CSE 250
Data Structures

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Lec 08: Sequences

Announcements

- PA1 Testing due Sunday at midnight
  - Be aware that course staff is not guaranteed to be available after 5PM or on weekends
  - Be thoughtful in your submissions to Autolab

Sequences (what are they?)

Fibonacci Sequence: 1, 1, 2, 3, 5, 8, 13, 21, 34, …

Characters in a String: 'H', 'e', 'l', 'l', 'o', ' ', 'W', 'o', 'r', 'l', 'd'

Lines in a File

People in a queue

Sequences (what are they?)

Fibonacci Sequence: 1, 1, 2, 3, 5, 8, 13, 21, 34, …

Characters in a String: 'H', 'e', 'l', 'l', 'o', ' ', 'W', 'o', 'r', 'l', 'd'

Lines in a File

People in a queue

An "ordered" collection of elements

Sequences (what can you do with them?)

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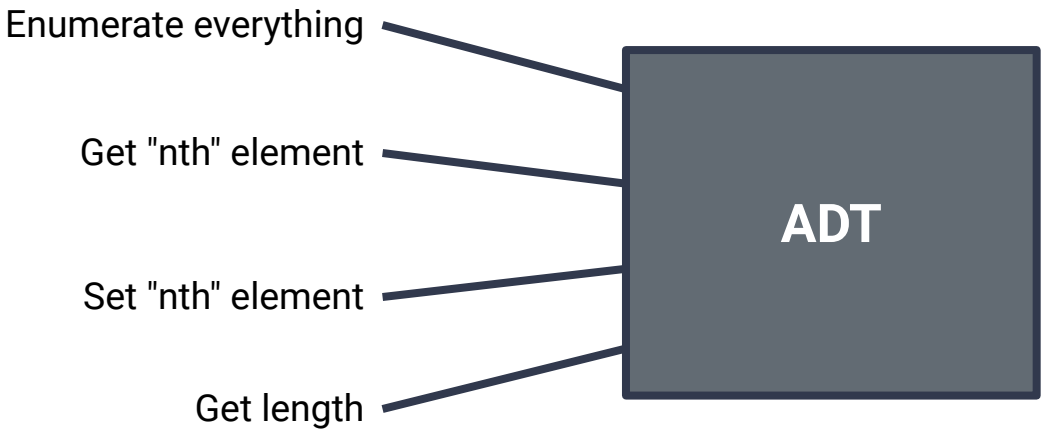
- Enumerate every element in sequence
  - ie: print out every element, sum every element
- Get the "nth" element
  - ie: what is the first element? what is the 42nd element?
- Modify the "nth" element
  - ie: set the first element to x, set the third element to y
- Count how many elements you have

Abstract Data Types (ADTs)

The specification of **what** a data structure can do



Abstract Data Types (ADTs)

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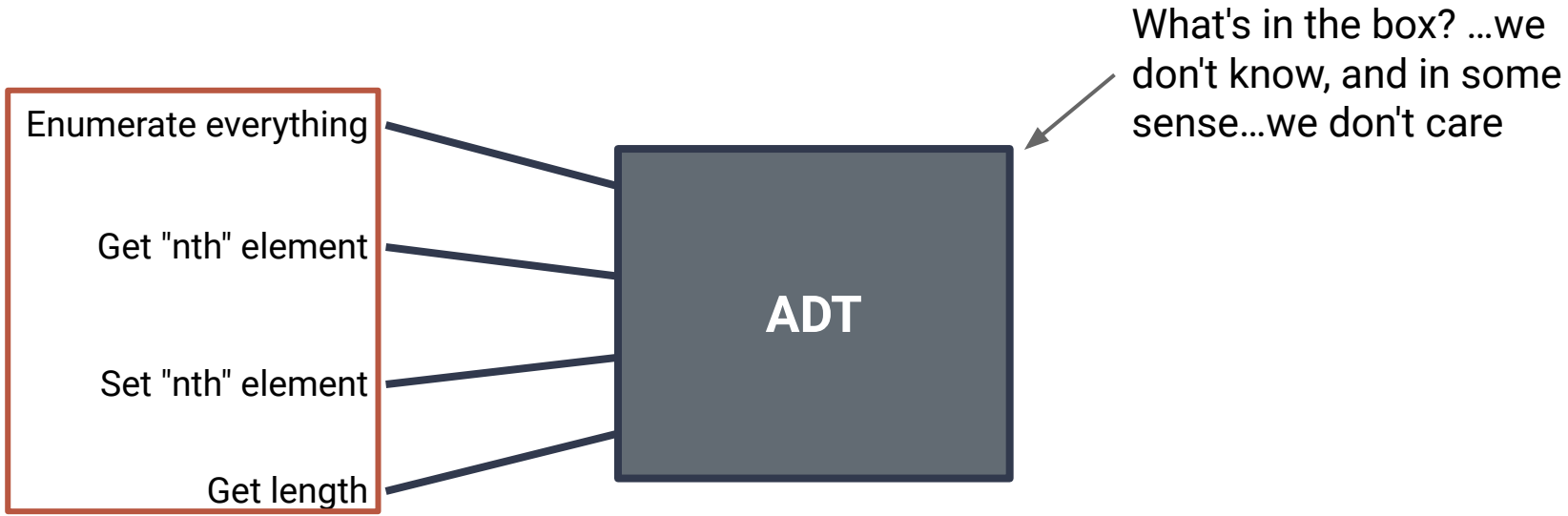

