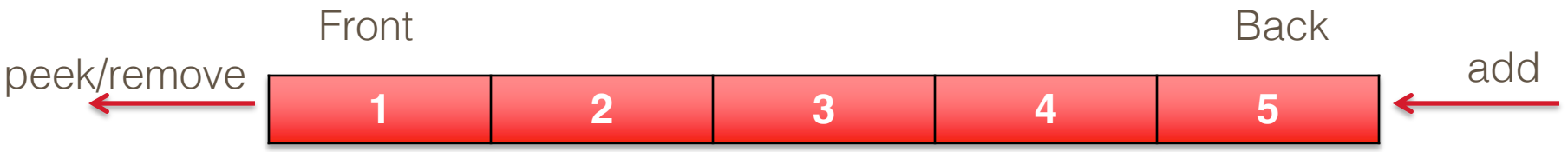
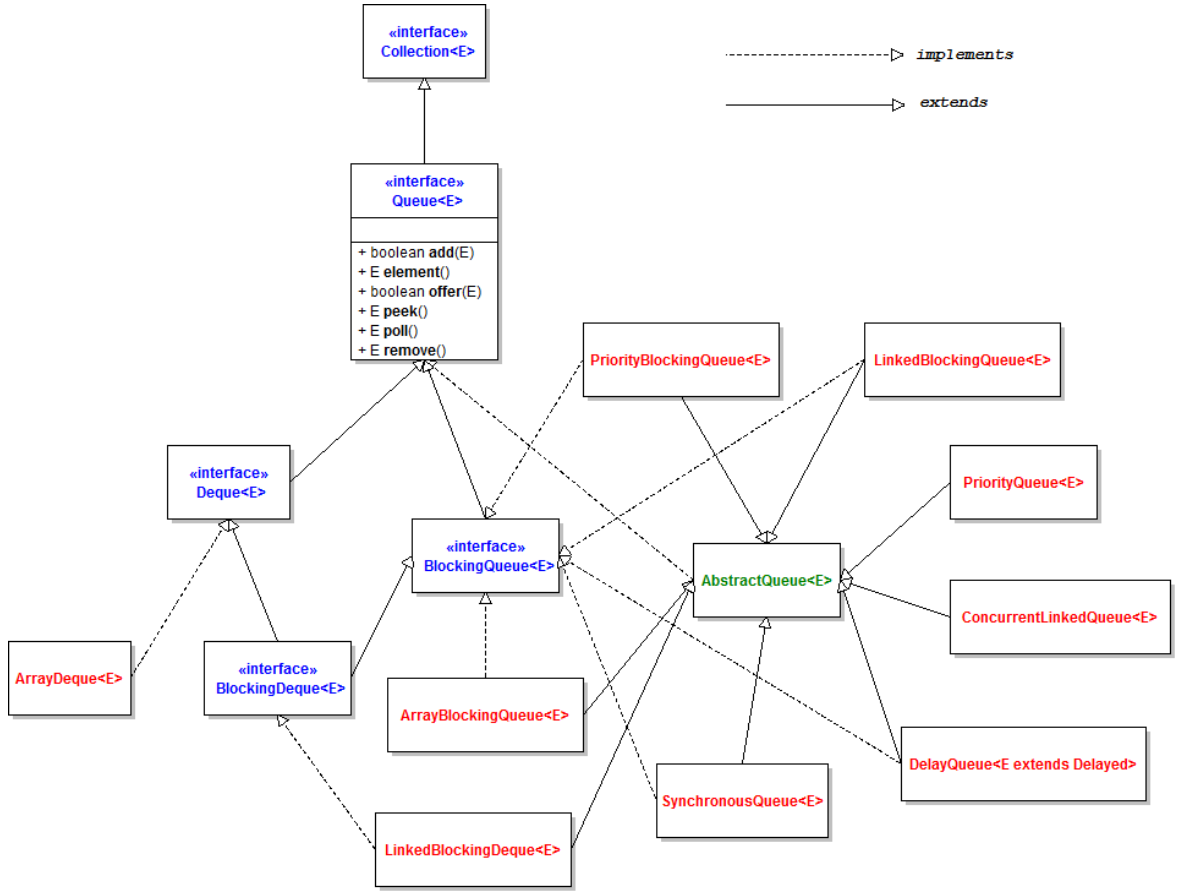
WHAT IS A QUEUE?

