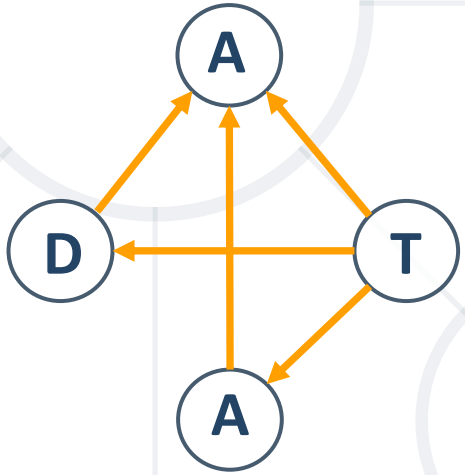
Linear Data Structures

Static and Dynamic Implementation



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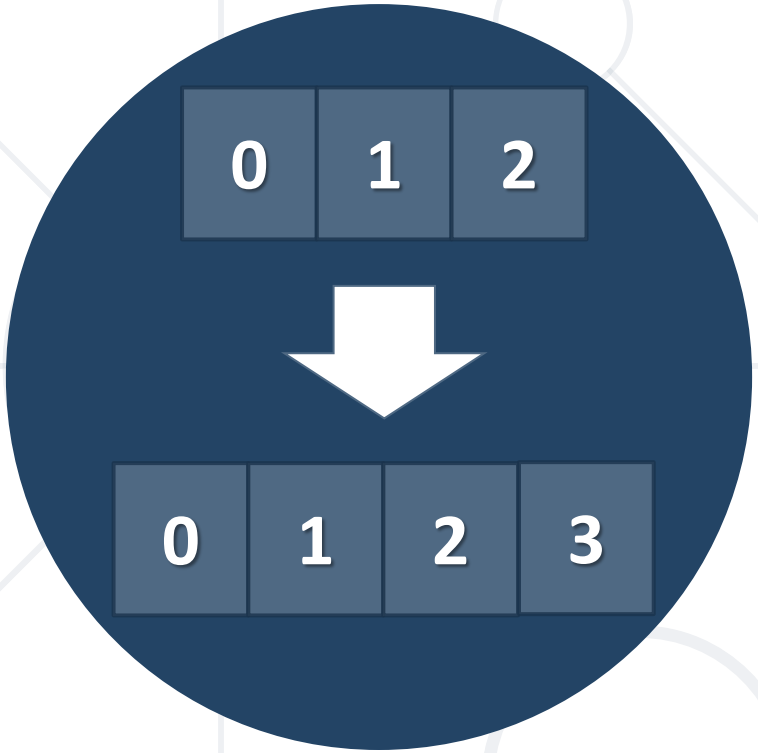


Dynamic Arrays

ArrayList

Dynamic Arrays – ArrayList

- ArrayList is the **implementation** of ADS **List**
  - Built **atop an array**, which is able to dynamically **grow** and **shrink** as you **add/remove** elements
- Stores the **elements** inside an array

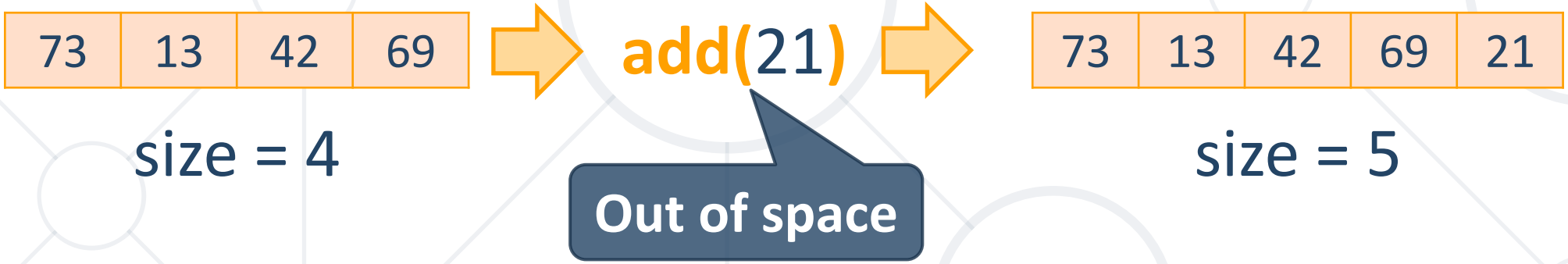
```
public class ArrayList<E> implements List<E> {
    private Object[] elements;
}
```

ArrayList - Operations

- Supported operations and complexity:
  - **size()**, **isEmpty()**, **get()**, **set()** – **O(1)**
  - **add()** – the operation runs in **amortized constant** time
  - adding **n** elements requires **O(n)** time
  - all of the other operations like: **add(int index, E element)**, **contains()**, **indexOf()**, **remove(int index) etc.**, run in **linear time O(n)** (roughly speaking)

ArrayList – Add O(n)

- Implemented **using an array**
- Adding **new item** requires **new array**



- This approach will copy **all the elements** for each add operation – **O(n)**

ArrayList – Add O(1)

- Implemented **using an array**
- When **adding**, if needed **double** the size

- This approach will copy at **log(n)** → n = 10^9, only ~33 copies – **O(1) amortized**

Problem: ArrayList

- Create an **ArrayList<E>** data structure, which supports
  - boolean **add**(T element)
  - E **get**(int index)
  - E **set**(int index, E elements)
  - E **remove**(int index)
  - int **size**()
  - int **indexOf**(E element)
  - etc…

