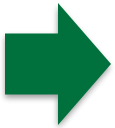
# CS 10:
# Problem solving via Object Oriented Programming

## Lists Part 1

# Agenda



1. Singly linked List ADT implementation
2. Exceptions

**Key points:**

1. **The List ADT specifies a set of operations that must be implemented**
2. **Those operations can be implemented using a singly linked list**

# The List ADT defines required operations, but not how to implement them

**Big idea: List works the same regardless of what data it holds**

**List ADT**

| Operation | Description |
|---|---|
| `size()` | Return number of items in List |
| `isEmpty()` | True if no items in List, otherwise false |
| `add(e)` | Add item *e* to end of the list |
| `add(i,e)` | Insert item *e* at index *i*, moving all subsequent items one index larger |
| `remove(i)` | Remove and return item at index *i*, move all subsequent items one index smaller |
| `get(i)` | Return the item at index *i* |
| `set(i,e)` | Replace the item at index *i* with item *e* |

These operations MUST be implemented to complete the ADT

Free to implement other methods, but must have these

**We never say how many items the list can hold; it grows as needed**

# SimpleList.java is an interface that specifies what operations MUST be implemented

**SimpleList.java**

```
public interface SimpleList<T>  {
  /**
   * Returns # elements in the List (they are indexed 0..size-1)
   */
  public int size();

  /**
   * Returns true if there are no elements in the List, false otherwise
   * @return true or false
   */
  public boolean isEmpty();

  /**
   * Adds the item at the index, which must be between 0 and size
   */
  public void add(int idx, T item) throws Exception;

  /**
   * Add item at end of List
   */
  public void add(T item) throws Exception;

  /**
   * Removes and returns the item at the index, which must be between 0 and size-1
   */
  public T remove(int idx) throws Exception;

  /**
   * Returns the item at the index, which must be between 0 and size-1
   */
  public T get(int idx) throws Exception;

  /**
   * Replaces the item at the index, which must be between 0 and size-1
   */
  public void set(int idx, T item) throws Exception;
```

**Interface keyword tells Java this is an interface**

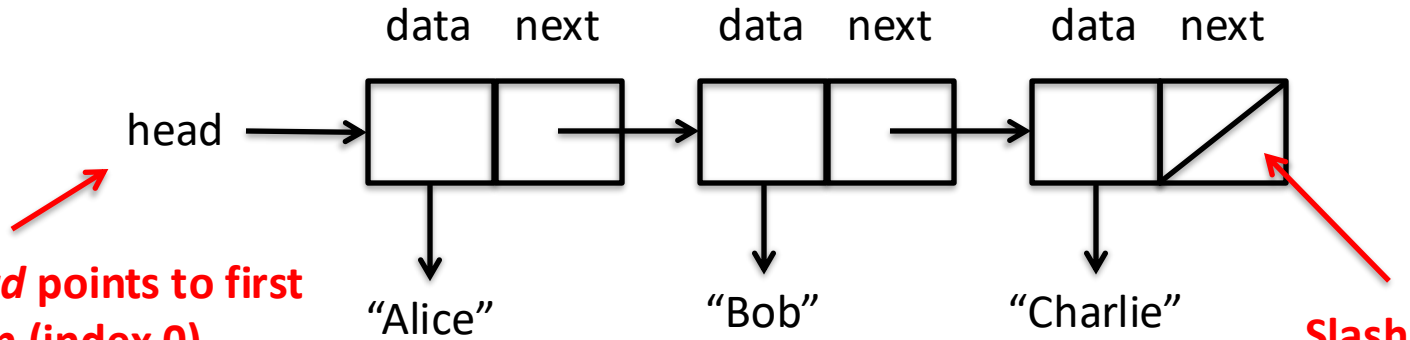
- **Methods defined to include parameters and return types (called a "signature")**
- **If you are going to implement SimpleList, then you MUST implement these methods**
- **How you implement is your business**
- **Java's List interface has a few more methods, our simplifies things a little**

# Singly linked list review: elements have data and a next pointer

**Singly linked list**

**"Box-and-pointer" diagram**

- **Data in Box**
- **Pointer to next item in List**




***head* points to first item (index 0)**

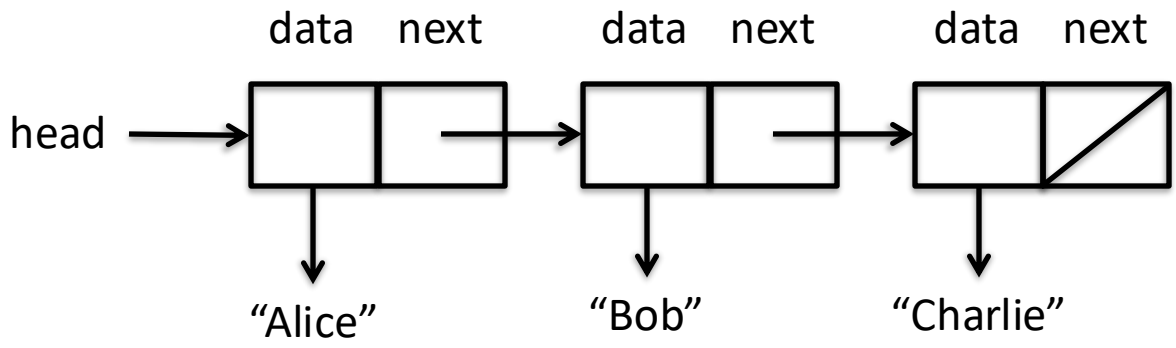
***null* if list is empty**

**Slash indicates end of List**

***next* pointer is *null***

# To get an item at index i, start at head and march down

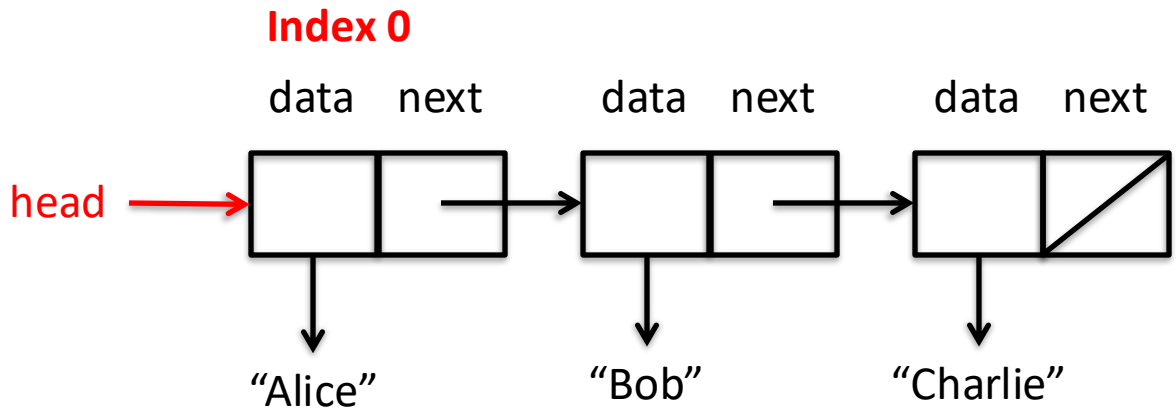
**get(i) – return item at specified index**




**Get item at index 2**

# To get an item at index i, start at head and march down

**get(i) – return item at specified index**




**Get item at index 2**

1. **Start at head (index 0)**

# To get an item at index i, start at head and march down

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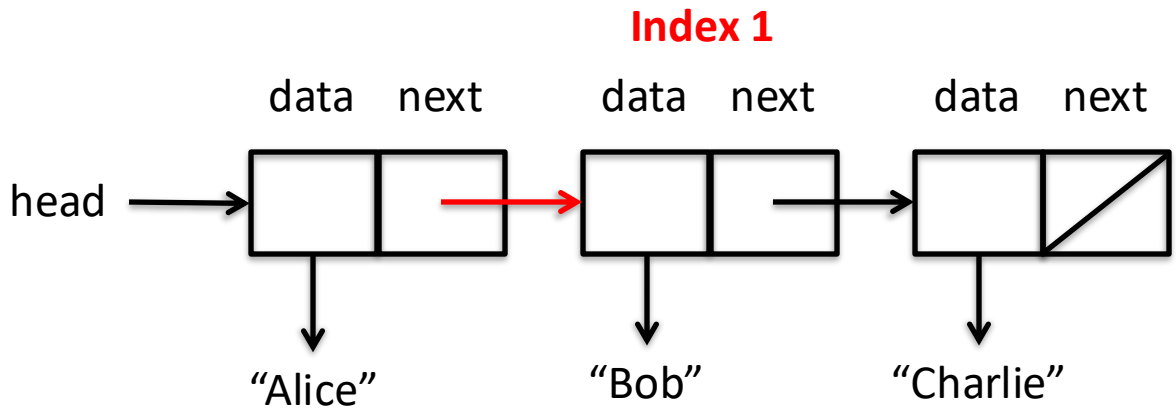
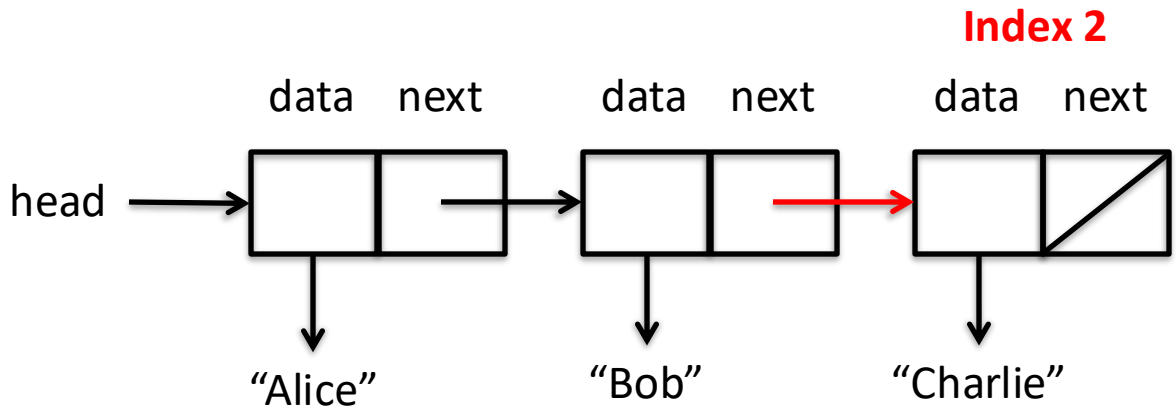



