Linked Lists

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Arrays

- Arrays are contiguous regions of memory directly accessible with an index

0	1	2	3	4
3	1	4	8	9

```
int[] array = new int[5];

array[0] = 3;

System.out.println(array[2]);
```

Arrays: Time Complexity of Operations

Operation	Time Complexity
Iteration	O(n)
Random Access	O(1)
Addition on end	Amortized O(1)
Addition to front	O(n)
Removal from end	O(1)
Removal from front	O(n)

0	1	2	3	4
3	1	4	8	9

Singly Linked Lists

- **Linked List:** list of dynamically allocated data linked together by pointers to form a chain in memory

- Head pointer indicates the start of the linked list
- Node pointing to null indicates the end of the linked list
- Singly linked because a single link only to the next node

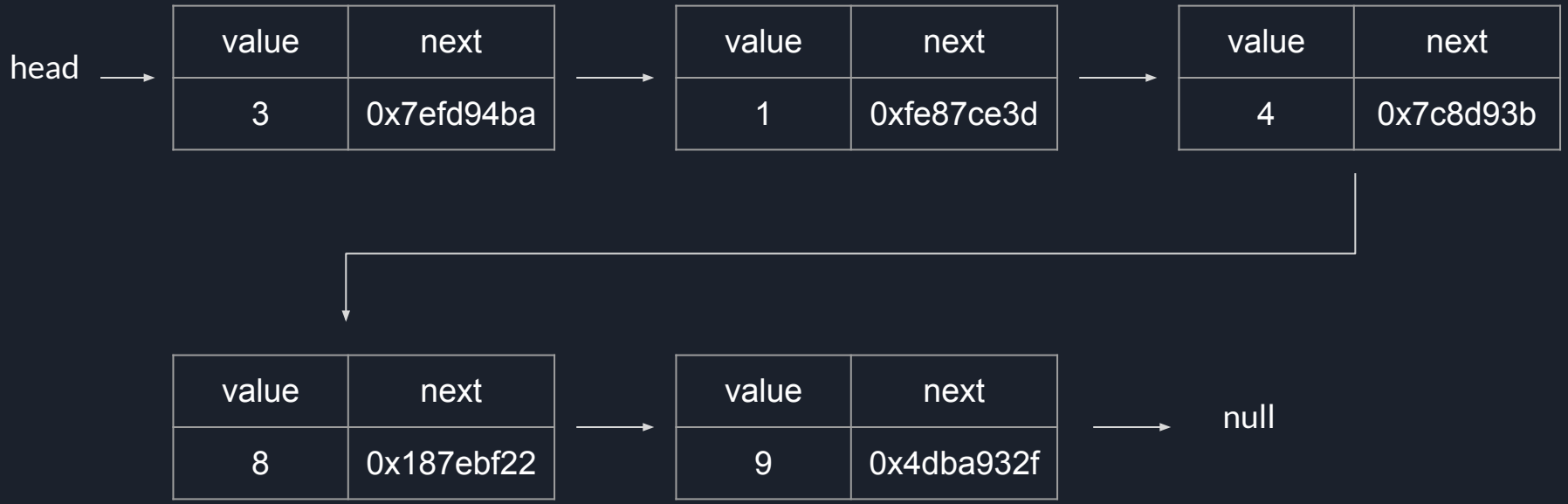
ListNode

```
private class ListNode<T> {
    private T value;
    private ListNode next;

    public ListNode(T value) {
        this(value, null);
    }

    public ListNode(T value, ListNode next) {
        this.value = value;
        this.next = next;
    }
}
```

ListNode

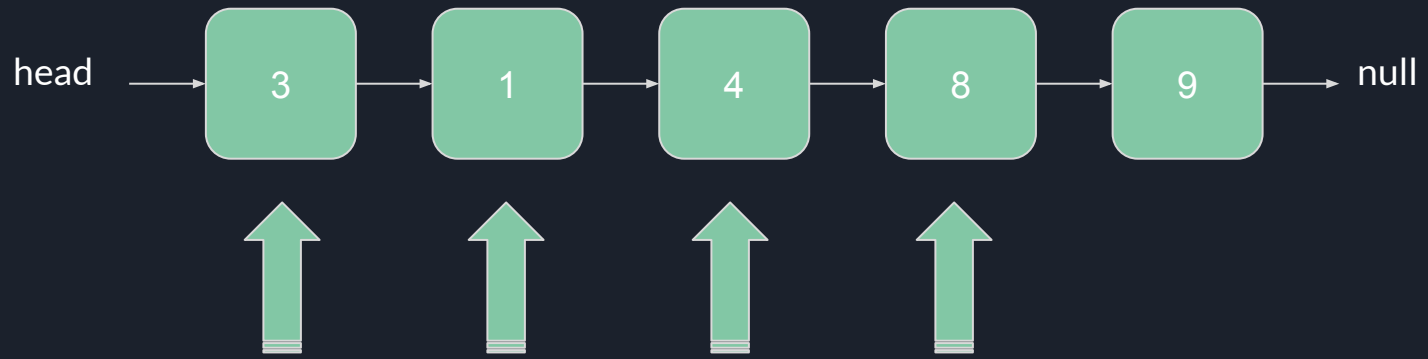
value	next
3	0x7efd94b

Under the Hood



Properties of a Linked List: Traversal

- Only the previous node knows where the next node lives in memory
- Cannot randomly access elements like we could in arrays