- Queue – a data collection that retrieves elements in the FIFO order (first in, first out)
  - Elements are stored in order of insertion, but don't have indexes
    - Client can only:
      - Add to the end of the queue,
      - Examine/remove the front of the queue

- Basic queue operations:
  - `Add (enqueue)` - add an element to the back of the queue
  - `Peek` - examine the front element
  - `Remove (dequeue)` - remove the front element



CLASS DIAGRAM OF THE QUEUE API



[Pictures credit: http://www.codejava.net/java-core/collections/class-diagram-of-queue-api]

JAVA INTERFACE QUEUE

`add(value)`	places given value at back of queue
`remove()`	removes value from front of queue and returns it; throws a `NoSuchElementException` if queue is empty
`peek()`	returns front value from queue without removing it; r eturns `null` if queue is empty
`size()`	returns number of elements in queue
`isEmpty()`	returns `true` if queue has no elements

- Example:

```
Queue<Integer> myQueue = new LinkedList<Integer>();
myQueue.add(10);
myQueue.add(18);
myQueue.add(2017); // front [10, 18, 2017] back
System.out.println(myQueue.remove()); // 10
```

DEQUE ADT

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DEQUE

[Pictures credit: http://www.java2novice.com/data-structures-in-java/queue/double-ended-queue/]

DEQUE

	First Element (Head)	
	Throws exception	*Special value*
Insert	`addFirst(e)`	`offerFirst(e)`
Remove	`removeFirst()`	`pollFirst()`
Examine	`getFirst()`	`peekFirst()`

	Last Element (Tail)	
	Throws exception	*Special value*
Insert	`addLast(e)`	`offerLast(e)`
Remove	`removeLast()`	`pollLast()`
Examine	`getLast()`	`peekLast()`

[Pictures credit:https://docs.oracle.com/javase/7/docs/api/java/util/Deque.html

DEQUE

Queue Method	Equivalent Deque Method
add(e)	addLast(e)
offer(e)	offerLast(e)
remove()	removeFirst()
poll()	pollFirst()
element()	getFirst()
peek()	peekFirst()

[Pictures credit:https://docs.oracle.com/javase/7/docs/api/java/util/Deque.html

DEQUE

Stack Method	Equivalent Deque Method
`push(e)`	`addFirst(e)`
`pop()`	`removeFirst()`
`peek()`	`peekFirst()`

SET ADT

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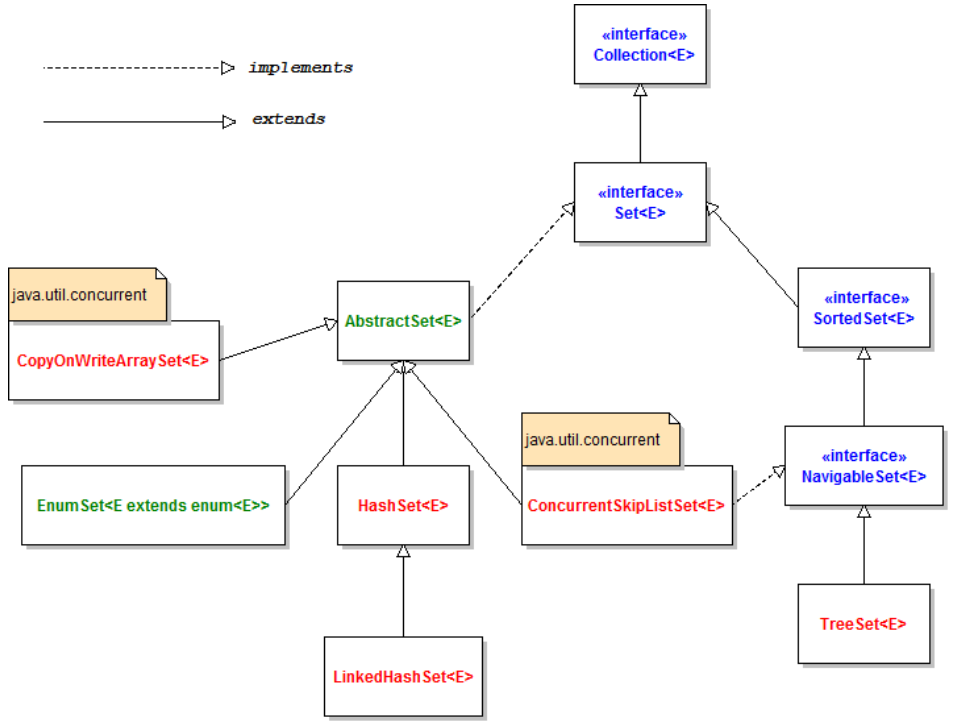
SET