Usage is governed by **what** we can do, not **how** it is done

The Sequence ADT

`T get(int idx)`
Get the element (of type **`T`**) at position **`idx`**

`T set(int idx, T value)`
Set the element (of type **`T`**) at position **`idx`** to a new value

`int length`
Get the number of elements in the seq

`Iterator<T> iterator()`
Get access to view all elements in the sequence, in order, once

So...what's in the box?
(how do we implement it)

A Brief Aside on RAM (220 crossover)

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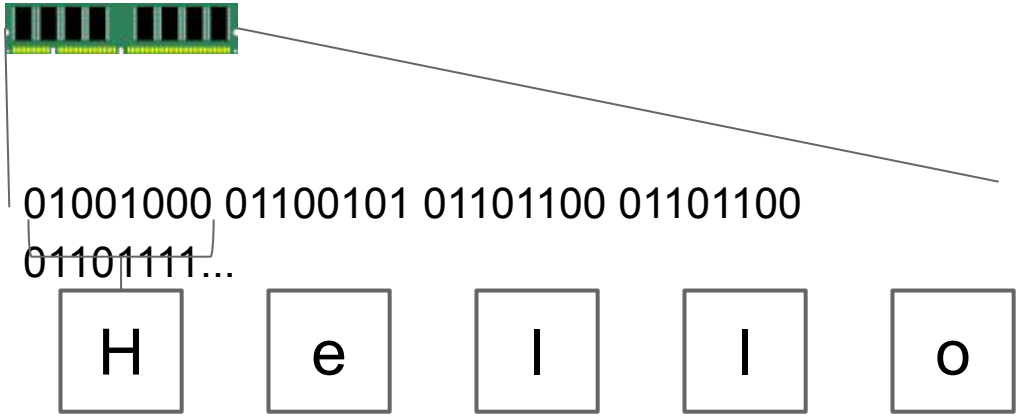
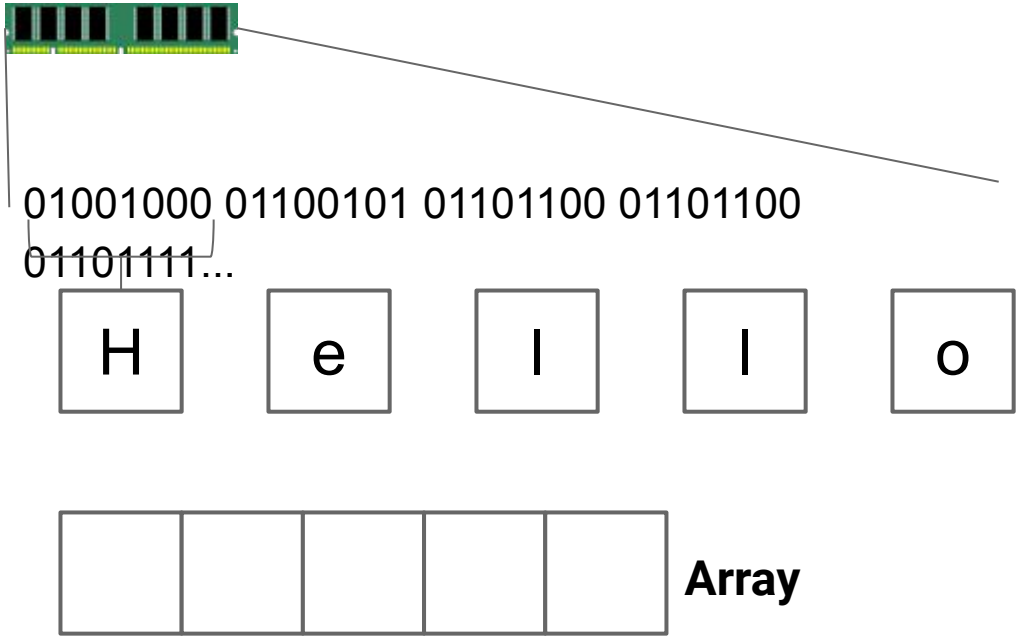
01001000 01100101 01101100 01101100
01101111...