**Get item at index 2**

1. **Start at head (index 0)**
2. **Follow next pointer to index 1**

# To get an item at index i, start at head and march down

**get(i) – return item at specified index**




**Get item at index 2**

1. **Start at head (index 0)**
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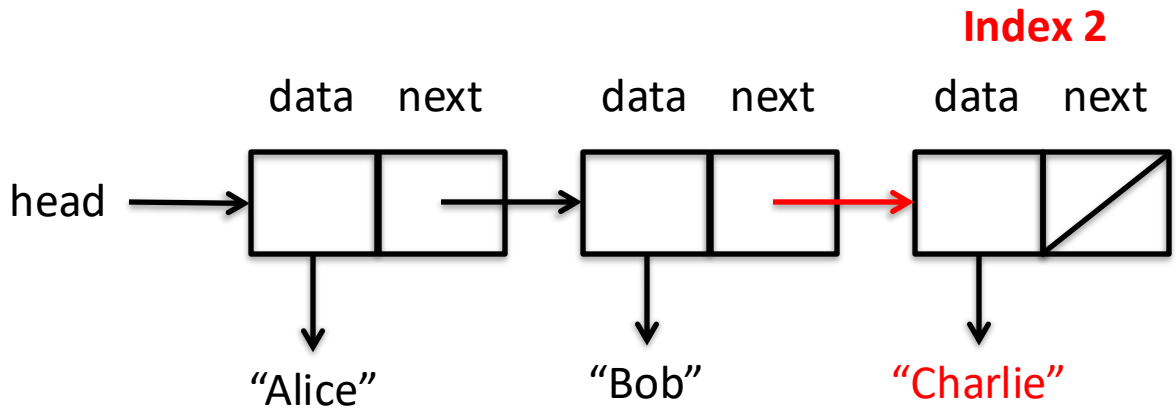
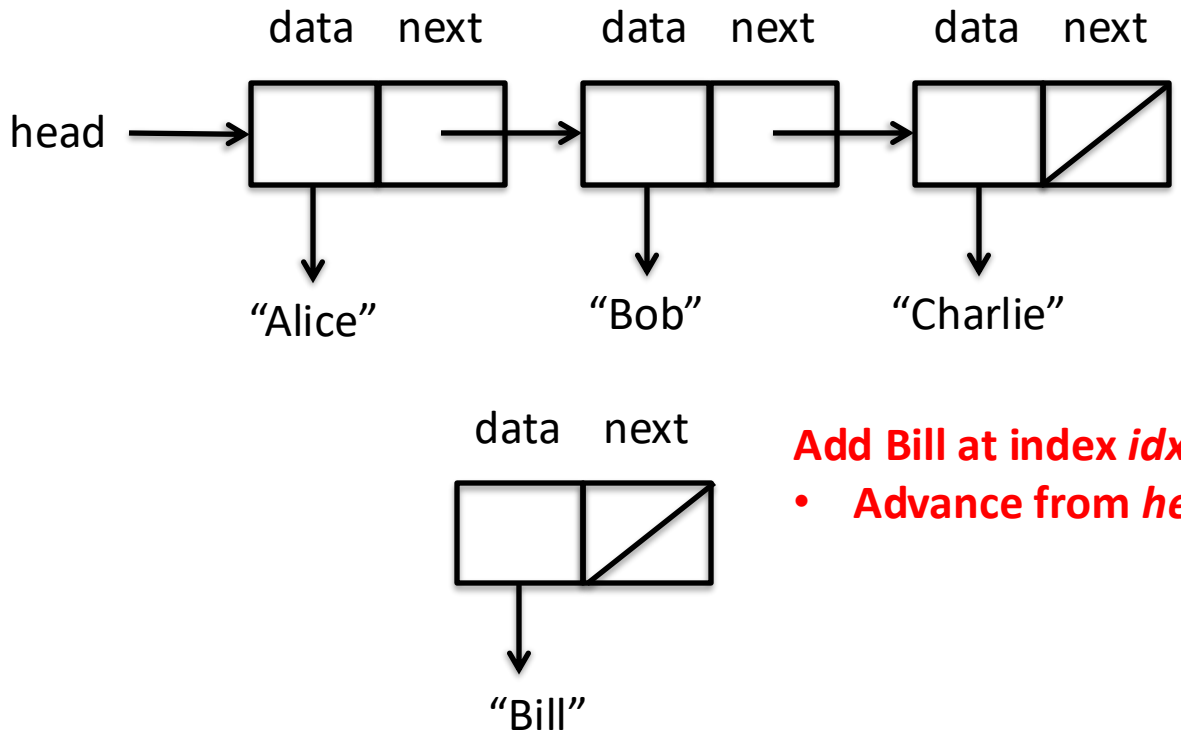



**Get item at index 2**

1. **Start at head (index 0)**
2. **Follow next pointer to index 1**
3. **Follow next pointer to index 2**
4. **Return "Charlie" (data of item 2)**

# *add()* "splices in" a new object anywhere in the list by updating next pointers

**add(1, "Bill")**




**Add Bill at index *idx=1***

- **Advance from *head* to *idx-1* (Alice)**

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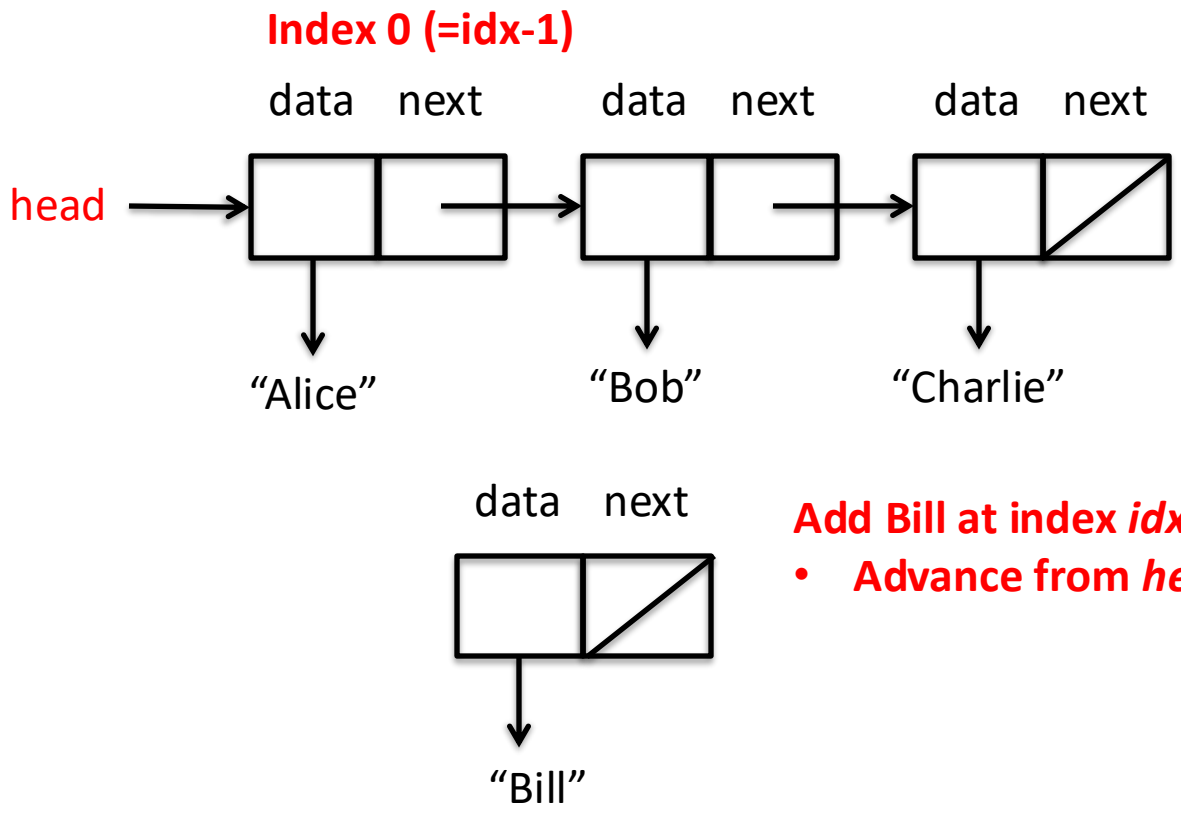