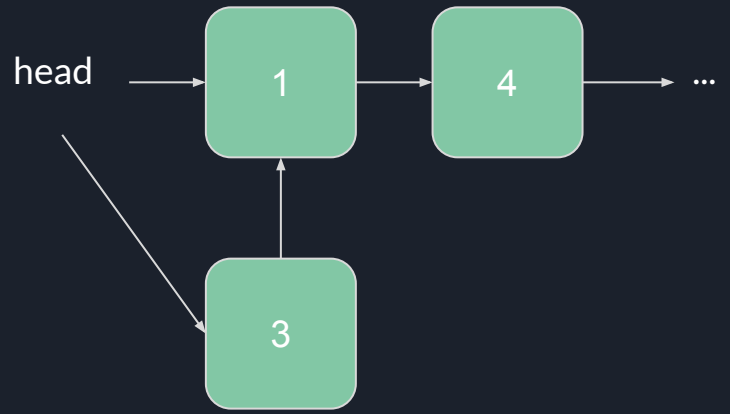
Properties of a Linked List: Dynamic Resize

- Arrays must shift all values to the right in order to insert at the front

0	1	2	3	4
1	4	8	9	

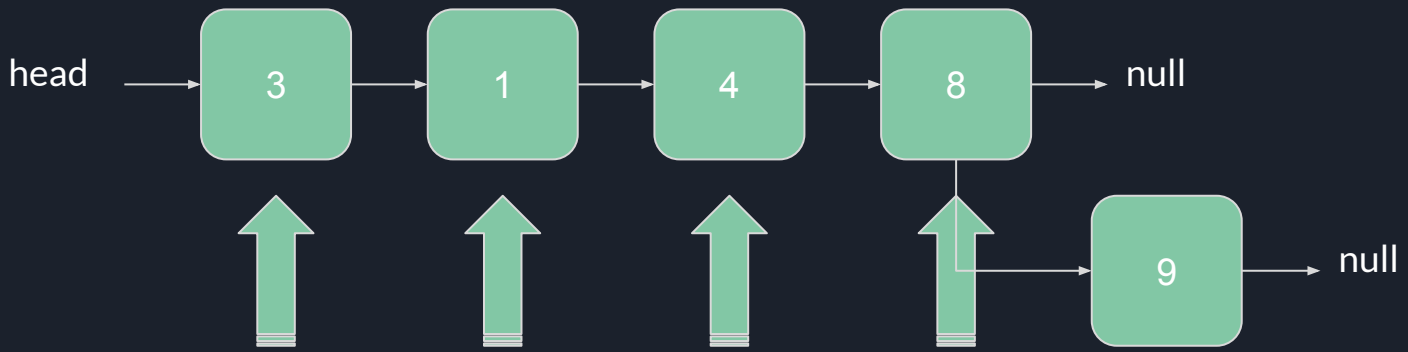
0	1	2	3	4
3	1	4	8	9

- Linked lists can modify pointers to magically add or remove a node to or from the front