A Brief Aside on RAM (220 crossover)



A Brief Aside on RAM (220 crossover)



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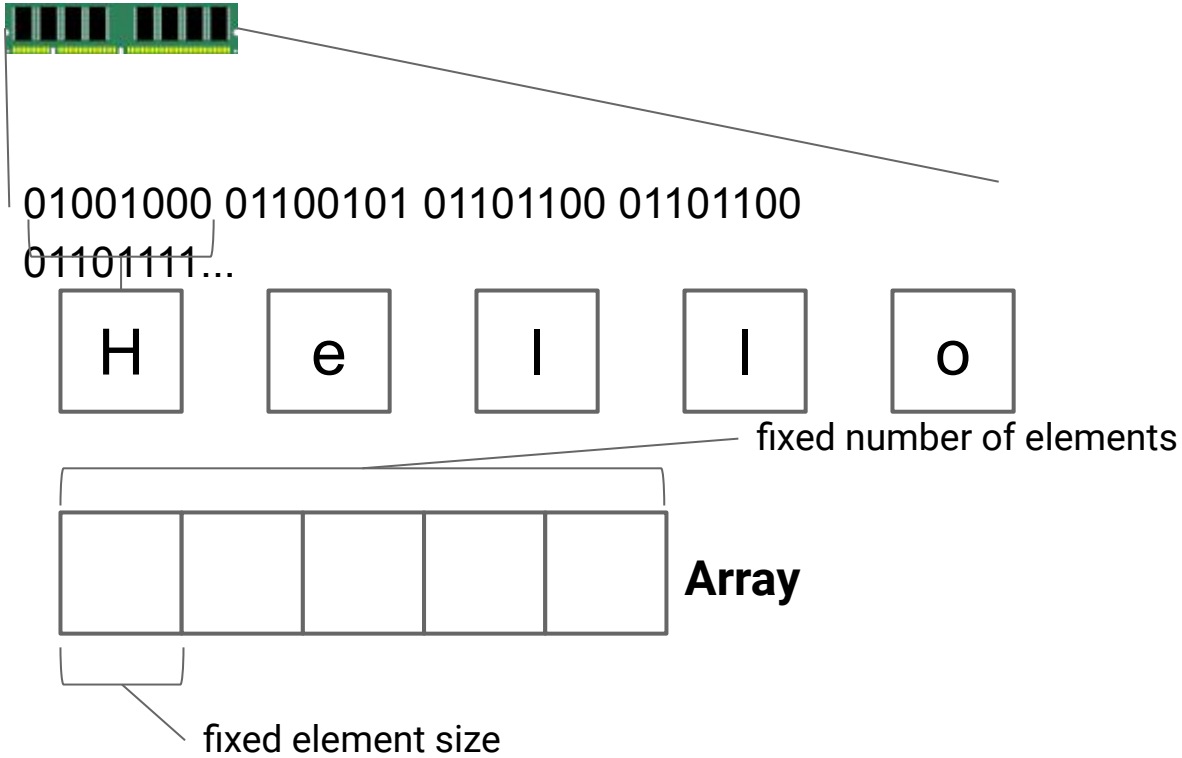

RAM

Allocation with `new T`:

Go find some unused part of memory that is big enough to fit a `T`, mark it as used, and return the ***address*** of that location in memory.

RAM

Allocation with `new T`:

Go find some unused part of memory that is big enough to fit a `T`, mark it as used, and return the ***address*** of that location in memory.

```
1 int[] arr = new int[50];
```

The above code allocates 50 * 4 = 200 bytes of memory*
(a single Java **`int`** takes of 4 bytes in memory)

** slightly more actually…see next slide*

Arrays in Detail

What does an array of *n* items of type `T` actually look like?

- 4 bytes for ***n*** (optional)
- 4 bytes for **`sizeof(T)`** (optional)
- ***n*** * **`sizeof(T)`** bytes for the data

Arrays in Detail

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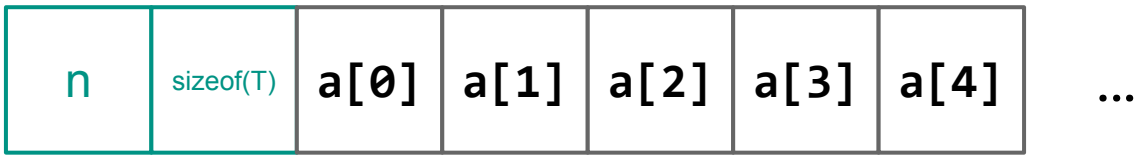

Arrays in Detail

How would we implement the methods of the Sequence ADT for an Array:

```
T get(int idx)


T set(int idx, T value)


int length
```

Arrays in Detail

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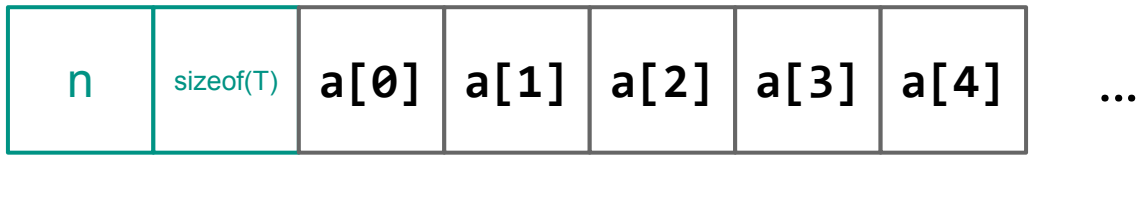

The length is stored in the memory allocated for the array…**Θ(1)** time to access

Arrays in Detail

How would we implement the methods of the Sequence ADT for an Array:

`T get(int idx)`

`T set(int idx, T value)`

`int length`

Access the **`length`** field in constant time $\Theta(1)$

Implementing get/set

```
1 int[] arr = new int[50];
```

If **arr** is at address ***a***, where should you look for **arr[19]**?