ArrayList – Constructor And Fields

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- Constructor and fields:

```
public class ArrayList<E> implements List<E> {
    private static final int DEFAULT_CAPACITY = 4;
    private Object[] elements;
    private int size;

    public ArrayList() {
        this.elements = new Object[DEFAULT_CAPACITY];
    }
}
```

ArrayList – Add

- Adds an element after the last element:

```
public boolean add(E element) {
    if(this.size == this.elements.length) {
        this.elements = grow();
    }
    this.elements[this.size++] = element;
    return true;
}
```

ArrayList – Get

- Returns an element at index:

```
public E get(int index) {
    checkIndex(index);
    return this.getElement(index);
}

private E getElement(int index) {
    return (E) this.elements[index];
}
```

ArrayList – Set

- Sets an element at index:

```
public E set(int index, E element) {
    checkIndex(index);
    E oldElement = this.getElement(index);
    this.elements[index] = element;
    return oldElement;
}
```

ArrayList – Remove

- Removes and returns an element at index:

```
public E remove(int index) {
    this.checkIndex(index);
    E element = this.getElement(index);
    this.elements[index] = null;
    this.size--;
    shift(index);
    ensureCapacity();
    return element;
}
```

ArrayList – Grow and Shrink

- Helper methods to sustain correct array behaviour:

```
private Object[] grow() {
    return Arrays.copyOf(this.elements, this.elements.length * 2);
}

private Object[] shrink() {
    return Arrays.copyOf(this.elements, this.elements.length / 2);
}
```

ArrayList – Other Operations

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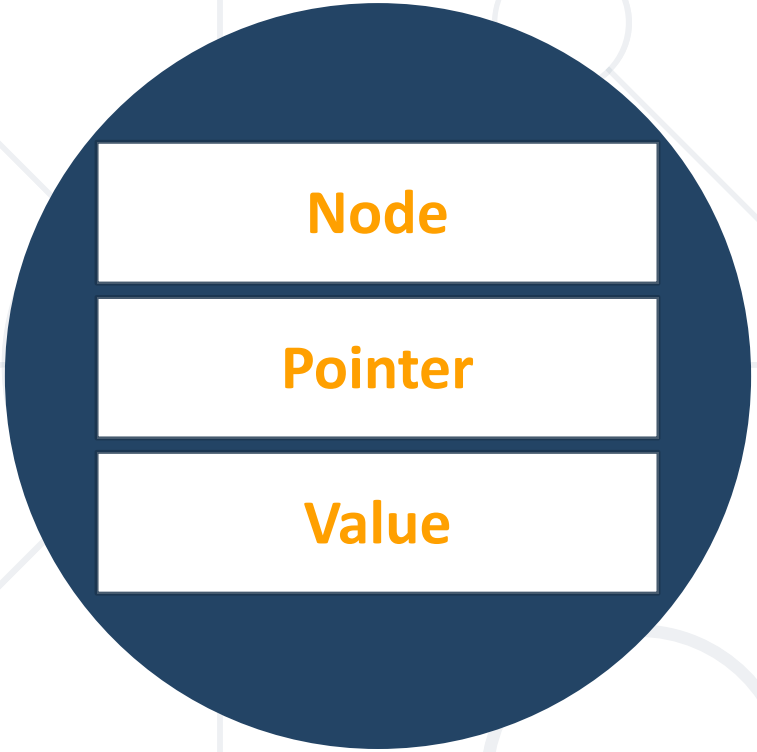
- **indexOf**(E element) – returns the **zero** based index of an element or **-1**
- **contains**(E element) – returns **whether** an element is present
- **size**() – returns the **number** of elements
- **toArray**() – returns the elements **as an array**
- Implement other operations – think about the complexity



Nodes

Building Block

Node Class

- The **Node** class is the **build block** for many data structures
- Inside Node object we store **an element and pointer to the next node at least**
- However, we **can store anything else**

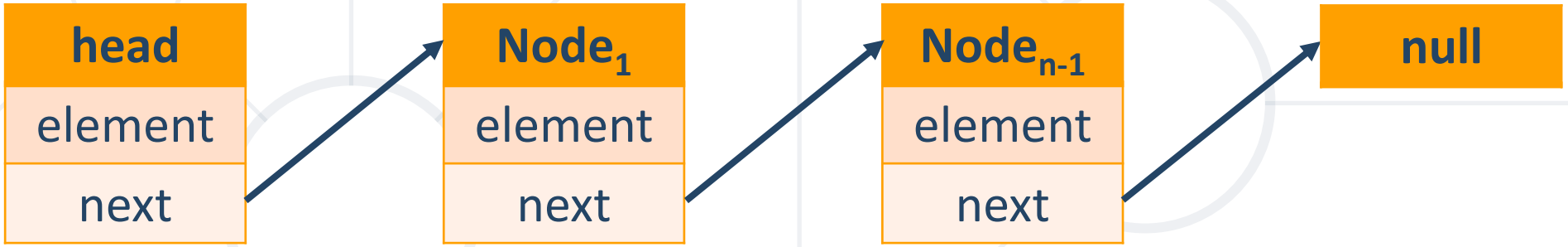
```
private static class Node<E> {
    private E element;              // Must have
    private Node<E> next;           // Must have
    private Node<E> previous;       // Additional
}`
```