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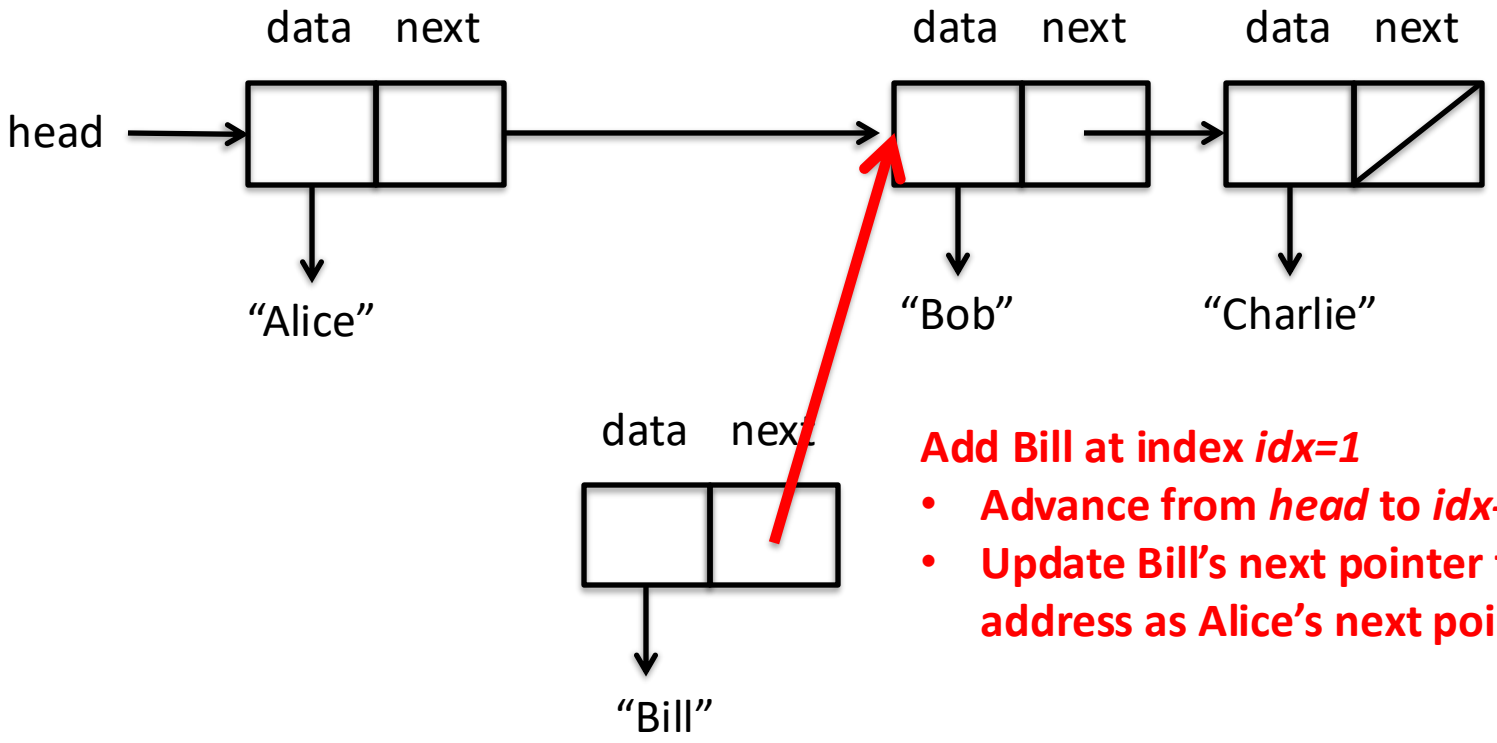
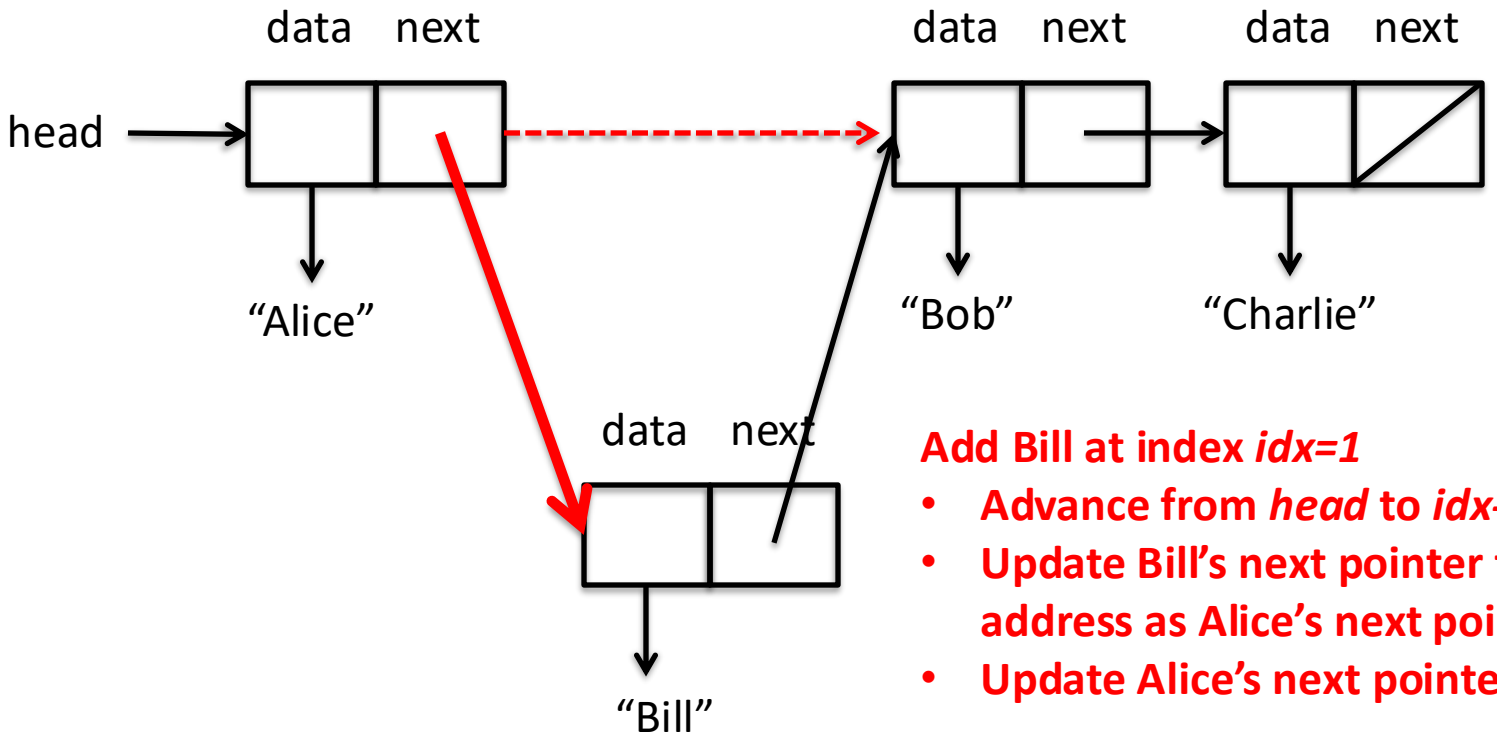



**Add Bill at index *idx=1***

- **Advance from *head* to *idx-1* (Alice)**
- **Update Bill's next pointer to same address as Alice's next pointer**

# *add()* "splices in" a new object anywhere in the list by updating next pointers

**add(1, "Bill")**




**Add Bill at index *idx=1***

- **Advance from *head* to *idx-1* (Alice)**
- **Update Bill's next pointer to same address as Alice's next pointer**
- **Update Alice's next pointer to Bill**

# *add()* "splices in" a new object anywhere in the list by updating next pointers

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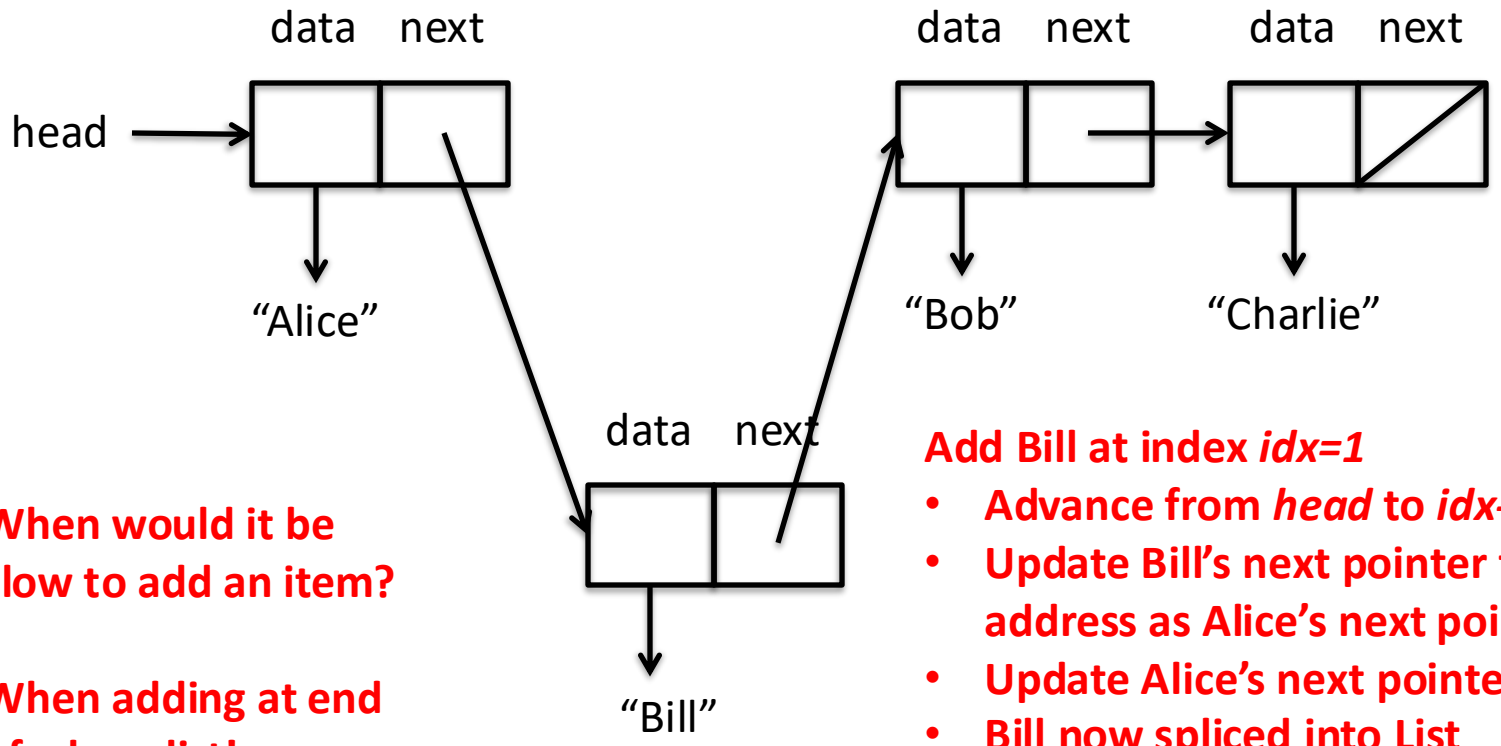