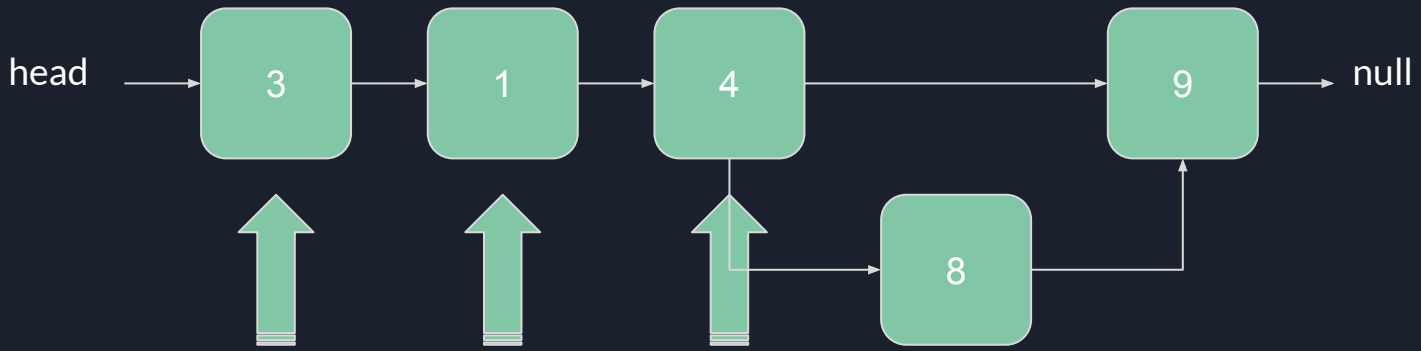
Singly Linked Lists: Insert at End

- Iterate through nodes
- If last element, add new element as next



Singly Linked Lists: Insert in Middle

- Iterate through nodes, until we find where we want to insert
- New node's next is current node's next
- Current node's next is new node

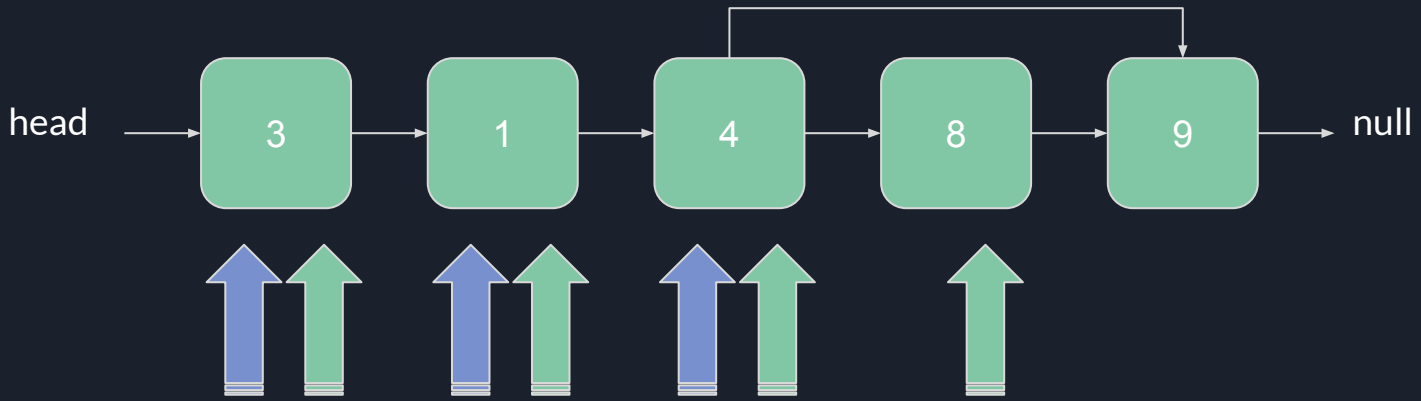


Singly Linked Lists: Remove from Front

- Head points to current head's next node

Singly Linked Lists: Remove from Middle

- Iterate until node is found, keeping track of previous node
- Previous node's next becomes current node's next



- Watch out for edge cases (removing the last element)

Time Complexity: Singly Linked Lists

Arrays

Operation	Time Complexity
Iteration	O(n)
Random Access	O(1)
Addition on end	Amortized O(1)
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Singly Linked Lists

Operation	Time Complexity
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Addition on end	O(n) 
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Optimization: Tail Pointer

Time Complexity: Singly Linked Lists

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Singly Linked Lists

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Example Linked List API

```
// insert value at front of list
void insertFront(...) { ... }

// insert value at end of list
void insertEnd(...) { ... }

// remove first element from list
void removeFront() { ... }

// remove last element from list
void removeFront() { ... }
```

```
// remove element from list, if exists
void remove(...) { ... }

// check if the list contains a value
boolean contains(...) { ... }

// get number of elements in the list
int size() { ... }

// check whether there are any elements
boolean isEmpty() { ... }
```

Linked List

```
public class LinkedList<T> {
    private ListNode head;
    private ListNode tail;

    public LinkedList() { ... }

    public void insert(T value) { ... }
    public void remove(T value) { ... }
    public bool contains(T value) { ... }
    public int size() { ... }
    public bool isEmpty() { ... }
}
```

Singly Linked Lists: Insertion

```
public void insertFront(T value) {
    ListNode ptr = new ListNode(value);
    if (isEmpty()) {
        head = ptr;
        tail = ptr;
    }
    else {
        ptr.next = head;
        head = ptr;
    }
}
```

```
public void insertEnd(T value) {
    ListNode ptr = new ListNode(value);
    if (isEmpty()) {
        head = ptr;
        tail = ptr;
    }
    else {
        tail.next = ptr;
        tail = ptr;
    }
}
```