Node - Application

- Many data structures use **node chaining**

```
public class LinkedList<E> implements Deque<E> {
    private Node<E> head;

}
```



Problem: Node

- Create a class **Node<E>**, that has:
  - **E** element
  - **Node**<E> next
  - **Constructor**

```
private static class Node<E> {
    private E element;
    private Node<E> next;

    public Node(E value) {
        this.element = value;
    }
}
```

Stacks

Dynamic Implementation

Stack

- Stack is the **implementation** of ADS **LIFO**
  Last **I**n **F**irst **O**ut
  - Build by using **Node** class or atop an **array**
- Stack example using Node

```
public class Stack<E> implements AbstractStack<E> {
    private Node<E> top;
    private int size;

}
```

Stack - Operations

- Supported operations and complexity:
  - **size**(), **isEmplty**(), **push**(), **pop**(), **peek**() – **O(1)**
  - all of the other operations run in linear time (roughly speaking):
    - **forEach**()
    - **contains**()
    - etc…

Stack – Constructor And Fields

- Constructor and fields:

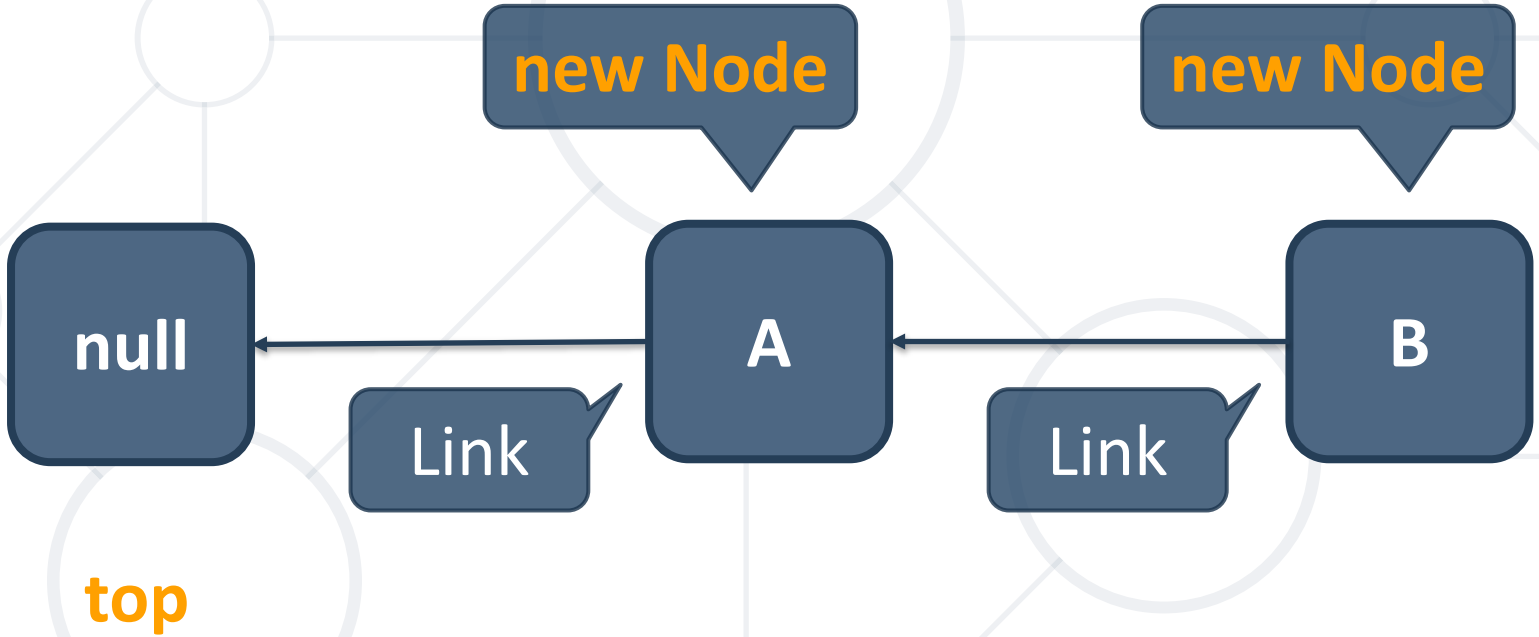
```
public class Stack<E> implements AbstractStack<E> {
    private Node<E> top;
    private int size;

    private static class Node<E> {...}   // Node class

    public Stack() {
    }
}
```

Stack – Push

- Chain the nodes by using the **top** field:



