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Introduction to Computer Science,
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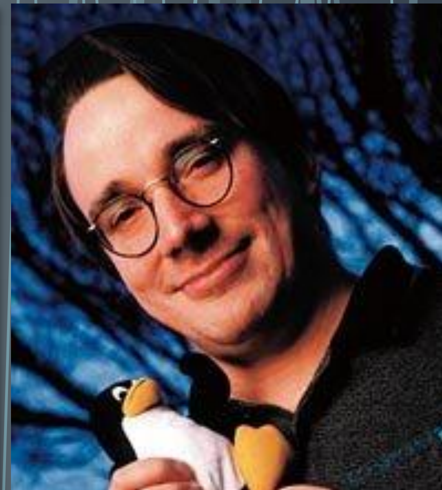
IDC Herzliya

Introduction to Data Structures

"Bad programmers worry about the code. Good programmers worry about data structures and their relationships.". - Linus Torvalds, 2006



Agenda

- Background theory, recap
  - Why data structures
  - Abstraction vs. Implementation
  - How to choose our data structure
  - Data structure characteristics
  - Linked list
- Exercise: “Barnes & Noble”:
  - Array implementation
  - Linked list implementation
- LinkedList.addElement depiction
- Queue
  - Array implementation
  - Linked list implementation
- Summary

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Why data structures?

- In order to develop an application or feature, we consider:
  - UI and I/O
  - Algorithm
  - Data handling
- Arrays are a simple data structure: linear, homogenous, direct access.
- These traits are sometimes very limiting and inefficient;
  - We can't define relations between elements, memory allocation is not dynamic, all the cells look the same, etc..
- **We write our own data structures to achieve better flexibility and efficiency**

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Abstraction vs. implementation

- Abstraction
  - What we want the data structure to do
- Implementation
  - How it should be done

Abstraction	Implementation
Stack	Array
Stack	Linked list
Stack.pop()	return array[--size];

Stack.pop()	temp = head;
	head = head.next;
	return head;

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How to choose our data structure

- We need to choose:
  - Data types and their relationships
  - Data structure
- Choosing data types is an OO task.
- To choose a data structure, ask these questions:
  - How dynamic is the collection?
  - According to what will we want to add/retrieve elements?
  - What are the performance requirements for adding/retrieving elements?

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Data structure characteristics

Data structure	Characteristics
Array	Static size, direct access
Linked list	Dynamic size, iterative
Stack	LIFO, access only to last
Queue	FIFO, access only to first
Graph	n:n relationships
Tree	1:n relationships
Hash, dictionary, maps, …	Future

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Linked list

- One of the most basic data structures
- The principal:
  - Keep only a reference to the first element (‘head’)
  - Each element points to the next one
  - The last element points to null
- Dynamic size:
  - Grows when adding elements, shrinks when removing elements
  - Unlimited number of elements
  - To add an element, “play” with references
- No direct access:
  - To get to an element, start with the head and iterate the entire collection

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Linked list abstraction (partial list)

Depending on your encapsulation design, the abstraction may work either with Data or directly with Element.

- `void isEmpty()`
- `void insertAtBeginning(Element element)`
- `void append(Element element)`
- `Element getFirst()`
- `Element getLast()`
- `Element getElement(Data data)`
- `void clear()`