**When would it be slow to add an item?**

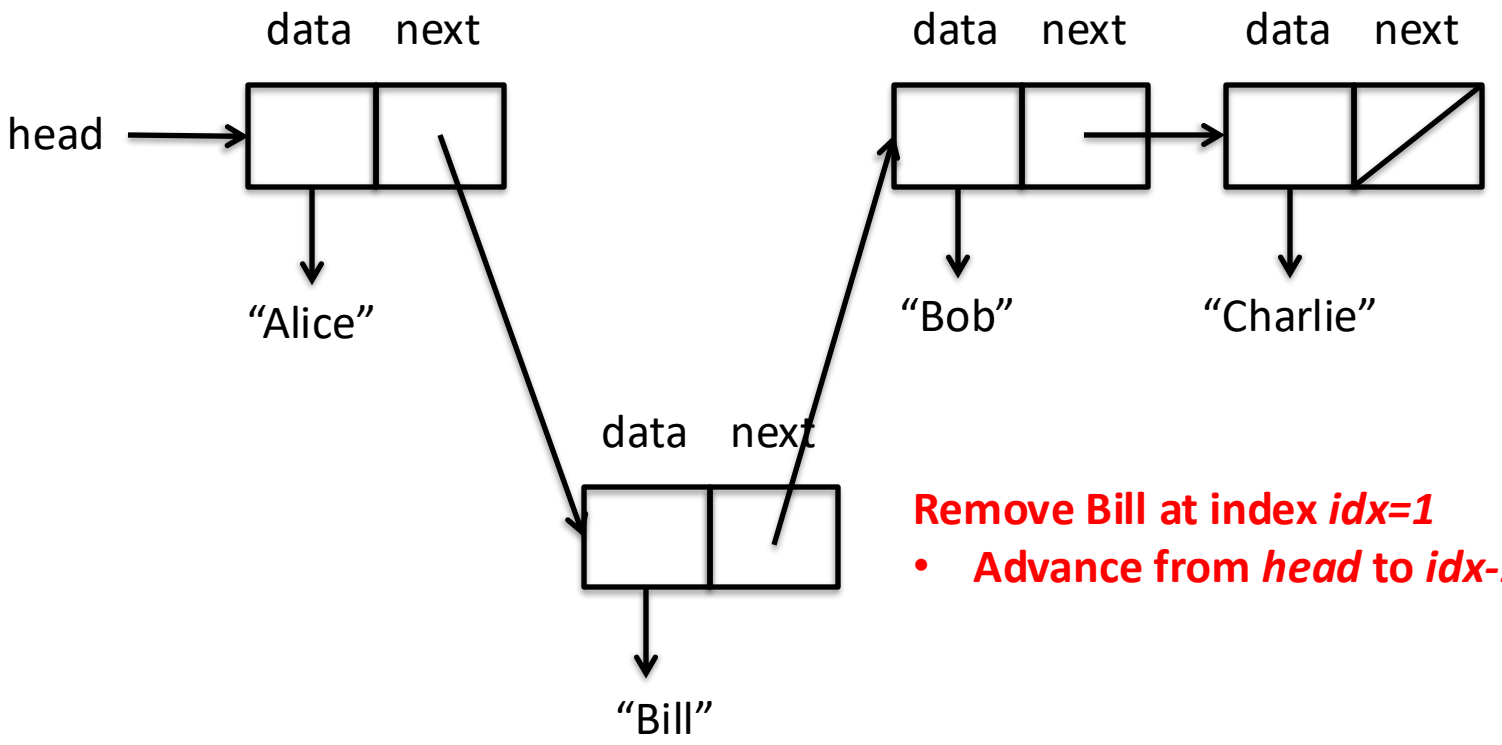
**When adding at end of a long list!**

**Add Bill at index *idx=1***

- **Advance from *head* to *idx-1* (Alice)**
- **Update Bill's next pointer to same address as Alice's next pointer**
- **Update Alice's next pointer to Bill**
- **Bill now spliced into List**
- **Once find idx-1, only two pointer updates needed – fast once at idx-1**

# *remove()* takes an item out of the list by updating next pointer

**remove(1)**

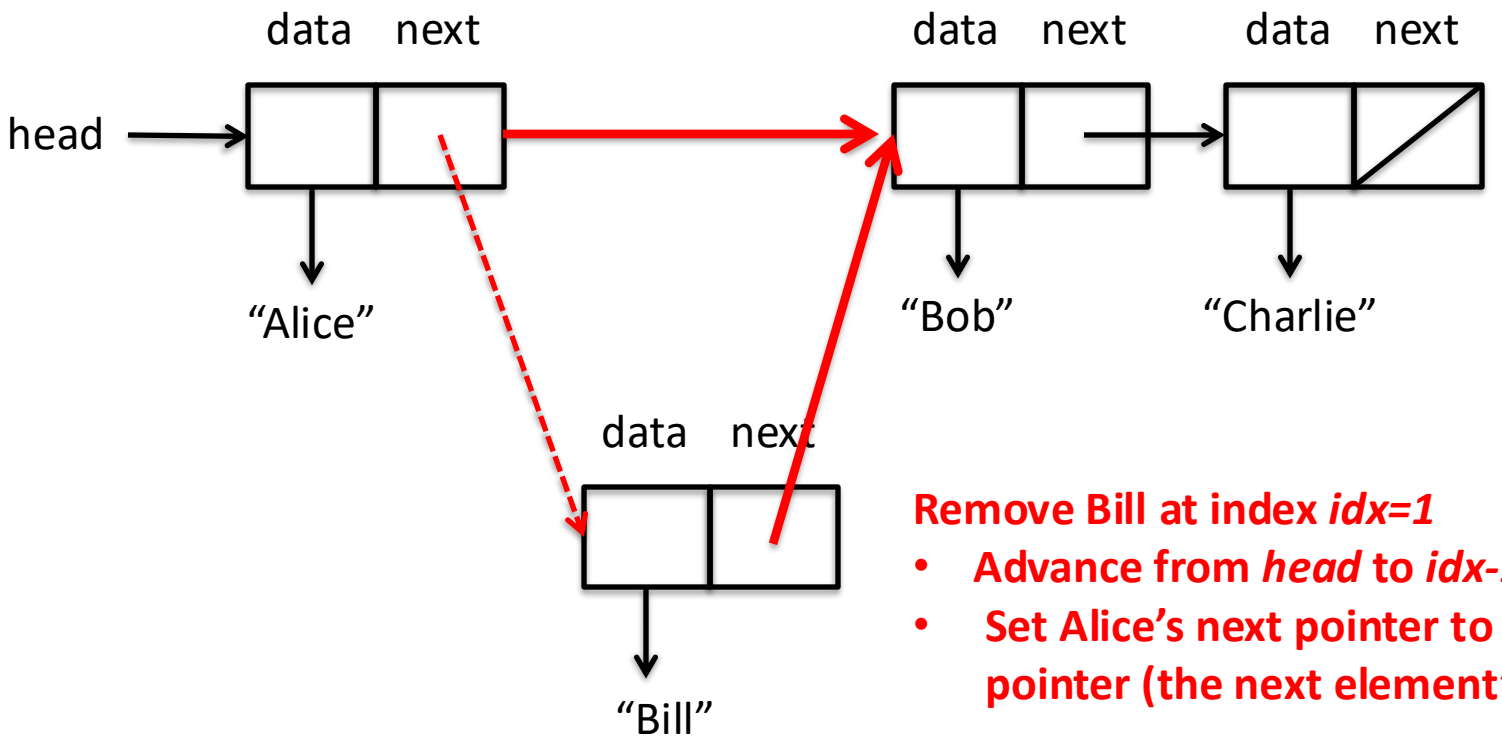



**Remove Bill at index *idx=1***

- **Advance from *head* to *idx-1* (Alice)**

# *remove()* takes an item out of the list by updating next pointer

**remove(1)**

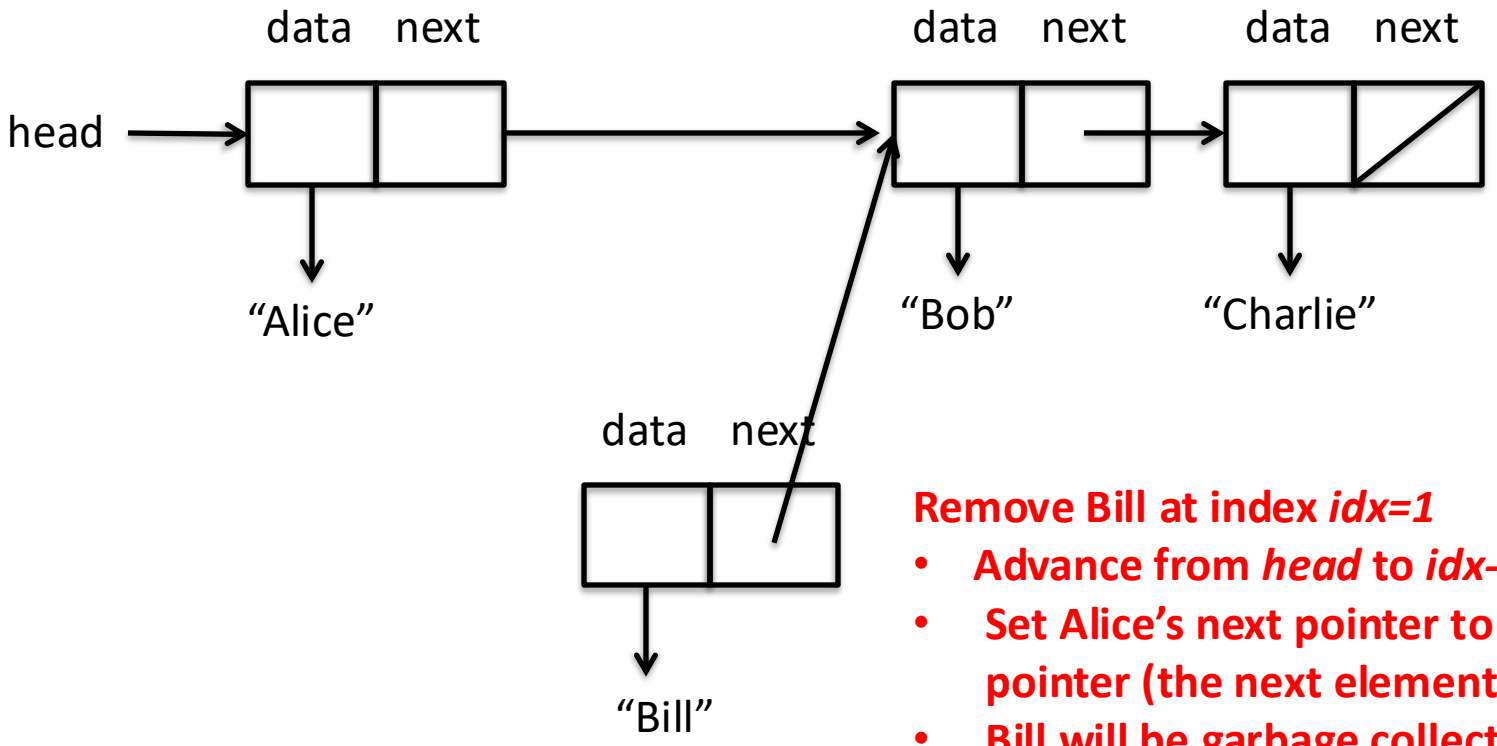



**Remove Bill at index *idx=1***

- **Advance from *head* to *idx-1* (Alice)**
- **Set Alice's next pointer to Bill's next pointer (the next element's next)**

# *remove()* takes an item out of the list by updating next pointer

**remove(1)**




**Remove Bill at index *idx=1***

- **Advance from *head* to *idx-1* (Alice)**
- **Set Alice's next pointer to Bill's next pointer (the next element's next)**
- **Bill will be garbage collected (in C we have to call *free()*)**