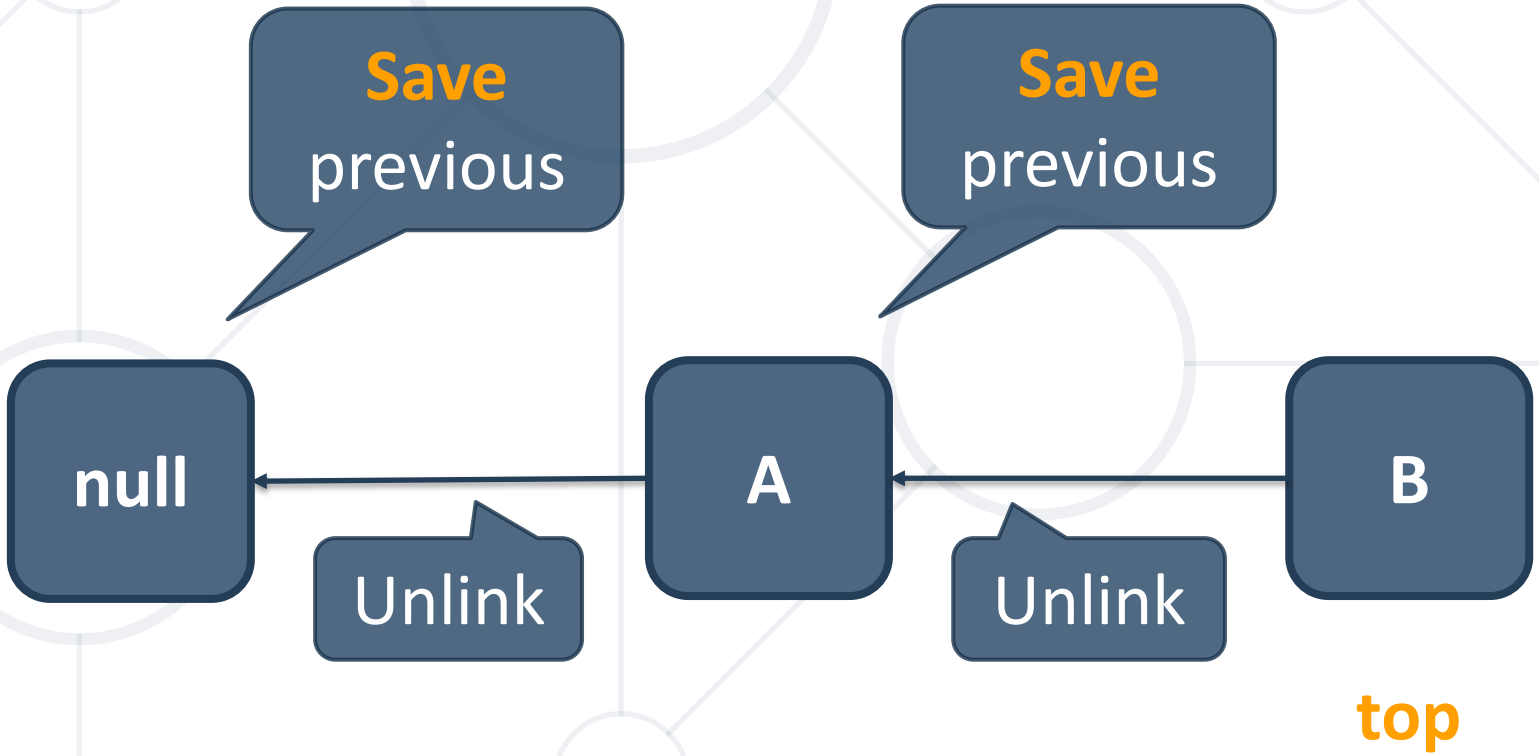
Stack – Push

- Add element at the top
  - **Link** the nodes and **increment** size

```
public void push(E element) {
    Node<E> newNode = new Node<>(element);
    newNode.previous = top;
    top = newNode;
    this.size++;
}
```

Stack – Pop

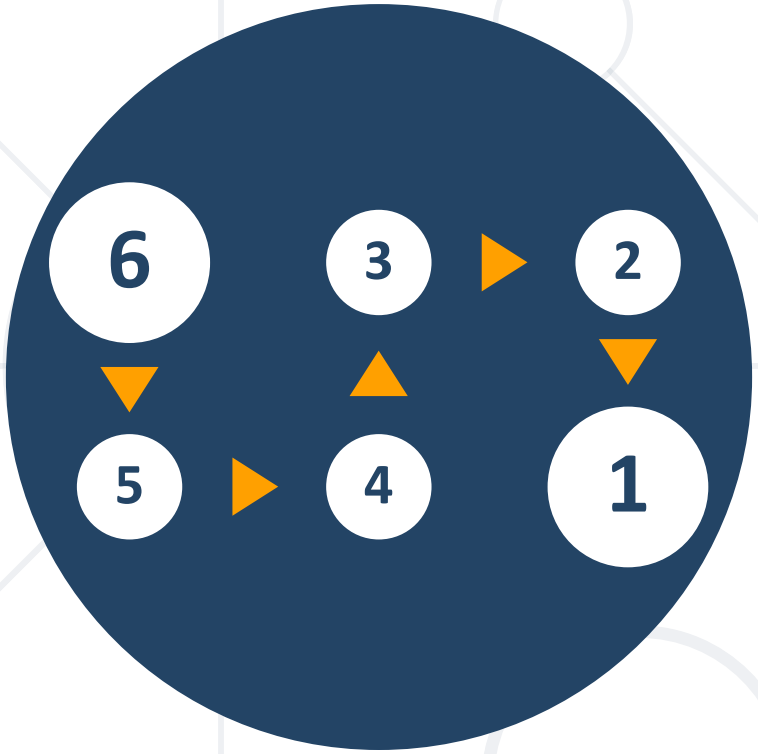
- Remove the **top** Node and return the element
  - **Unlink** the nodes and **decrease** size



Stack – Pop

- Remove and return element at the top:

```
public E pop() {
    ensureNonEmpty();
    E element = this.top.element;
    Node<E> temp = this.top.previous;
    this.top.previous = null;
    this.top = temp;
    this.size--;
    return element;
}
```