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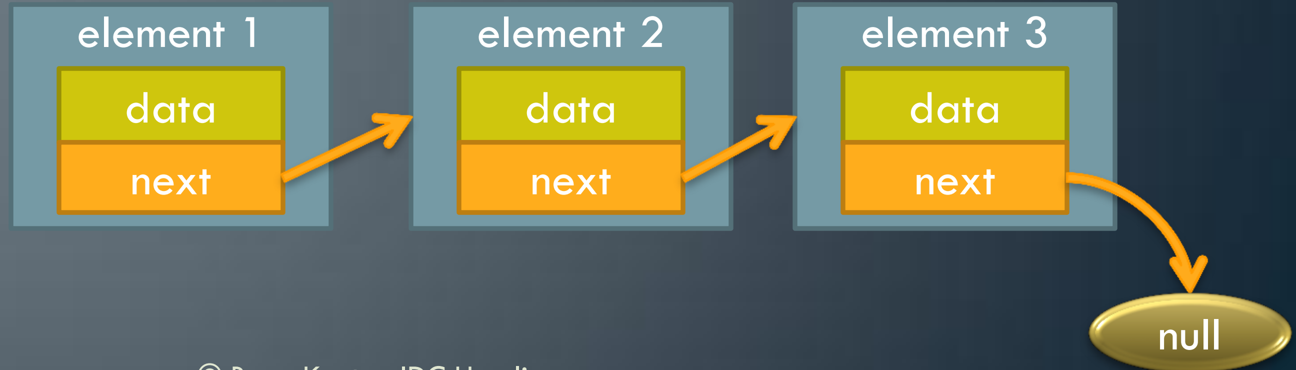
```
class ListElement {
        private SomeType data;
        private ListElement next = null;
        // constructors
        // 'data' setters and getters
        // 'next' setters and getters
}
```



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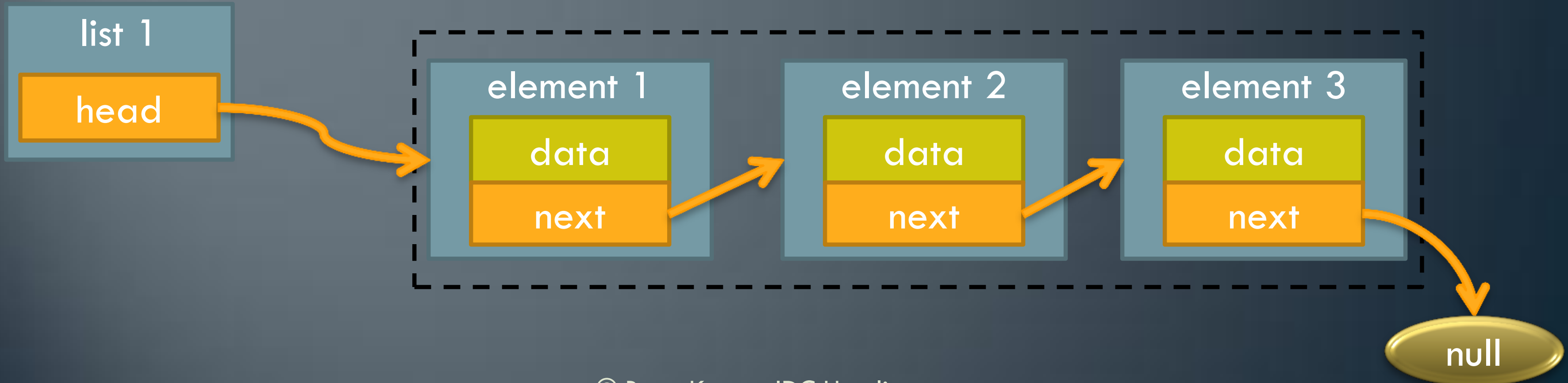
```
class LinkedList {
        private ListElement head = null;
        // is the list empty?
        // add element (to beginning, end, or anywhere)
        // remove element
        // get first/last/specific element
}
```



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BARNES & NOBLE
BOOKSELLERS
www.bn.com

Exercise

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- Exercise: “Barnes & Noble” has asked you to rewrite their ordering system (they’re paying a lot).
- They want to provide you with book orders. You need to keep these orders.
- Their storage manager wants to retrieve the orders, oldest order first, so they can process the order and deliver the books.
- Plan:
  - Provide both users with a book orders data type.
  - Provide B&N with an interface for adding orders.
  - Provide the storage manager with an interface for getting the next order.

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Step 1, custom data type

Assume classes Book and Customer (provided by B&N)

```
public class BookOrder {
	private Book book = null;
	private Customer customer = null;
	// constructors, setters and getters
}
```

Step 1.1: implement.