# SinglyLinked.java: Implementation of List interface

**SinglyLinked.java**

```
public class SinglyLinked<T> implements SimpleList<T>, Iterable<T> {
  private Element head;  // front of the linked list
  private int size;     // # elements in the list

  /**
   * The linked elements in the list: each has a piece of data and a next pointer
   */
  private class Element {
    private T data;
    private Element next;

    private Element(T data, Element next) {
      this.data = data;
      this.next = next;
    }
  }

  public SinglyLinked() {
    head = null;
    size = 0;
  }
```

**We will deal with Iterable soon, standby for more info, but can implement multiple interfaces**

**"implements" is a promise to implement all required methods specified by Interface SimpleList**

- ***size()***
- ***isEmpty()***
- ***add()***
- ***remove()***
- ***get()***
- ***set()***

# Lists hold items of generic type

**SinglyLinked.java**

```
public class SinglyLinked<T> implements SimpleList<T>, Iterable<T> {
  private Element head;  // front of the linked list
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  /**
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   */
  private class Element {
    private T data;
    private Element next;

    private Element(T data, Element next) {
      this.data = data;
      this.next = next;
    }
  }

  public SinglyLinked() {
    head = null;
    size = 0;
  }
```

- **Type of data is generic T**
- **Don't care what kind of data the List holds, could be Strings, Integers, Student Objects,…**
- **This way we don't have to write a separate implementation if use Strings as elements, and other implementation if use Integers, and third implementation if use …**
- **Just implement the List once and hold whatever data type needed for the application**

# Implement a private "nested" class to hold data and next pointer

**SinglyLinked.java**

```
public class SinglyLinked<T> implements SimpleList<T>, Iterable<T> {
  private Element head;  // front of the linked list
  private int size;    // # elements in the list

  /**
   * The linked elements in the list: each has a piece of data and a next pointer
   */
  private class Element {
    private T data;
    private Element next;

    private Element(T data, Element next) {
      this.data = data;
      this.next = next;
    }
  }

  public SinglyLinked() {
    head = null;
    size = 0;
  }
```

- **Define a private class within SinglyLinked called *Element* to implement *data* and *next* pointers (could be in its own file)**
- ***Element* constructor takes *data* as type T and pointer to next *Element* (could be null)**
- ***Element* is private to SinglyLinked (internal to this file, no need for others to change it)**

# Set head to null and size to zero in constructor

**SinglyLinked.java**

```
public class SinglyLinked<T> implements SimpleList<T>, Iterable<T> {
  private Element head; // front of the linked list
  private int size;     // # elements in the list

  /**
   * The linked elements in the list: each has a piece of data and a next pointer
   */
  private class Element {
    private T data;
    private Element next;

    private Element(T data, Element next) {
      this.data = data;
      this.next = next;
    }
  }

  public SinglyLinked() {
    head = null;
    size = 0;
  }
```

- **Creates *head* Element and *size* counter**
- **Constructor initializes *head* to null and *size* to 0**
- **Notice *head* is of type Element but is never "newed"**
- ***head* will be a pointer to first *Element* in the List**
- ***head* and *size* are private, don't want outsiders to be able to set them to something we don't expect!**

# Increment size instance variable on add, decrement on remove operation

**SinglyLinked.java**

```
/**
 * Return the number of elements in the List (they are indexed 0..size-1)
 * @return number of elements
 */
public int size() {
   return size;
}

/**
 * Returns true if there are no elements in the List, false otherwise
 * @return true or false
 */
public boolean isEmpty() {

}
```

- ***size* instance variable will be incremented on *add()*, decremented on *remove()***
- ***size()* method just returns instance variable *size***
- **Run-time complexity?**
- **O(1)**

- **How can *isEmpty()* be easily implemented?**

# Implementing *isEmpty* "isEasy" ☺

**SinglyLinked.java**

```
/**
 * Return the number of elements in the List (they are indexed 0..size-1)
 * @return number of elements
 */
public int size() {
   return size;
}

/**
 * Returns true if there are no elements in the List, false otherwise
 * @return true or false
 */
public boolean isEmpty() {
   return size == 0;
}
```

- **How can *isEmpty()* be easily implemented?**
- **Check if *size == 0***
- **Run-time complexity?**
- **O(1)**

# *advance* is a helper method to move to the $n^{th}$ item in the List

**SinglyLinked.java**

```
/**
 * Helper function, advancing to the nth Element in the list and returning it
 * (exception if not that many elements)
 */
private Element advance(int n) throws Exception {
  Element e = head;
  //safety check for valid index (don't assume caller checked!)
  if (e == null || n < 0 || n >= size) {
    throw new Exception("invalid advance");
  }

  // Just follow the next pointers n times
  for (int i = 0; i < n; i++) {
    e = e.next;
  }
  return e;
}
```

**Key point: to get to an index in a SinglyLinked List, must always start at *head* and march down List!**

- **advance() helper method**
- **Start at *head and* marches down *n* items (*e* not new'ed, it is an alias)**
- **Loop until hit $n^{th}$ item**
- **Return $n^{th}$ item (or throw exception)**
- **Note: return type from *advance()* is *Element***
- ***advance()* not specified by interface, but implementations can have more methods than required**
- **Do not assume caller checked for valid index!**
- **Run-time complexity?**
- **O(n), where *n* is the number of items in the List**

# *add* method uses *advance*

```
public void add(int idx, T item) throws Exception {
   //safety check for valid index (can add at size index)
   if (idx < 0 || idx > size) {
      throw new Exception("invalid index");
   }
   else if (idx == 0) {
      // Insert at head
      head = new Element(item, head);
   }
   else {
      // It's the next thing after element # idx-1
      Element e = advance(idx-1);
      // Splice it in
      e.next = new Element(item, e.next);
   }
   size++;
}
```

**SinglyLinked.java**

***add()/remove()* use *advance()* to march down list to item before index *idx*, then adjust pointers**

# *add* method uses *advance*

**SinglyLinked.java**

```
public void add(int idx, T item) throws Exception {
  //safety check for valid index (can add at size index)
  if (idx < 0 || idx > size) {
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    head = new Element(item, head);
  }
  else {
    // It's the next thing after element # idx-1
    Element e = advance(idx-1);
    // Splice it in
    e.next = new Element(item, e.next);
  }
  size++;
}
```
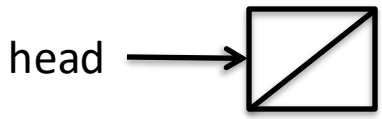

**Safety check for valid index**

**Throw an exception to tell the *caller* we didn't carry out this operation if *idx* is invalid**



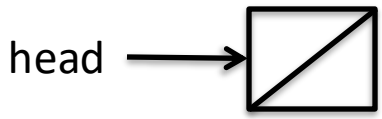
# No need to advance if adding at the head

**SinglyLinked.java**

```
public void add(int idx, T item) throws Exception {
  //safety check for valid index (can add at size index)
  if (idx < 0 || idx > size) {
    throw new Exception("invalid index");
  }
  else if (idx == 0) {
    // Insert at head
    head = new Element(item, head);
  }
  else {
    // It's the next thing after element # idx-1
    Element e = advance(idx-1);
    // Splice it in
    e.next = new Element(item, e.next);
  }
  size++;
}
```

**If adding at head (index 0)**

**add(0,15)**



# Just create a new Element and point head to it

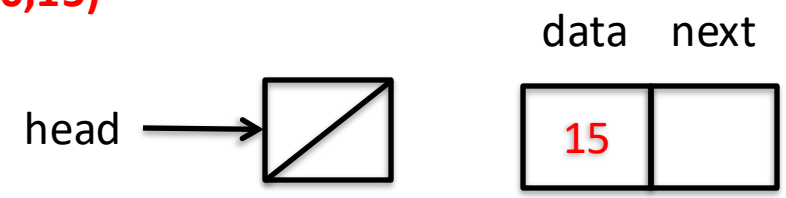
**SinglyLinked.java**

```
public void add(int idx, T item) throws Exception {
  //safety check for valid index (can add at size index)
  if (idx < 0 || idx > size) {
    throw new Exception("invalid index");
  }
  else if (idx == 0) {
    // Insert at head
    head = new Element(item, head);
  }
  else {
    // It's the next thing after element # idx-1
    Element e = advance(idx-1);
    // Splice it in
    e.next = new Element(item, e.next);
  }
  size++;
}
```

**If adding at head (index 0)**

- **Create new element with data set to parameter *item***

**add(0,15)**



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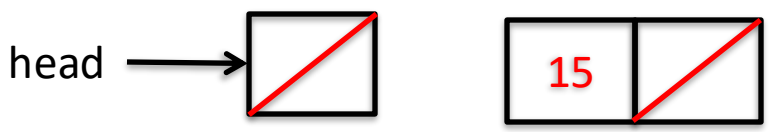
}
```

**SinglyLinked.java**

**If adding at head (index 0)**

- **Create new element with data set to parameter *item***
- **Set new element next pointer to wherever *head* points**

**add(0,15)**



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```
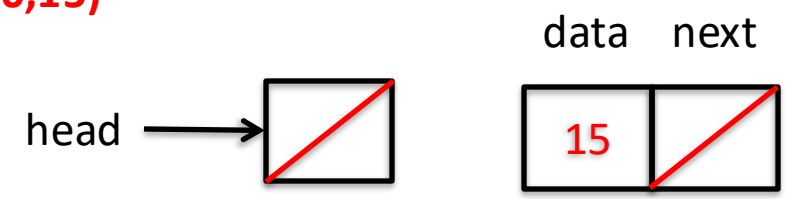

**SinglyLinked.java**

**If adding at head (index 0)**

- **Create new element with data set to parameter *item***
- **Set new element next pointer to wherever *head* points**
- ***head* will initially point to null**

**add(0,15)**



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      // Insert at head
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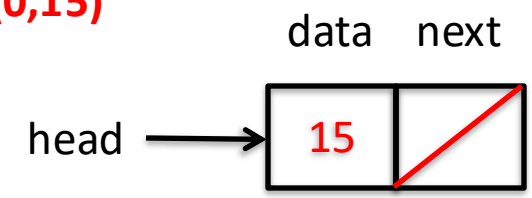
      Element e = advance(idx-1);
      // Splice it in
      e.next = new Element(item, e.next);
   }
   size++;
}
```

**SinglyLinked.java**

**If adding at head (index 0)**

- **Create new element with data set to parameter *item***
- **Set new element next pointer to wherever *head* points**
- ***head* will initially point to null**
- **Set *head* to new element**