Implementing `get/set`

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If **`arr`** is at address ***a***, where should you look for **`arr[19]`**?

- *a* + 19 * 4

Implementing `get/set`

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If **`arr`** is at address ***a***, where should you look for **`arr[19]`**?

- *a* + 19 * 4 (does this computation depend on the size of **`arr`**?)

What is the complexity?

Implementing `get/set`

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- *a* + 19 * 4 (does this computation depend on the size of **`arr`**?)

What is the complexity? **$\Theta(1)$**

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What is the complexity? $\Theta(1)$

What about **`a[55]`**?

Implementing `get/set`

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If **`arr`** is at address ***a***, where should you look for **`arr[19]`**?

- *a* + 19 * 4 (does this computation depend on the size of **`arr`**?)

What is the complexity? $\Theta(1)$

What about **`a[55]`**?

- *a* + 55 * 4 …but that memory was not reserved for this array.
- Java will prevent you from accessing an *out of bounds* element

Arrays in Detail

How would we implement the methods of the Sequence ADT for an Array:

`T get(int idx)`

Compute the address of the element in constant time **$\Theta(1)$**

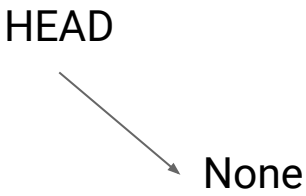
`T set(int idx, T value)`

Compute the address of the element in constant time **$\Theta(1)$**

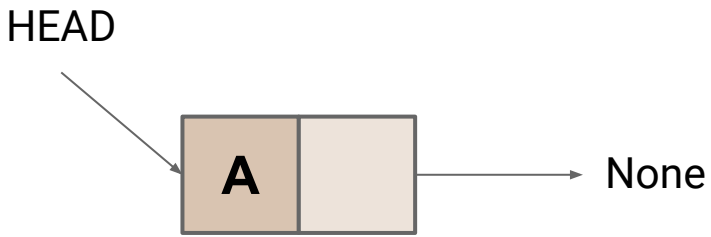
`int length`

Access the **`length`** field in constant time **$\Theta(1)$**

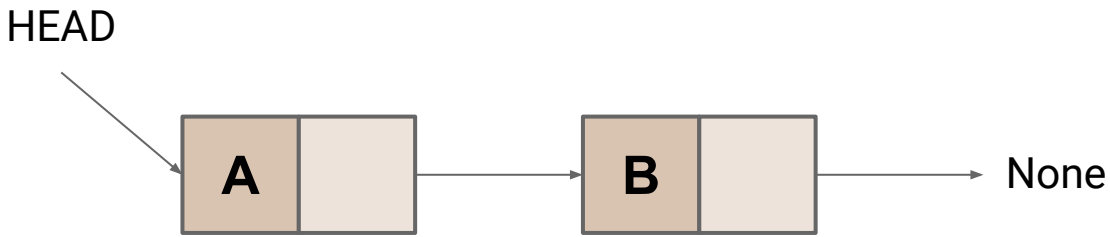
Linked Lists



Linked Lists



Linked Lists



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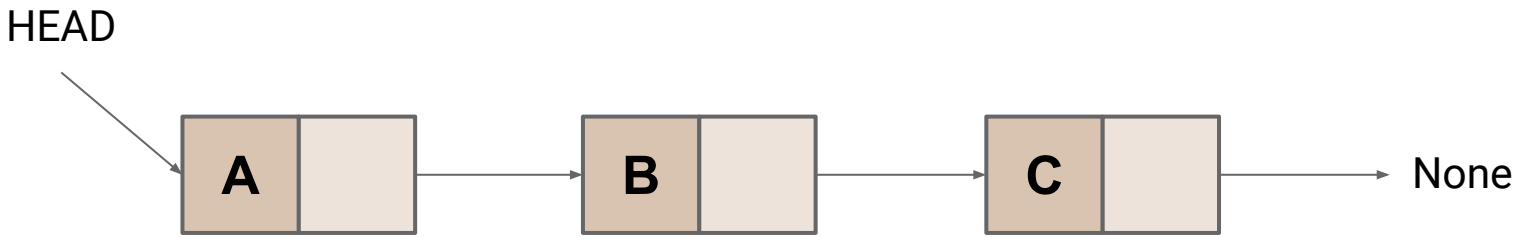
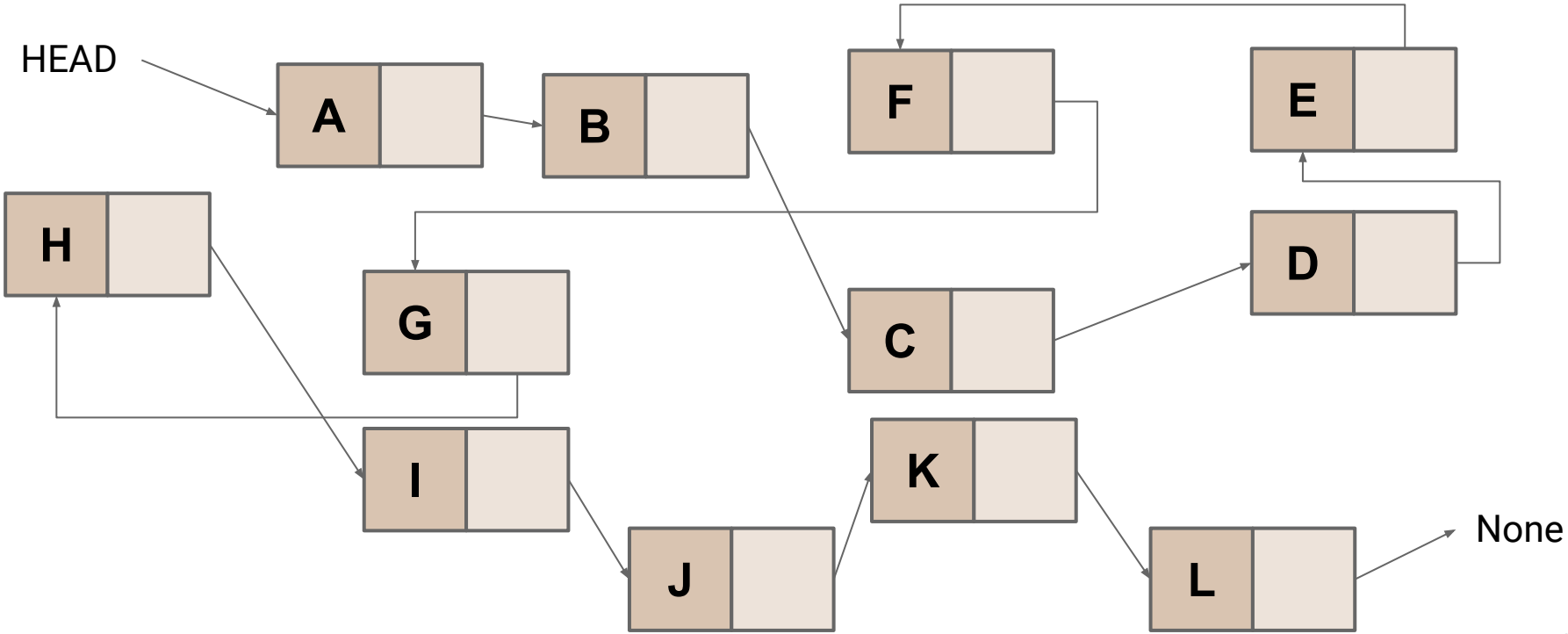


Linked Lists



Linked Lists in Detail

```
1 class LinkedList<T> {
2   Optional<LinkedListNode<T>> head = Optional.empty();
3   /* ... */
4 }
```

Class for our list, which right now just has a **`Optional`** reference to **`head`**