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Step 2, SDK for B&N and storage manager

```
public class OrdersCollection {

    // adds an order to the collection
    public void addOrder(BookOrder order)

    // returns and removes the oldest order
    public BookOrder getNextOrder()
}
```

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Step 3, implementation

```
// in this implementation, the oldest order is at the end of the array
public class OrdersCollection {
        private static final int MAX_ORDERS = 50000;
        private BookOrder[] orders = new BookOrder[MAX_ORDERS];
        private int numberOfOrders = 0;

        // adds an order to the collection
        public void addOrder(BookOrder order) {
                orders[numberOfOrders++] = order;
        }

        // returns and removes the oldest order
        public BookOrder getNextOrder() {
        // see next slide..
```

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Step 3, implementation (cont'd)

```
// returns and removes the oldest order
public BookOrder getNextOrder() {
       BookOrder order = orders[0];

       // shift all orders one cell to the left
       System.arraycopy(orders, 1,
                        orders, 0,
                        numberOfOrders);

       numberOfOrders--;
       return order;
}
```

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Implementing with Linked List

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Our list element

- Remember:
  - The list holds a reference only to the head.
  - Each element references the next one.
- This means that our data type is not good enough (no ‘next’ member)
- We have two options:

1. Add a ‘next’ field to our existing class (convert BookOrder to an element)
2. “Wrap” our existing class with an ‘element’ class.

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Option 1: converting to a list element

```
public class BookOrder {
    private Book book = null;
    private Customer customer = null;
    private BookOrder next = null;
    // constructors, getters and setters
}
```

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Option 2: wrapping with an element

```
public class BookOrder {
        private Book book = null;
        private Customer customer = null;
        // constructors, getters and setters
}

public class BookOrderElement {
        private BookOrder data;
        private BookOrderElement next;
        // constructors, getters and setters
}
```

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Which one is preferred?

- If we don't have access to the data type (if someone else is responsible for it), we have to use option #2.
- In order to use option #1, we have to redesign our class as a list element:
  - Name it BookOrderElement
  - Not expose it to customers, they don't care about elements.
- Option #2 is usually clearer and conforming with OOD.

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Linked list implementation (using option #2)

```
// in this implementation, the oldest order is at the beginning of the array
public class OrdersCollection {
	BookOrderElement head = null;

	// adds an order to the collection
	public void addOrder(BookOrder order) {
		BookOrderElement newOrder = new BookOrderElement(order);
		newOrder.setNext(this.head);
		head = newOrder;
	}

	// returns and removes the oldest order
	public BookOrder getNextOrder() {
	// see next slide..
}
```

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Linked list implementation (using option #2)

```
public BookOrder getNextOrder() {
        // TODO handle an empty list

        BookOrderElement previousElement = head;
        BookOrderElement currentElement = head;

        // TODO handle a special case where there is only one order in the list

        while (currentElement.getNext() != null) {
                previousElement = currentElement;
                currentElement = currentElement.getNext();
        }

        // remove the element from the list and return its data
        previousElement.setNext(null);
        return currentElement.getData();
}
```