Queues

Dynamic Implementation

Queue

- Queue is the **implementation** of ADS **FIFO**
  First **I**n **F**irst **O**ut
  - Build by using **Node** class or atop an **array**
- Queue example using Node

```
public class Queue<E> implements AbstractQueue<E> {
    private Node<E> head;
    private int size;
}
```

Queue - Operations

- Supported operations and complexity:
  - **size**(), **isEmplty**(), **poll**(), **peek**() – **O(1)**
  - **offer**():
    - if we keep the reference to the that node – **O(1)**
    - If we have to chase pointers to that node – **O(n)**
  - all of the other operations run in linear time (roughly speaking):
    - **forEach**(), **contains**(), etc…

Queue – Constructor And Fields

- Constructor and fields:

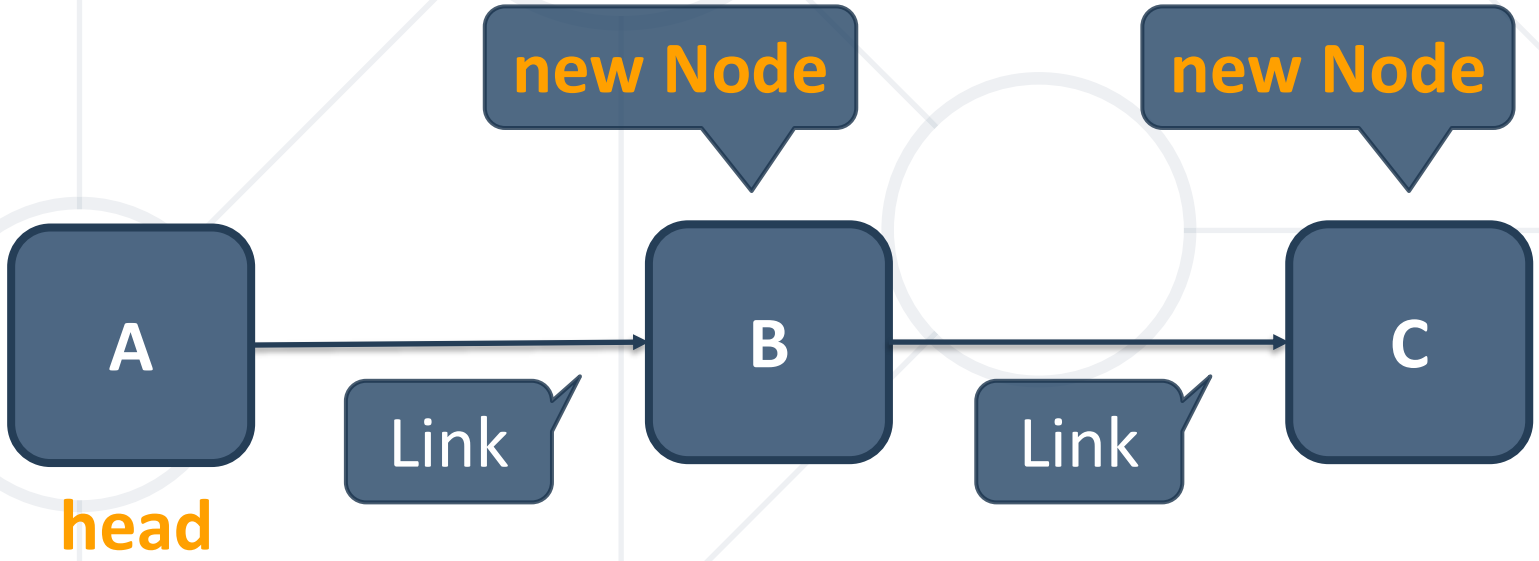
```
public class Queue<E> implements AbstractQueue<E> {
    private Node<E> head;
    private int size;

    private static class Node<E> {...}   // Node class

    public SimpleQueue() {
    }
}
```

Queue – Offer

- Head == null → head = **new Node**
- Size > 0 → chain the nodes by adding **new Node** after the last one the so called **tail**:



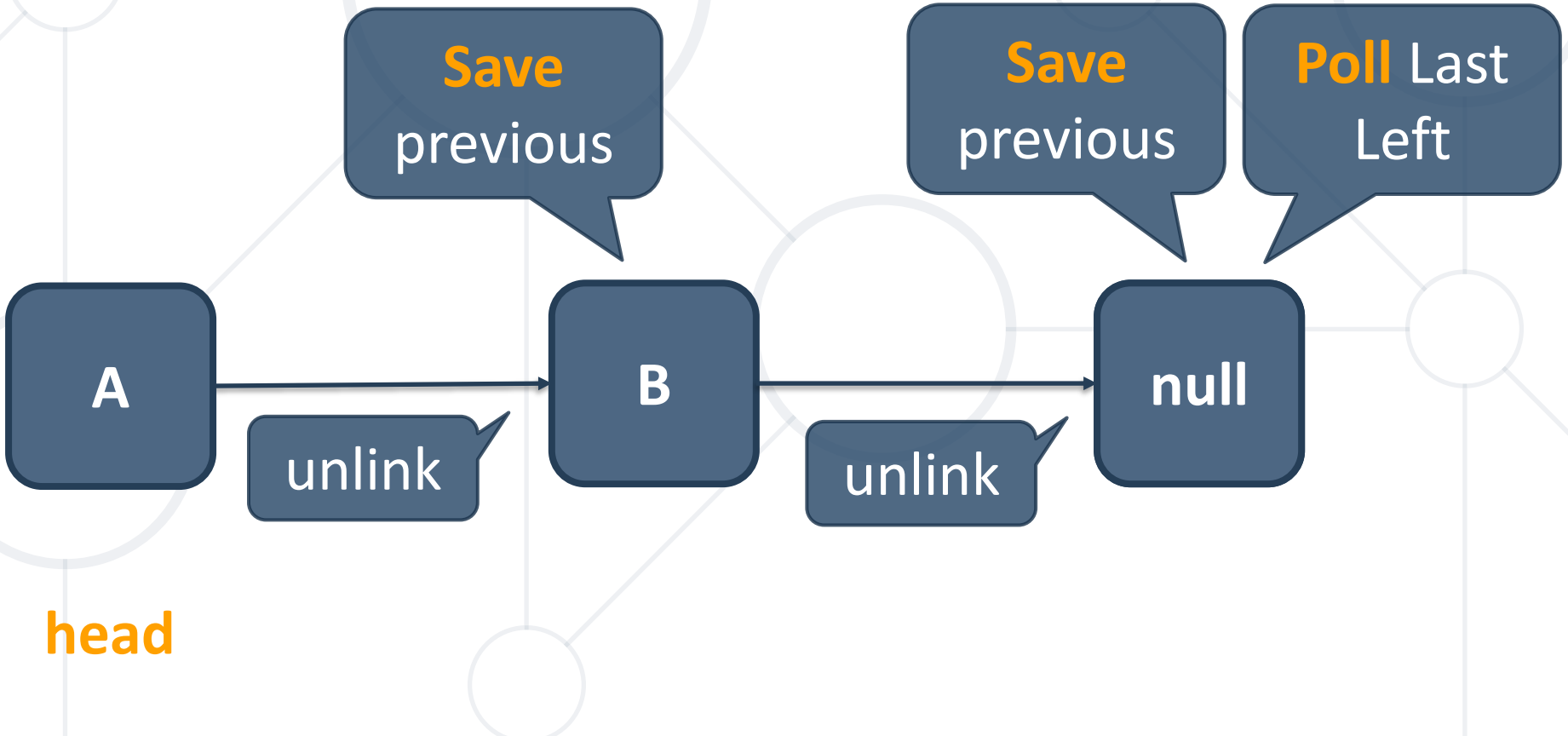
Queue – Offer

- Add element at the end – **Link** the nodes and **increase** size

```
public void offer(E element) {
    Node<E> newNode = new Node<>(element);
    if (this.head == null) {
        this.head = newNode;
    } else {
        Node<E> current = this.head;
        while (current.next != null) {
            current = current.next;
        }
        current.next = newNode;
    }
    this.size++;
}
```

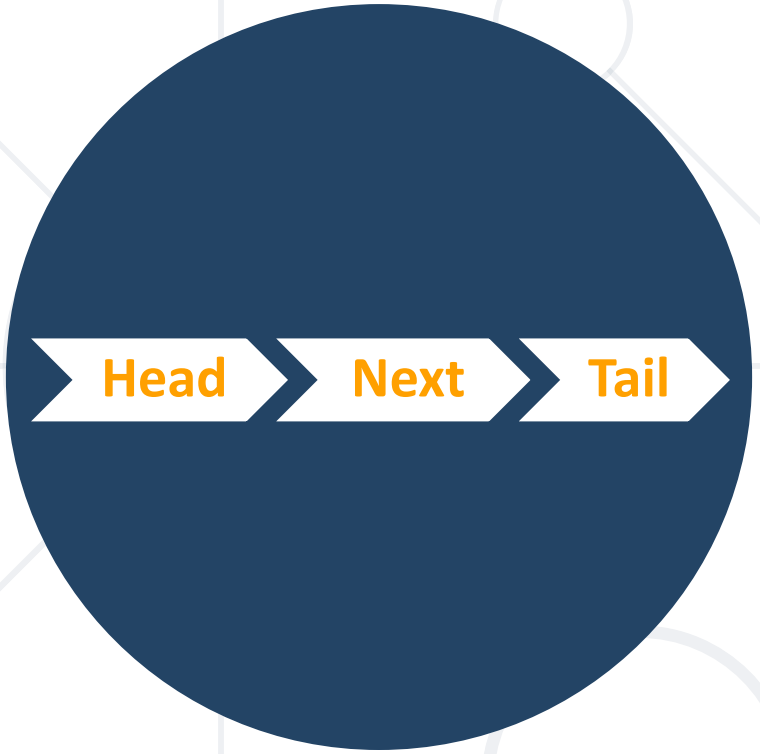
Queue – Poll

- Remove the **head** Node and return the element
  - **Unlink** the node and **decrease** size



Stack / Queue – Real-World Applications

- Stack
  - Undo operations
    - Browser history
    - Chess game progress
  - Math expression evaluation
  - Implementation of function (method) calls
  - Tree-like structures traversal (DFS algorithm)
- Queue
  - Operation system process scheduling
  - Resource sharing, e.g.:
    - Printer document queue
    - Server requests queue
  - Tree-like structures traversal (BFS algorithm)



Linked Lists

SinglyLinkedList

SinglyLinkedLists

- Linear data structure where each **element** is a **separate object** – **Node**
- The elements are **not** stored at **contiguous** memory
- The entry point is commonly the **head** of the list
- However we define what is the entry point

```
public class SinglyLinkedList<E> implements LinkedList<E> {
    private Node<E> head;
    private int size;
}
```