**add(0,15)**



# Don’t forget to increment *size*

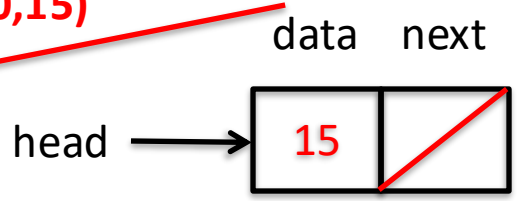
```
public void add(int idx, T item) throws Exception {
   //safety check for valid index (can add at size index)
   if (idx < 0 || idx > size) {
      throw new Exception("invalid index");
   }
   else if (idx == 0) {
      // Insert at head
      head = new Element(item, head);
   }
   else {
      // It's the next thing after element # idx-1
      Element e = advance(idx-1);
      // Splice it in
      e.next = new Element(item, e.next);
   }
   size++;
}
```

**SinglyLinked.java**

**If adding at head (index 0)**

- **Create new element with data set to parameter *item***
- **Set new element next pointer to wherever *head* points**
- ***head* will initially point to null**
- **Set *head* to new element**
- **Finally increment *size***

**add(0,15)**

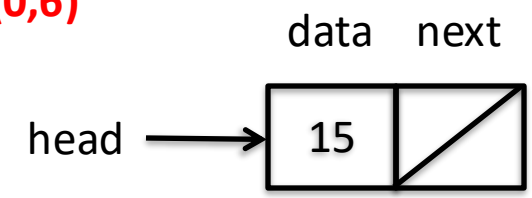


# Adding at head if the List is not empty is easy

**SinglyLinked.java**

```
public void add(int idx, T item) throws Exception {
   //safety check for valid index (can add at size index)
   if (idx < 0 || idx > size) {
      throw new Exception("invalid index");
   }
   else if (idx == 0) {
      // Insert at head
      head = new Element(item, head);
   }
   else {
      // It's the next thing after element # idx-1
      Element e = advance(idx-1);
      // Splice it in
      e.next = new Element(item, e.next);
   }
   size++;
}
```

**add(0,6)**



# Adding at head if the List is not empty is easy

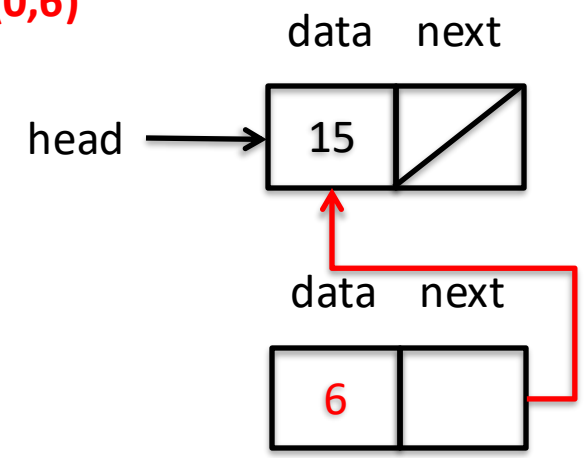
```
public void add(int idx, T item) throws Exception {
  //safety check for valid index (can add at size index)
  if (idx < 0 || idx > size) {
    throw new Exception("invalid index");
  }
  else if (idx == 0) {
    // Insert at head
    head = new Element(item, head);
  }
  else {
    // It's the next thing after element # idx-1
    Element e = advance(idx-1);
    // Splice it in
    e.next = new Element(item, e.next);
  }
  size++;
}
```

**SinglyLinked.java**

**If adding at head (index 0)**

- **Create new element with data set to parameter *item***
- **Set new element next pointer to wherever *head* points**

**add(0,6)**



# Adding at head if the List is not empty is easy

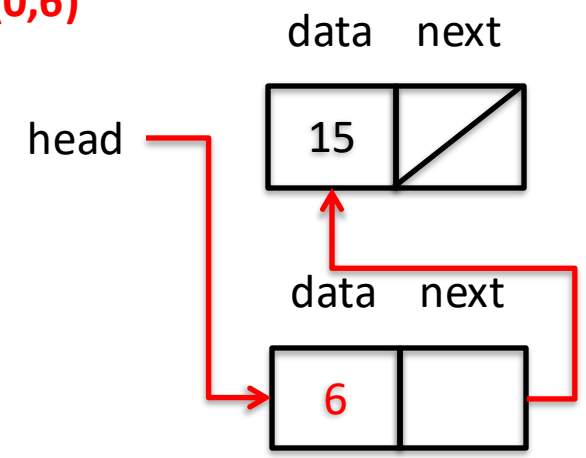
```
public void add(int idx, T item) throws Exception {
  //safety check for valid index (can add at size index)
  if (idx < 0 || idx > size) {
    throw new Exception("invalid index");
  }
  else if (idx == 0) {
    // Insert at head
    head = new Element(item, head);
  }
  else {
    // It's the next thing after element # idx-1
    Element e = advance(idx-1);
    // Splice it in
    e.next = new Element(item, e.next);
  }
  size++;
}
```

**SinglyLinked.java**

**If adding at head (index 0)**

- **Create new element with data set to parameter *item***
- **Set new element next pointer to wherever *head* points**
- **Set *head* to new element**
- **Finally increment *size***

**add(0,6)**



# If adding NOT at head, use *advance* method

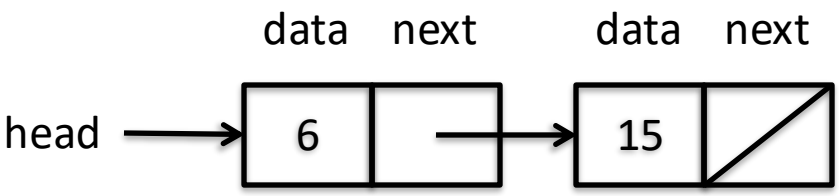
**SinglyLinked.java**

```
public void add(int idx, T item) throws Exception {
  //safety check for valid index (can add at size index)
  if (idx < 0 || idx > size) {
    throw new Exception("invalid index");
  }
  else if (idx == 0) {
    // Insert at head
    head = new Element(item, head);
  }
  else {
    // It's the next thing after element # idx-1
    Element e = advance(idx-1);
    // Splice it in
    e.next = new Element(item, e.next);
  }
  size++;
}
```

**If adding not at head**

- ***advance*() to *e=(idx-1)$^{th}$* item**

**add(1,3)**



# Move to index idx-1

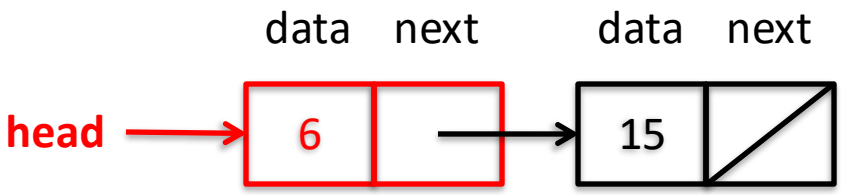
```
public void add(int idx, T item) throws Exception {
   //safety check for valid index (can add at size index)
   if (idx < 0 || idx > size) {
      throw new Exception("invalid index");
   }
   else if (idx == 0) {
      // Insert at head
      head = new Element(item, head);
   }
   else {
      // It's the next thing after element # idx-1
      Element e = advance(idx-1);
      // Splice it in
      e.next = new Element(item, e.next);
   }
   size++;
}
```

**SinglyLinked.java**

**If adding not at head**

- ***advance*() to *e=(idx-1)*$^{th}$ item**

**add(1,3)**




**Advance to item idx-1**
**Here (index 1)-1 = index 0**
**So *e* points to index 0 with data = 6**

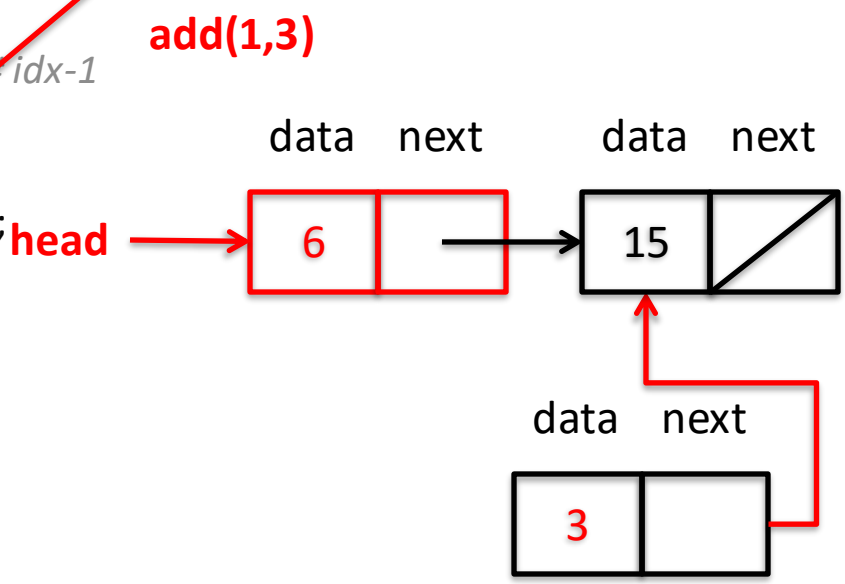
# Splice in a new Element that points to where Element at idx-1 points

**SinglyLinked.java**

```
public void add(int idx, T item) throws Exception {
  //safety check for valid index (can add at size index)
  if (idx < 0 || idx > size) {
    throw new Exception("invalid index");
  }
  else if (idx == 0) {
    // Insert at head
    head = new Element(item, head);
  }
  else {
    // It's the next thing after element # idx-1
    Element e = advance(idx-1);
    // Splice it in
    e.next = new Element(item, e.next);
  }
  size++;
}
```

**If adding not at head**

- ***advance*() to *e=(idx-1)$^{th}$* item**
- **Create new *Element* with *data* set to *item* and *next* to *e.next***