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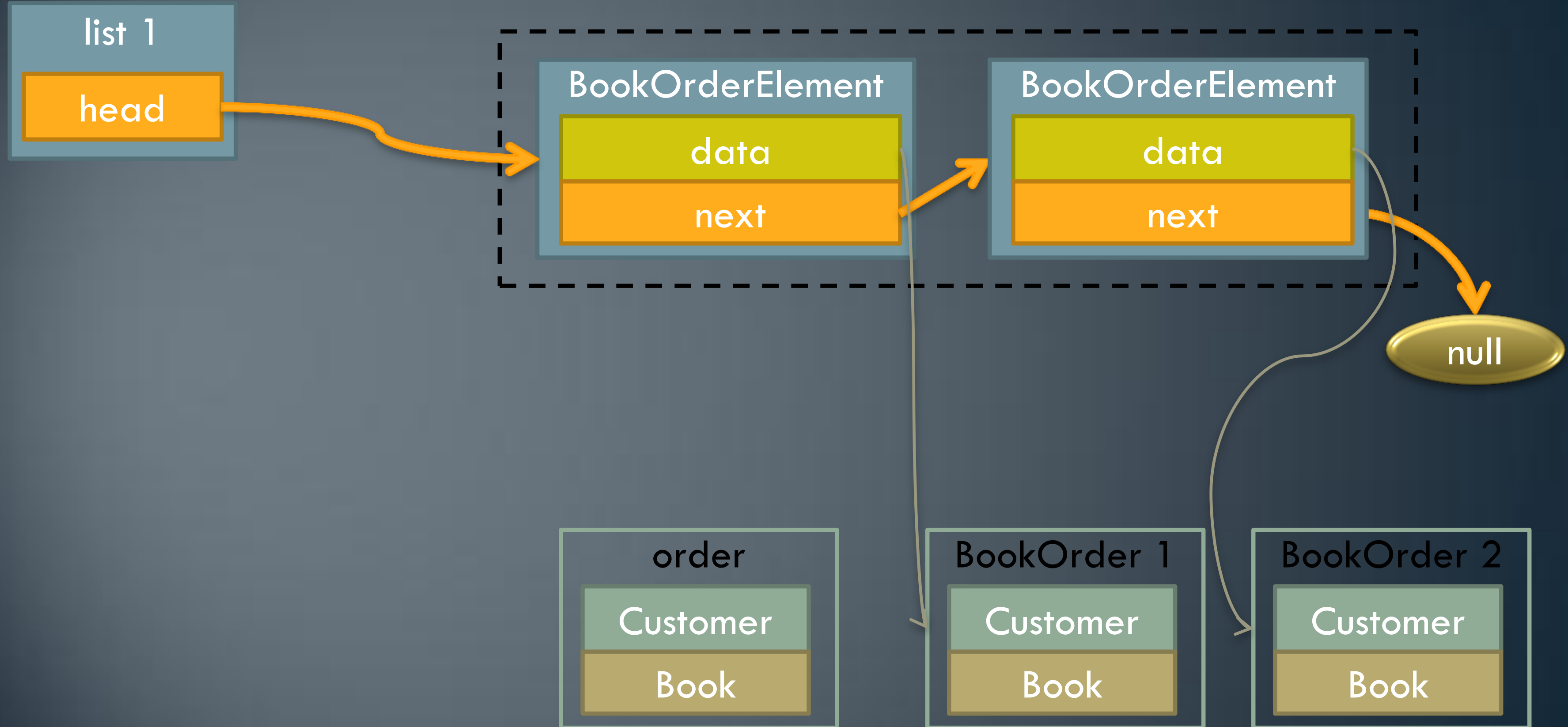
public void addOrder(BookOrder order)