```
1 class LinkedListNode<T> {
2   T value;
3   Optional<LinkedListNode<T>> next = Optional.empty();
4 }
```

Class for a node in the list, which has a **`value`**, and an **`Optional`** reference to the **`next`** node

Linked Lists in Detail

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Class for a node in the list, which has a **`value`**, and an **`Optional`** reference to the **`next`** node

What is Optional<T>...a brief digression

- Let's say we have a function that we know can possibly return **`null`**
- What can go wrong in the following code snippet?

```
1 Integer x = functionThatCanReturnNull();
2 x.doAThing();
```

What is Optional<T>...a brief digression

- Let's say we have a function that we know can possibly return **`null`**
- What can go wrong in the following code snippet?

```
1 Integer x = functionThatCanReturnNull();
2 x.doAThing();
```

`java.lang.NullPointerException` (runtime error)

What is Optional<T>...a brief digression

```
1 Integer x = functionThatCanReturnNull();
2 if (x == null) { /* do something special */ }
3 else { x.doAThing(); }
```

We need to add a check for **`null`** to avoid this…but this is easy to forget

What if our function returns **`Optional<Integer>`** instead?

What is Optional<T>...a brief digression

- Now our function returns **`Optional<Integer>`**
- What can go wrong in the following code snippet?

```
1 Optional<Integer> x = functionThatCanReturnEmpty();
2 x.doAThing();
```

What is Optional<T>...a brief digression

- Now our function returns **`Optional<Integer>`**
- What can go wrong in the following code snippet?

```
1 Optional<Integer> x = functionThatCanReturnEmpty();
2 x.doAThing();
```

`Cannot resolve method doAThing() in Optional`

(compile error)

What is Optional<T>...a brief digression

```
1 Optional<Integer> x = functionThatCanReturnNull();
2 if (x.isPresent()) { x.get().doAThing(); }
3 else { /* do something special */ }
```

Java makes us do something sensible!