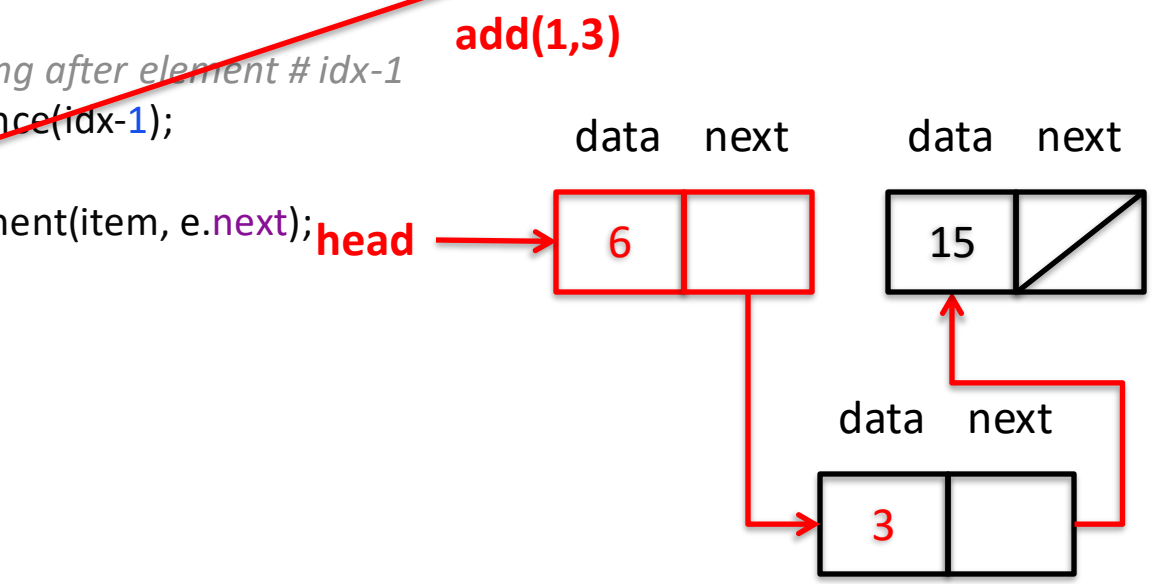
# Set idx-1 to point to new Element

**SinglyLinked.java**

```
public void add(int idx, T item) throws Exception {
   //safety check for valid index (can add at size index)
   if (idx < 0 || idx > size) {
      throw new Exception("invalid index");
   }
   else if (idx == 0) {
      // Insert at head
      head = new Element(item, head);
   }
   else {
      // It's the next thing after element # idx-1
      Element e = advance(idx-1);
      // Splice it in
      e.next = new Element(item, e.next);
   }
   size++;
}
```

**If adding not at head**

- ***advance*() to *e=(idx-1)$^{th}$* item**
- **Create new *Element* with *data* set to *item* and *next* to *e.next***
- **Set *e.next* = new item**



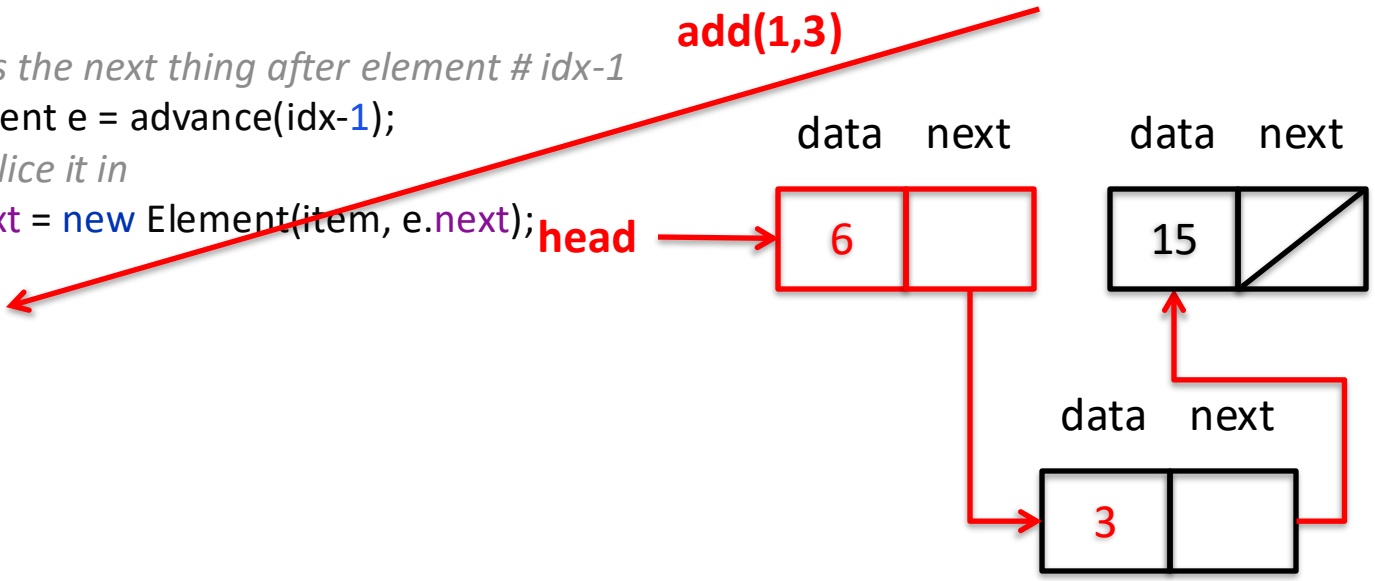
# Don’t forget to increment *size*

**SinglyLinked.java**

```
public void add(int idx, T item) throws Exception {
  //safety check for valid index (can add at size index)
  if (idx < 0 || idx > size) {
    throw new Exception("invalid index");
  }
  else if (idx == 0) {
    // Insert at head
    head = new Element(item, head);
  }
  else {
    // It's the next thing after element # idx-1
    Element e = advance(idx-1);
    // Splice it in
    e.next = new Element(item, e.next);
  }
  size++;
}
```

**If adding not at head**

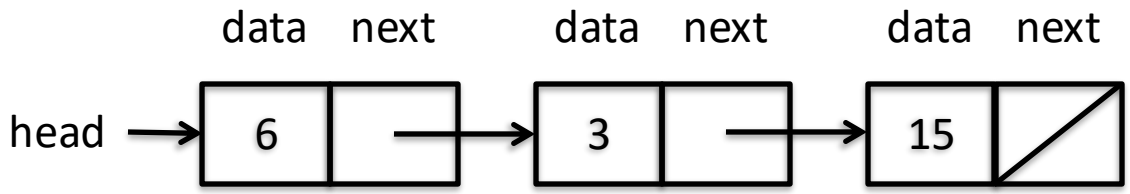
- ***advance*() to *e=(idx-1)$^{th}$* item**
- **Create new *Element* with *data* set to *item* and *next* to *e.next***
- **Set *e.next* = new item**
- **Finally, increment *size***



# Adding at the end is easy

**SinglyLinked.java**

```
public void add(int idx, T item) throws Exception {
   //safety check for valid index (can add at size index)
   if (idx < 0 || idx > size) {
      throw new Exception("invalid index");
   }
   else if (idx == 0) {
      // Insert at head
      head = new Element(item, head);
   }
   else {
      // It's the next thing after element # idx-1
      Element e = advance(idx-1);
      // Splice it in
      e.next = new Element(item, e.next);
   }
   size++;
}
```




```
public void add(T item) throws Exception {
   add(size,item);
}
```

**How to easily add at the end?**
**Just call add with size as index**

**On SA-4 you'll do something more efficient using a tail pointer**

# *remove* method removes and returns data at *idx*

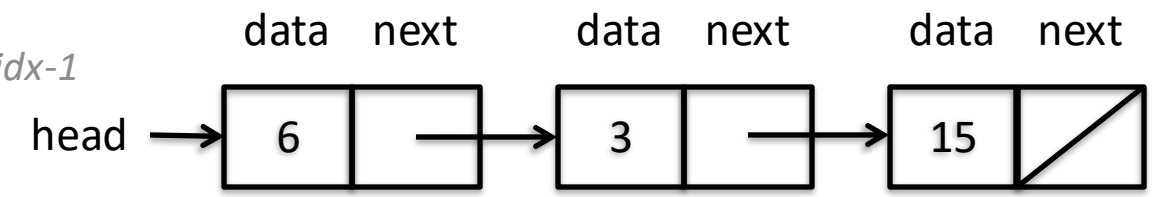
**SinglyLinked.java**

```
public T remove(int idx) throws Exception {
   T data = null; //data to return
   //safety check for valid index
   if (head == null || idx < 0 || idx >= size) {
     throw new Exception("invalid index");
   }
   else if (idx == 0) {
     data = head.data;
     head = head.next;
   }
   else {
     // It's the next thing after element # idx-1
     Element e = advance(idx-1);
     data = e.next.data;
     // Splice it out
     e.next = e.next.next;  //nice!
   }
   size--;
   return data;
}
```

**If removing at *head***

- **Save data at head**
- **Set *head* to next**

**remove(0)**



# If removing at head, just set head to head.next

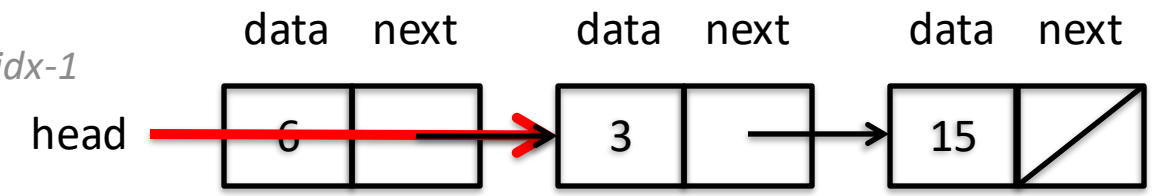
**SinglyLinked.java**

```
public T remove(int idx) throws Exception {
   T data = null; //data to return
   //safety check for valid index
   if (head == null || idx < 0 || idx >= size) {
     throw new Exception("invalid index");
   }
   else if (idx == 0) {
     data = head.data;
     head = head.next;
   }
   else {
     // It's the next thing after element # idx-1
     Element e = advance(idx-1);
     data = e.next.data;
     // Splice it out
     e.next = e.next.next;  //nice!
   }
   size--;
   return data;
}
```

**If removing at *head***

- **Save data at head**
- **Set *head* to next**

**remove(0)**




- **What happens to the old head element?**
- **Garbage collected! (memory returned to the Operating System)**

# If removing at head, just set head to head.next

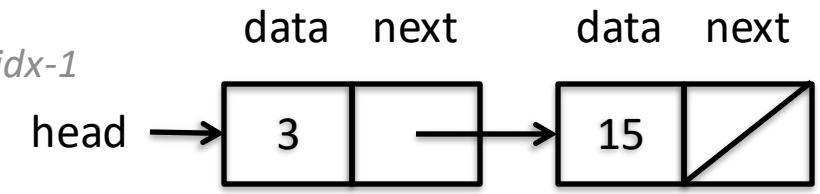
**SinglyLinked.java**

```
public T remove(int idx) throws Exception {
  T data = null; //data to return
  //safety check for valid index
  if (head == null || idx < 0 || idx >= size) {
    throw new Exception("invalid index");
  }
  else if (idx == 0) {
    data = head.data;
    head = head.next;
  }
  else {
    // It's the next thing after element # idx-1
    Element e = advance(idx-1);
    data = e.next.data;
    // Splice it out
    e.next = e.next.next;  //nice!
  }
  size--;
  return data;
}
```