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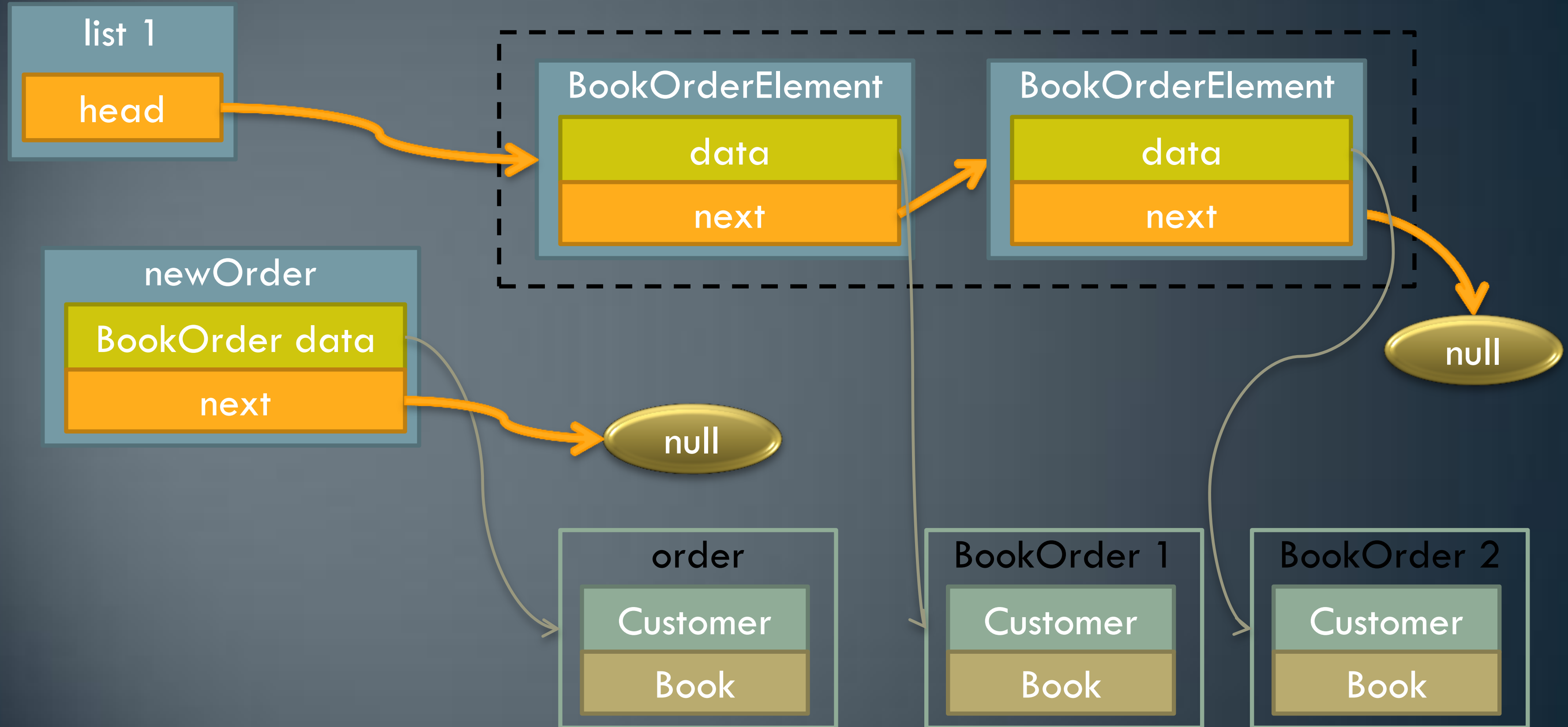
```
BookOrderElement newOrder = new BookOrderElement(order);
```



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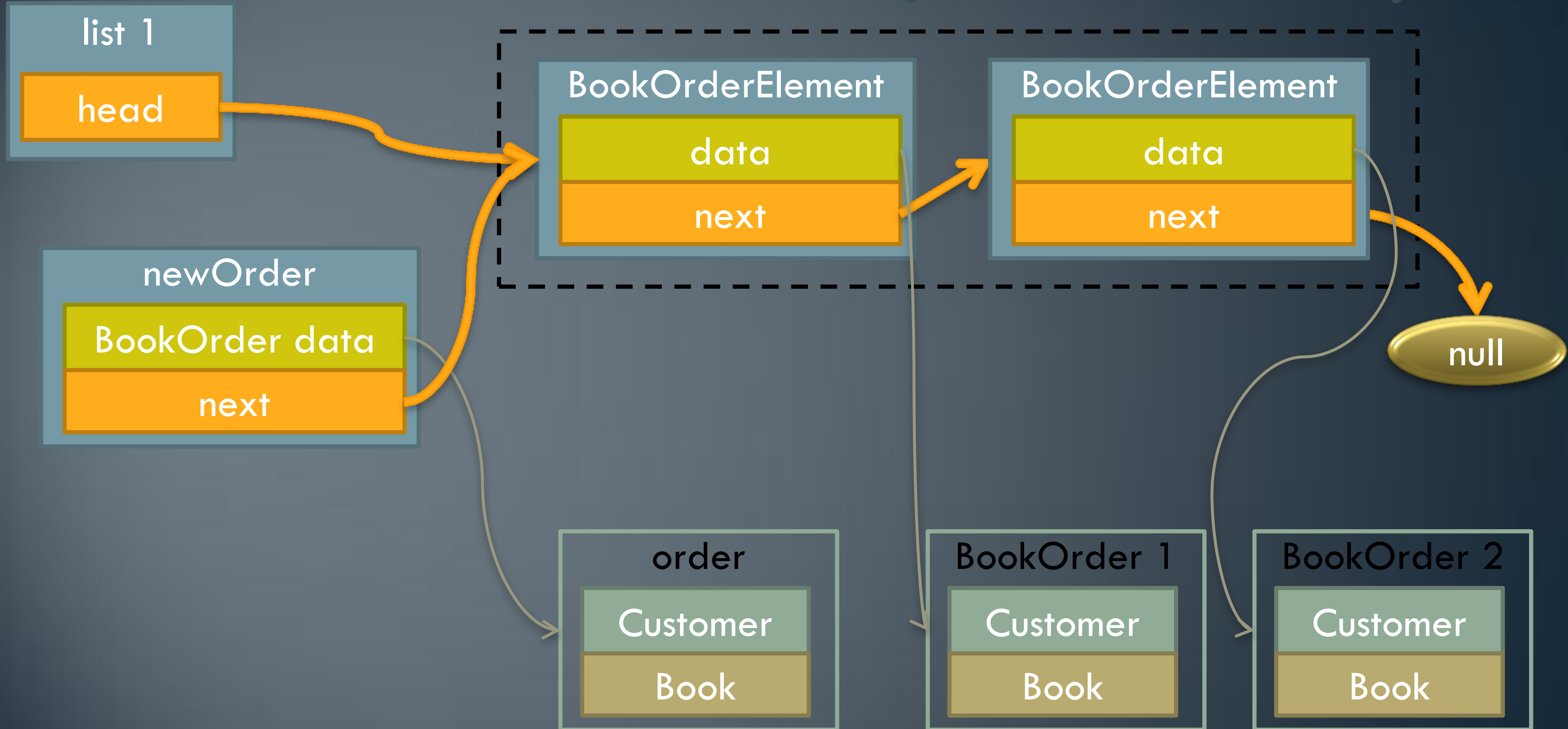
newOrder.setNext(this.head);