Singly Linked List – Operations

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- Supported operations and complexity:
  - **addFirst**(), **removeFirst**(), **getFirst**(), **size**() – **O(1)**
  - How about operations on the **last element**?
    - **addLast**(), **removeLast**(), **getLast**() – again depends if we keep the reference to the last node or no can be constant – **O(1)** or linear – **O(n)**
  - operations that **index** into the list will run in **linear time O(n)** (roughly speaking)

Singly LinkedList – Constructor And Fields

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- Constructor and fields:

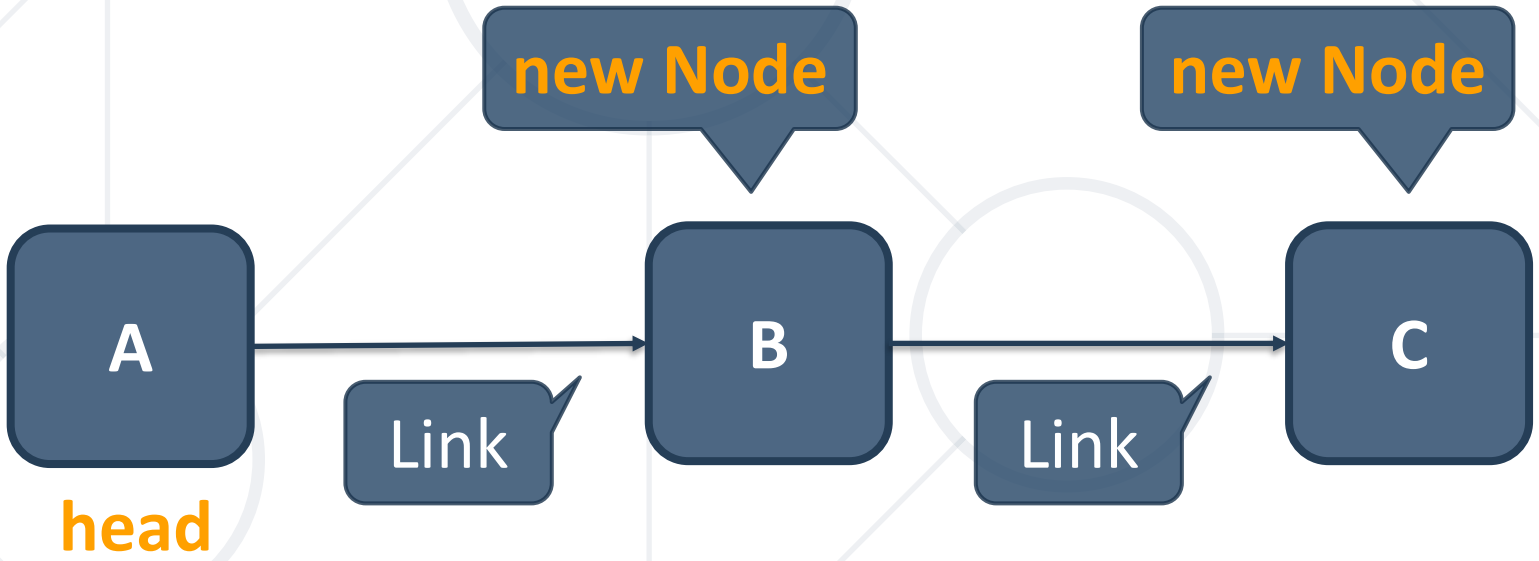
```
public class SinglyLinkedList<E> implements LinkedList<E> {
    private Node<E> head;
    private int size;

    private static class Node<E> {...}   // Node class

    public LinkedList() {
    }
}
```