What is Option[T]...a brief digression

Creating `Optional` objects:

```
Optional.empty()        // Like null
Optional.of(x)          // Optional object w with value x
Optional.ofNullable(x) // If x is null same as .empty()
```

Using `Optional` objects:

```
.isPresent()        // True if there is a value
.get()              // gets the value
.orElse(y)          // return value if present, y if not
```

Linked Lists in Detail

How do we implement the methods of the Sequence ADT for a Linked List:

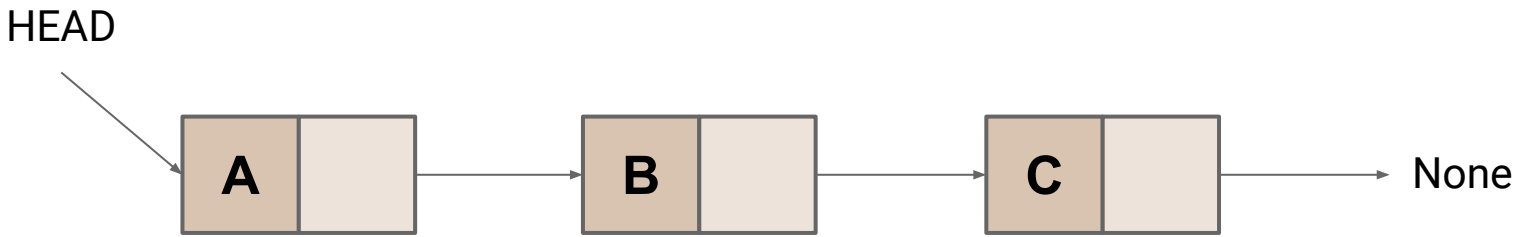
```
T get(int idx)

T set(int idx, T value)

int length
```