Singly Linked Lists: Remove

```
public void removeFront() {
    if (isEmpty()) {
        return;
    }
    if (head == tail) {
        head = null;
        tail = null;
        return;
    }
    head = head.next;
}
```

```
public void removeEnd() {
    if (isEmpty()) {
        return;
    }

    if (head == tail) {
        head = null;
        tail = null;
        return;
    }

    ListNode curr = head;
    ListNode prev = null;
    while (curr != tail) {
        prev = curr;
        curr = curr.next;
    }

    prev.next = null;
    tail = prev;
}
```

Singly Linked Lists: Remove

```
public void remove(T value) {
    if (isEmpty()) {
        return;
    }
    if (head == tail) {
        head = null;
        tail = null;
        return;
    }

    ListNode prev = null;
    ListNode curr = head;
    while (curr != null) {
        if (curr.value != value) {
            prev = curr;
            curr = curr.next;
            continue;
        }
        if (curr == head) {
            head = head.next;
        }
        else if (curr == tail) {
            prev.next = null;
            tail = prev;
        }
        else {
            prev.next = curr.next;
        }
    }
```

Singly Linked Lists: Contains

```
public boolean contains(T value) {
    ListNode curr = head;
    while (curr != null) {
        if (curr.value == value) {
            return true;
        }
        curr = curr.next;
    }
    return false;
}
```

Singly Linked Lists: Size

```
public int size() {
    ListNode curr = head;

    int size = 0;
    while (curr != null) {
        curr = curr.next;
        size++;
    }

    return size;
}
```

Singly Linked Lists: Is Empty

```
public int isEmpty() {
    if (head == null && tail == null) {
      return true;
    }
    return false;
}
```

Time Complexity: Singly Linked Lists

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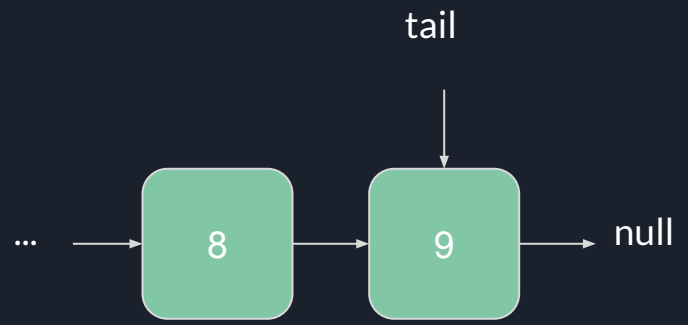
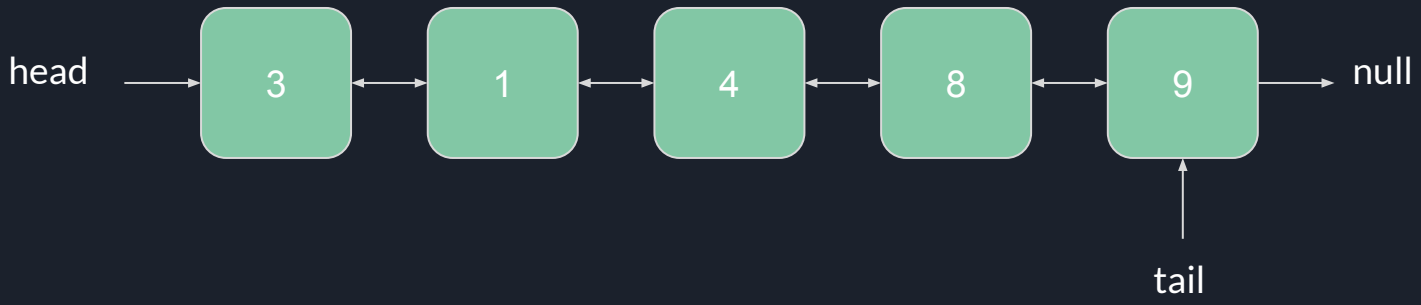
Limitations of a Singly Linked List

- Only the previous node knows where the next node lives in memory
- Tail pointer gives direct access to the last node in the list
- How can we get from the last node of the list to the node before the last?
    - We can’t
- Solution: use links that point backwards as well



Doubly Linked Lists

- Each node has both a next and prev pointer
- Can get to previous node by following the prev pointer



Time Complexity: Doubly Linked Lists

Arrays

Operation	Time Complexity
Iteration	O(n)
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Addition on end	Amortized O(1)
Addition to front	O(n)
Removal from end	O(1)
Removal from front	O(n)

Doubly Linked Lists

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Doubly Linked List: `ListNode`

```
private class ListNode<T> {
    private T value;
    private ListNode prev;
    private ListNode next;

    public ListNode(T value) {
        this(value, null, null);
    }

    public ListNode(T value, ListNode prev, ListNode next) {
        this.value = value;
        this.prev = prev;
        this.next = next;
    }
}
```