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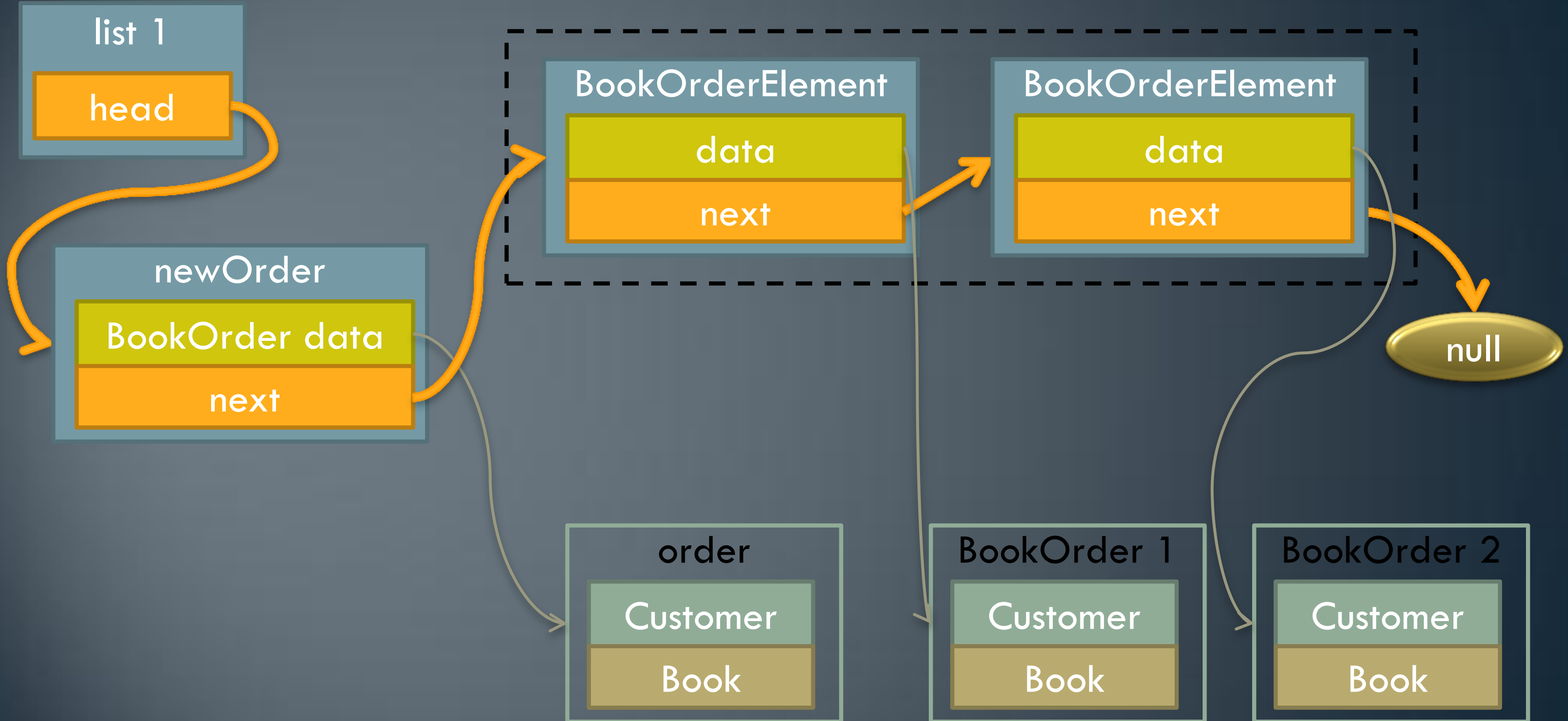
this.head = newOrder;