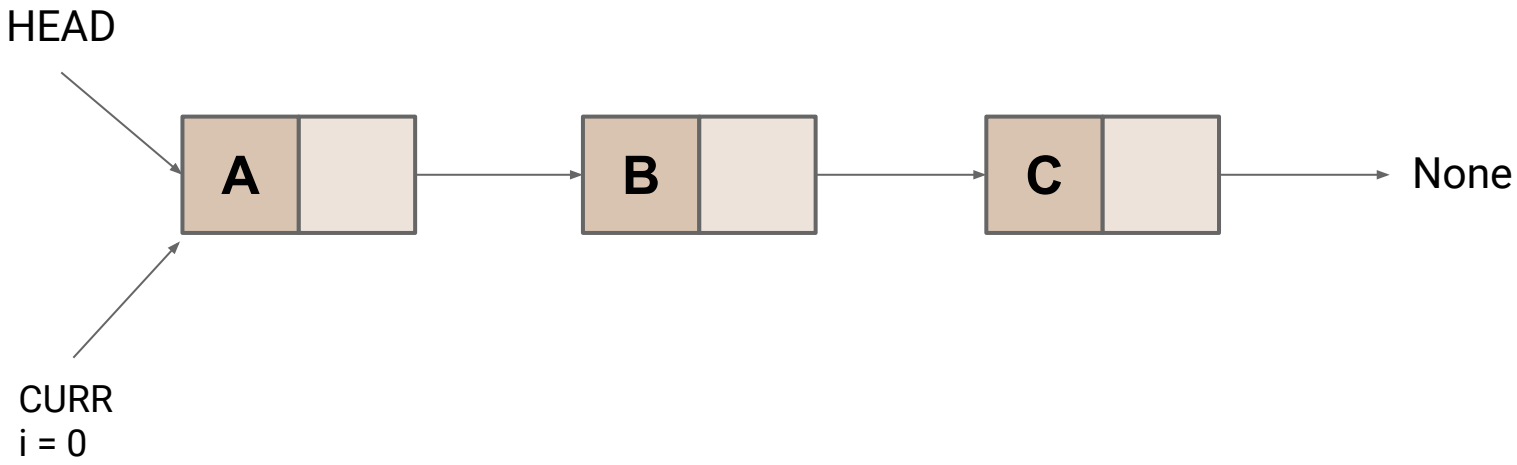
Implementing `get/set`

`get(2)`

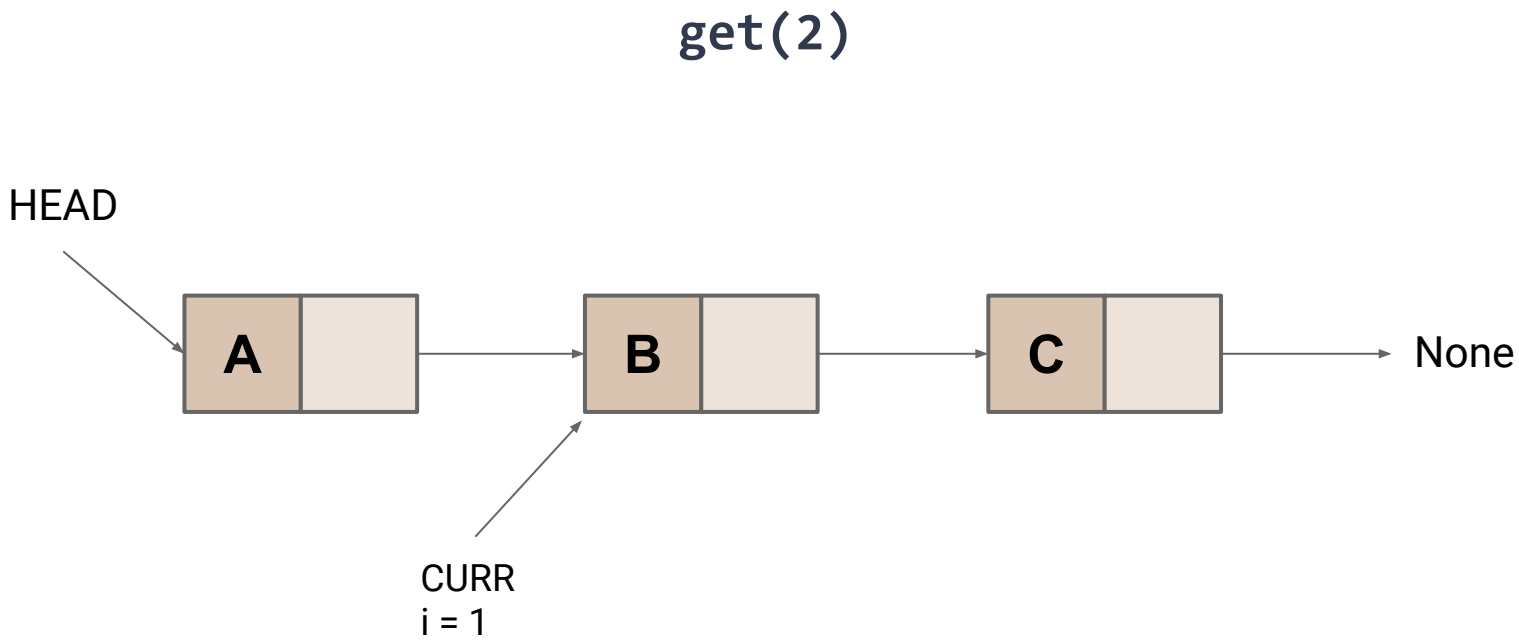


Implementing get/set

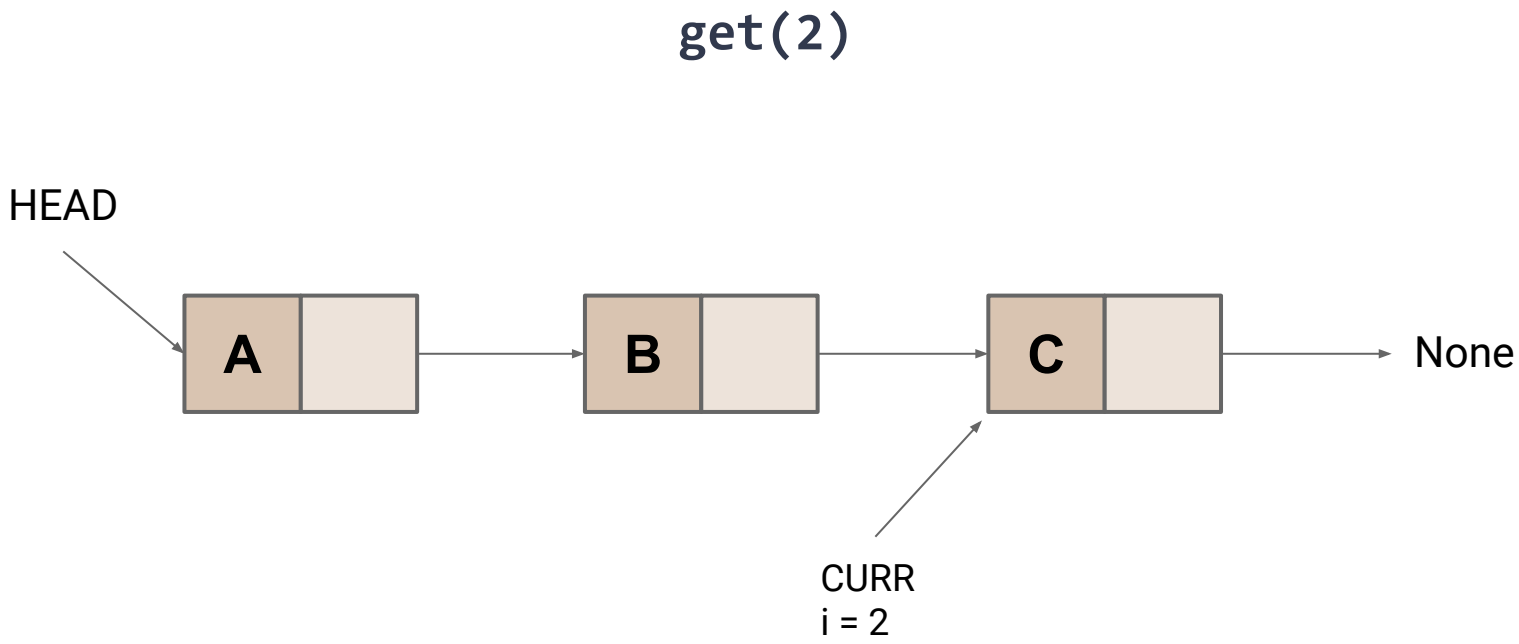
`get(2)`



Implementing get/set



Implementing get/set



Implementing get/set

```
1  public T get(int idx) {
2    int i = 0;
3    Optional<LinkedListNode<T>> curr = head;
4    while(i < idx) {
5      if (!curr.isPresent()) { throw new IndexOutOfBoundsException(); }
6      i++;
7      curr = curr.get().next;
8    }
9    if(!curr.isPresent()) { throw new IndexOutOfBoundsException(); }
10   return curr.get().value;
11 }
```

Implementing get/set

```
1  public T get(int idx) {
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7      curr = curr.get().next;
8    }
9    if(!curr.isPresent()) { throw new IndexOutOfBoundsException(); }
10   return curr.get().value;
11 }
```

All of this is $\Theta(1)$

Implementing get/set

```
1  public T get(int idx) {
2    Θ(1)
3    while(i < idx) {
4      Θ(1)
5    }
6    Θ(1)
7  }
```

Implementing get/set

```
1  public T get(int idx) {
2    Θ(1)
3    Θ(idx)
4    Θ(1)
5  }
```

Complexity: $\Theta(idx) \subset O(n)$

Linked Lists in Detail

How do we implement the methods of the Sequence ADT for a Linked List:

`T get(int idx)`

Go node-by-node until you reach **`idx`** $\Theta(\texttt{idx}) \subset O(n)$

`T set(int idx, T value)`

Go node-by-node until you reach **`idx`** $\Theta(\texttt{idx}) \subset O(n)$

`int length`

Implementing `length`

```
1  public int length() {
2      int i = 0;
3      Optional<LinkedListNode<T>> curr = head;
4      while(curr.isPresent()) { i++; curr = curr.get().next; }
5      return i;
6  }
```

Implementing `length`

```
1  public int length() {
2      Θ(1)
3      while(curr.isPresent()) { Θ(1) }
4      Θ(1)
5  }
```

Implementing `length`

```
1  public int length() {
2      Θ(1)
3      Θ(n)
4      Θ(1)
5  }
```

Complexity: $\Theta(n)$
Can we do better?

Implementing `length`

Idea: Have the Linked List class store the length

```
1  class LinkedList<T> {