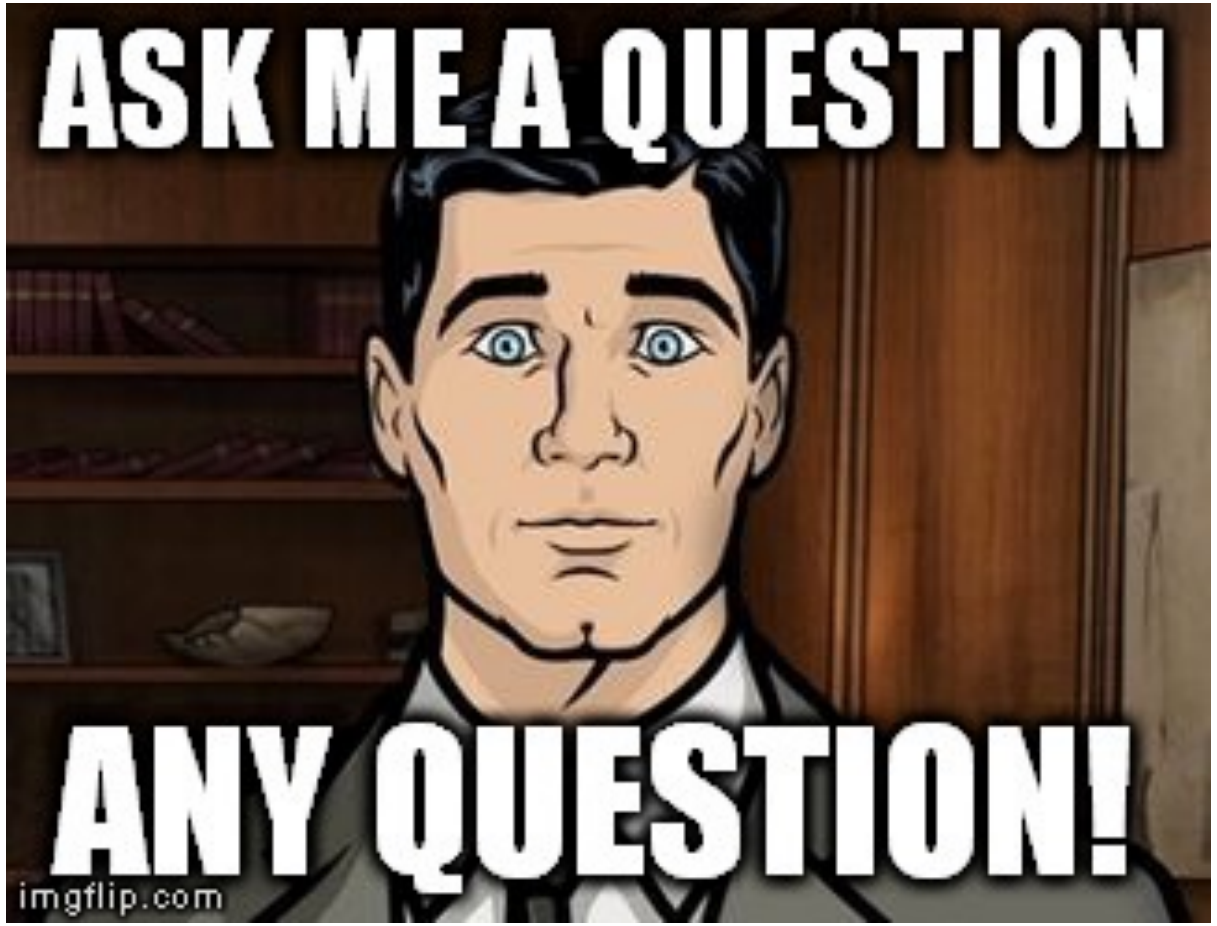
- Set - a collection of unique values (no duplicates allowed) that can perform the following operations efficiently:
  - `add`,
  - `remove`,
  - `search (contains)`
- We don't think of a set as having indexes; we just add things to the set in general and don't worry about order

SET API CLASS DIAGRAM



[Pictures credit:
http://www.codejava.net/images/articles/javacore/collections/Set%20API%20class%20diagram.png]

YOUR QUESTIONS



[Meme credit: imgflip.com]

REFERENCES AND READING MATERIAL

- Java Getting Started (https://docs.oracle.com/javase/tutorial/getStarted/index.html)
- Object-Oriented Programming Concepts (https://docs.oracle.com/javase/tutorial/java/concepts/index.html)
- Language Basics (https://docs.oracle.com/javase/tutorial/java/nutsandbolts/index.html)
- How to Design Classes (HtDC), Chapters 1-3
- JUnit: Getting Started (https://github.com/junit-team/junit4/wiki/Getting-started)
- JUnit: Assertions (https://github.com/junit-team/junit4/wiki/Assertions)
- Unit testing with JUnit: http:/www.vogella.com/tutorials/JUnit/article.html
- Java Tutorial: Interfaces and Inheritance: https://docs.oracle.com/javase/tutorial/java/IandI/index.html
- Java – Exceptions (https://www.tutorialspoint.com/java/java_exceptions.htm)
- Declare Your Own Exception (https://www.ibm.com/developerworks/community/blogs/738b7897-cd38-4f24-9f05-48dd69116837/entry/declare_your_own_java_exceptions?lang=en)