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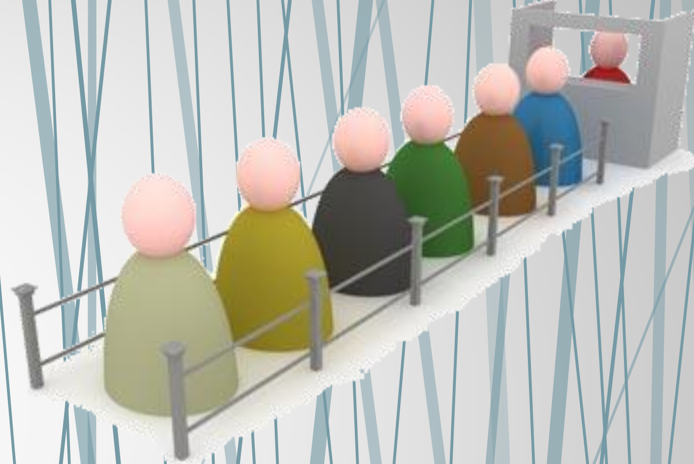

Queue

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Concept

- FIFO: First In First Out
- Like in real life: “first come first served”
- The abstraction:
  - boolean isEmpty()
  - void enqueue(Element element)
  - Element dequeue(); // sometimes split in two:
    - void dequeue()
    - Element peek()

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Implementation

- We can either use an array or our own linked list.
- If the queue size is finite/small/known in advance, we'll use an array. Otherwise, we'll be using a linked list.
- Upcoming: both implementations

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Queue implementation #1, Array

```
public class Queue {
        private Element[] elements = new Element[MAX];
        private int numberOfElements = 0;
        public void enqueue(Element element) {
                elements[numberOfElements++] = element;
        }
        public Element dequeue() {
                Element result = elements[0];
                // shift all elements to the left…
                numberOfElements--;
                return result;
        }
        public boolean isEmpty() {
                return numberOfElements == 0;
        }
}
```

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Queue implementation #2, Linked List

```
public class Queue {
        private LinkedList list = new LinkedList();
        public void enqueue(Element element) {
                list.insertAtBeginning(element);
        }
        public Element dequeue() {
                Element result = list.getFirst();
                list.remove(result);
                return result;
        }
        public boolean isEmpty() {
                return list.isEmpty();
        }
}
```

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Summary (or: this is a total mess! Help!!)

- Arrays are inherent in the language
- Linked lists are based on custom classes
- Any other data structure can be implemented using:
  - Arrays
  - Lists
  - Other data structures
- Always find the most suitable data structure to implement your new data structure
- Always find the most suitable data structure to handle your data

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Hands on thinking task

- Recall the book ordering system we wrote for Barnes & Noble:
  - We used array/linked list directly
  - A more suitable data structure would be the queue!
- Rewrite the Barnes & Noble ordering system using a queue

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Questions?