2    Optional<LinkedListNode<T>> head = Optional.empty();
3    int length;
4    /* ... */
5  }
```

Now complexity of getting **`length`** is $\Theta(1)$

Implementing `length`

Idea: Have the Linked List class store the length

```
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Now complexity of getting **`length`** is $\Theta(1)$

How much extra space is required? $\Theta(1)$

How much extra work is required to insert/remove? $\Theta(1)$

Implementing `length`

Idea: Have the Linked List class store the length

```
1  class LinkedList<T> {
2    0
3    i
4    /
5  }
```

Common trade-off: Sometimes storing extra information can decrease complexity!

Now complexity of getting `length` is $\Theta(1)$

How much extra space is required? $\Theta(1)$

How much extra work is required to insert/remove? $\Theta(1)$

Access by-Reference vs by-Index

Complexity of getting the value of the ***n***th node in a Linked List?

Complexity of getting the value of the ***n***th node if we have a reference to that node?

Complexity of getting the value of (***n*+1**)th node if we have a reference to the ***n***th node?

Complexity of getting the value of (***n*-1**)th node if we have a reference to the ***n***th node?

Access by-Reference vs by-Index

Complexity of getting the value of the ***n***th node in a Linked List? $\Theta(n)$

Complexity of getting the value of the ***n***th node if we have a reference to that node? $\Theta(1)$

Complexity of getting the value of **(*n*+1)**th node if we have a reference to the ***n***th node? $\Theta(1)$

Complexity of getting the value of **(*n*-1)**th node if we have a reference to the ***n***th node? $\Theta(n)$

Doubly Linked Lists

```
1  class LinkedList<T> {
2    Optional<LinkedListNode<T>> head = Optional.empty();
3    Optional<LinkedListNode<T>> tail = Optional.empty();
4    int length;
5  }
```

```
1  class LinkedListNode<T> {
2    T value;
3    Optional<LinkedListNode<T>> next = Optional.empty();
4    Optional<LinkedListNode<T>> prev = Optional.empty();
6  }
```