Singly Linked List – Adding Last

- Head == null → head = new Node
- Size > 0 →



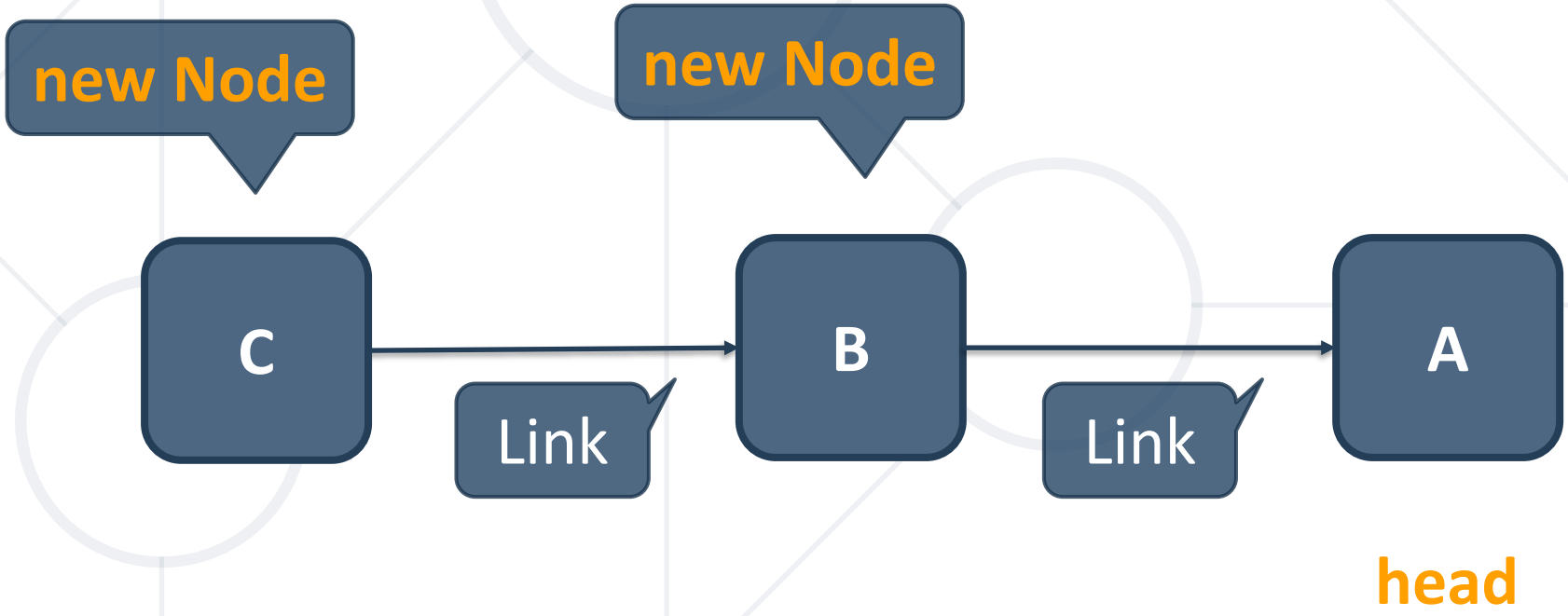
LinkedList – Add Last

- Add element at the end:

```
public void addLast(E element) {
    Node<E> newNode = new Node<>(element);
    if (this.head == null) {
        this.head = newNode;
    } else {
        Node<E> current = this.head;
        while (current.next != null) {
            current = current.next;
        }
        current.next = newNode;
    }
    this.size++;
}
```

Singly Linked List – Adding First

- Head == null → head = new Node
- Size > 0 →



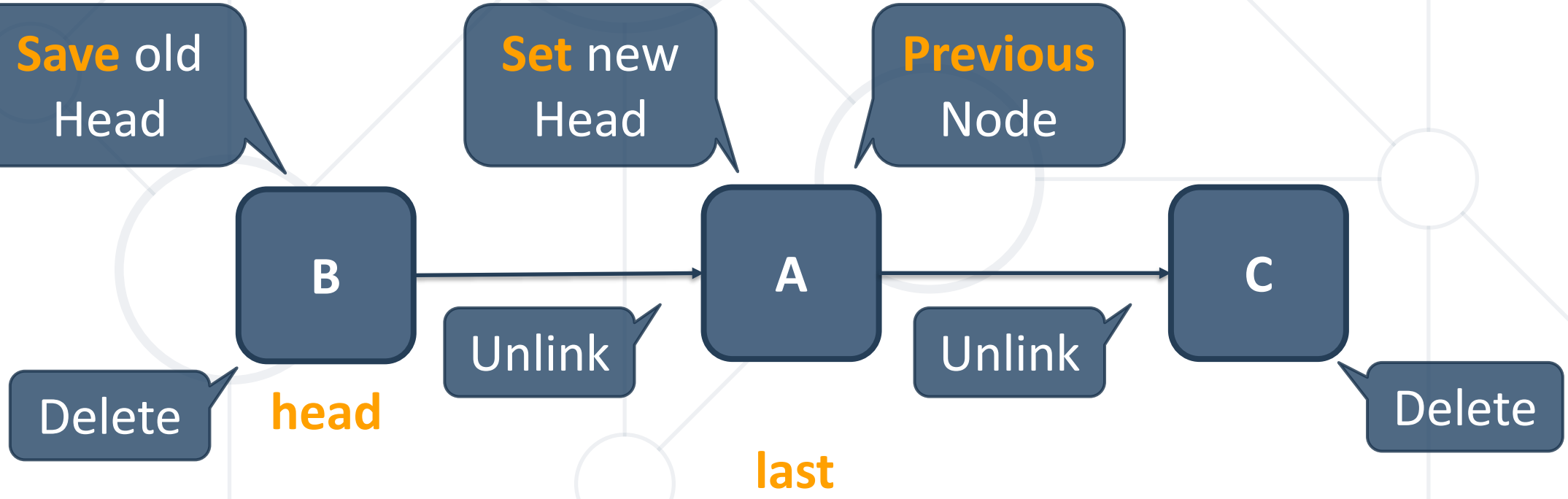
LinkedList – Add First

- Add element at the beginning:

```
public void addFirst(E element) {
    Node<E> newNode = new Node<>(element);
    if (this.head != null) {
        newNode.next = this.head;
    }
    this.head = newNode;
    this.size++;
}
```

Linked List – Removing First/Last

- Size == 0 → Do Nothing / Throw Exception
- Size == 1 → head = null
- Size > 1



Node Implementation

- So far we have implemented some Data Structures by using the **Node class properties**. However the way we did it **introduces** some **performance problems** when **chaining** nodes.
- **Can** we **solve** them?
- Add/Remove/Get in **constant time**?
- We will try to **understand** and **solve** those **problems** at the exercise.

Summary

- Stack is **LIFO** structure (**L**ast **I**n **F**irst **O**ut)
  - Linked implementation is pointer-based
- Queue is **FIFO** (**F**irst **I**n **F**irst **O**ut) structure
  - Linked implementation is pointer-based
- SinglyLinkedList
  - Linked implementation is pointer-based

Questions?

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