**If removing at *head***

- **Save data at head**
- **Set *head* to next**

**remove(0)**




- **What happens to the old head element?**
- **Garbage collected! (memory returned to the Operating System)**

# If removing NOT at head, advance to idx-1

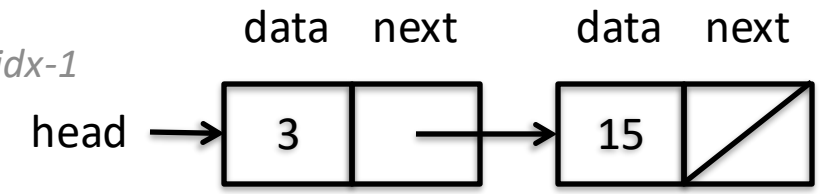
**SinglyLinked.java**

```
public T remove(int idx) throws Exception {
   T data = null; //data to return
   //safety check for valid index
   if (head == null || idx < 0 || idx >= size) {
     throw new Exception("invalid index");
   }
   else if (idx == 0) {
     data = head.data;
     head = head.next;
   }
   else {
     // It's the next thing after element # idx-1
     Element e = advance(idx-1);
     data = e.next.data;
     // Splice it out
     e.next = e.next.next;  //nice!
   }
   size--;
   return data;
}
```

**If removing not at *head***

- ***advance()* to *idx-1 (data 3 here)***
- **Save data at idx**
- **Set *e.next* to *e.next.next***

**remove(1)**



# Set idx-1 Element next to point to next.next

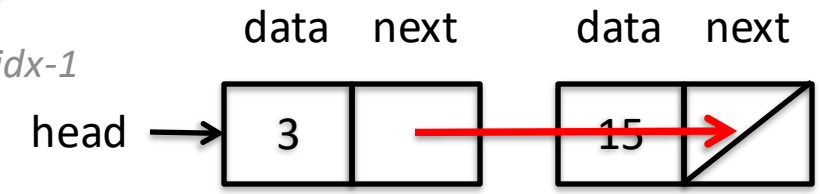
**SinglyLinked.java**

```
public T remove(int idx) throws Exception {
   T data = null; //data to return
   //safety check for valid index
   if (head == null || idx < 0 || idx >= size) {
     throw new Exception("invalid index");
   }
   else if (idx == 0) {
     data = head.data;
     head = head.next;
   }
   else {
     // It's the next thing after element # idx-1
     Element e = advance(idx-1);
     data = e.next.data;
     // Splice it out
     e.next = e.next.next;  //nice!
   }
   size--;
   return data;
}
```

**If removing not at *head***

- ***advance()* to *idx-1 (data 3 here)***
- **Save data at idx**
- **Set *e.next* to *e.next.next***

**remove(1)**



# Set idx-1 Element next to point to next.next

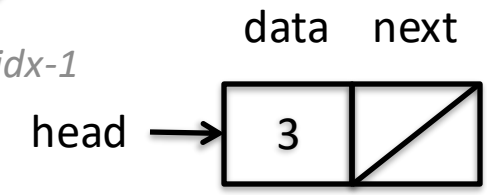
**SinglyLinked.java**

```
public T remove(int idx) throws Exception {
   T data = null; //data to return
   //safety check for valid index
   if (head == null || idx < 0 || idx >= size) {
     throw new Exception("invalid index");
   }
   else if (idx == 0) {
     data = head.data;
     head = head.next;
   }
   else {
     // It's the next thing after element # idx-1
     Element e = advance(idx-1);
     data = e.next.data;
     // Splice it out
     e.next = e.next.next;  //nice!
   }
   size--;
   return data;
}
```

**If removing not at *head***

- ***advance()* to *idx-1 (data 3 here)***
- **Save data at idx**
- **Set *e.next* to *e.next.next***

**remove(1)**



# *get* and *set* are straightforward with *advance* method

**SinglyLinked.java**

```
public T get(int idx) throws Exception {
   //safety check for valid index
   if (idx < 0 || idx >= size) {
     throw new Exception("invalid index");
   }
   Element e = advance(idx);
   return e.data;
}

public void set(int idx, T item) throws Exception {
   //safety check for valid index
   if (idx < 0 || idx >= size) {
     throw new Exception("invalid index");
   }
   Element e = advance(idx);
   e.data = item;
}
```

- ***get()/set()* also use *advance()* to march down list, this time to index *idx***
- ***Run-time complexity?***
- ***O(n)* where *n* is the number of items in the List**

# toString returns a String representation of the List (doesn't print!)

**SinglyLinked.java**

***Key point: all operations start at head and march down list***

```
public String toString() {
   String result = "";
   for (Element x = head; x != null; x = x.next)
      result += x.data + "->";
   result += "[/]";

   return result;
}
```

**Note: no curly braces around for loop body!**

**Only the line following for statement is included in loop**

***On an exam: make sure you return a String with toString(), don't print in toString()***

***toString()* overrides a Java Object method and allows us to create a string representation of the object**

**If *toString()* not overriden, defaults to the memory address of object**

**Return type is String, if used in print, doesn't actually do the printing**

**Run-time complexity Θ(n)**

# ListTest.java: Test of List implementation

**ListTest.java**

```
public class ListTest {
  public static void main(String[] args) throws Exception {
    SimpleList<String> list = new SinglyLinked<String>();
    System.out.println(list);
    list.add("1"); System.out.println(list);
    list.add("2"); System.out.println(list);
    list.add(0, "a"); System.out.println(list);
    list.add(1, "c"); System.out.println(list);
    list.add(1, "b"); System.out.println(list);
    list.set(2, "e"); System.out.println(list.get(2));
    list.add(0, "z"); System.out.println(list);
    String data = list.remove(2); System.out.println(data);
    System.out.println(list);
    data = list.remove(0); System.out.println(data);
    System.out.println(list);
    data = list.remove(1); System.out.println(data);
    System.out.println(list);
    data = list.remove(list.size()-1); System.out.println(list);
```

**Declare SinglyLinked List to hold Strings, so T = String in the implementation**

**Implementation is SinglyLinked which implemented SimpleList interface**

**Next class we'll look at an array implementation which will also be a SimpleList**

**Output**

```
[/]
1->[/]
1->2->[/]
a->1->2->[/]
a->c->1->2->[/]
a->b->c->1->2->[/]
e
z->a->b->e->1->2->[/]
b
z->a->e->1->2->[/]
z
a->e->1->2->[/]
e
a->1->2->[/]
a->1->[/]
```

# ListTest.java: Test of List implementation

**ListTest.java**

```
public class ListTest {
  public static void main(String[] args) throws Exception {
    SimpleList<String> list = new SinglyLinked<String>();
    System.out.println(list);
    list.add("1"); System.out.println(list);
    list.add("2"); System.out.println(list);
    list.add(0, "a"); System.out.println(list);
    list.add(1, "c"); System.out.println(list);
    list.add(1, "b"); System.out.println(list);
    list.set(2, "e"); System.out.println(list.get(2));
    list.add(0, "z"); System.out.println(list);
    String data = list.remove(2); System.out.println(data);
    System.out.println(list);
    data = list.remove(0); System.out.println(data);
    System.out.println(list);
    data = list.remove(1); System.out.println(data);
    System.out.println(list);
    data = list.remove(list.size()-1); System.out.println(list);
```

***toString()* method called in print statements**

**Output**

```
[/]
1->[/]
1->2->[/]
a->1->2->[/]
a->c->1->2->[/]
a->b->c->1->2->[/]
e
z->a->b->e->1->2->[/]
b
z->a->e->1->2->[/]
z
a->e->1->2->[/]
e
a->1->2->[/]
a->1->[/]
```

# ListTest.java: Test of List implementation

**ListTest.java**

```
public class ListTest {
  public static void main(String[] args) throws Exception {
    SimpleList<String> list = new SinglyLinked<String>();
    System.out.println(list);
    list.add("1"); System.out.println(list);
    list.add("2"); System.out.println(list);
    list.add(0, "a"); System.out.println(list);
    list.add(1, "c"); System.out.println(list);
    list.add(1, "b"); System.out.println(list);
    list.set(2, "e"); System.out.println(list.get(2));
    list.add(0, "z"); System.out.println(list);
    String data = list.remove(2); System.out.println(data);
    System.out.println(list);
    data = list.remove(0); System.out.println(data);
    System.out.println(list);
    data = list.remove(1); System.out.println(data);
    System.out.println(list);
    data = list.remove(list.size()-1); System.out.println(list);
```

***toString()* method called in print statements**

**Remember, *toString()* returns a String (doesn't do the printing)**

**Output**

```
[/]
1->[/]
1->2->[/]
a->1->2->[/]
a->c->1->2->[/]
a->b->c->1->2->[/]
e
z->a->b->e->1->2->[/]
b
z->a->e->1->2->[/]
z
a->e->1->2->[/]
e
a->1->2->[/]
a->1->[/]
```

# Summary of SinglyLinked run-time complexity

**Run-time complexity**

| | Linked list |
|---|---|
| *get(i)* | ? |
| *set(i,e)* | ? |
| *add(i,e)* | ? |
| *remove(i)* | ? |

# Summary of SinglyLinked run-time complexity

**Run-time complexity**

| | Linked list |
|---|---|
| *get(i)* | O(n) |
| *set(i,e)* | O(n) |
| *add(i,e)* | O(n) |
| *remove(i)* | O(n) |

- **Start at *head* and march down to find index *i***
- **Slow to get to index, O(n) in worst case**
- **Once there, operations are fast O(1)**
- **Best case: all operations on head**
- **If constrain to only operate at head**
  - **All operations become O(1)**

# Agenda

1. Singly linked List ADT implementation
2. Exceptions

**Key points:**

1. **Exceptions are used when something unexpected happens**
2. **The *called* method can tell the *calling* method about the exception**
3. **The *calling* method can *catch* the exception and continue running**

# An exception indicates that something unexpected happened at run-time

- Cannot check for all errors at compile time
- What if we ask for element at an index of -1 in an array?
  - There is no clear, “always-do-this”, answer
  - Maybe we should return null or maybe we should stop execution
- Exceptions provide a way to show something is amiss, and let calling functions deal with error (or not)
- Exceptions not handled by a method are passed to calling method. If exception not handled in *main()* or before, program stops
- “Throw” error with `throw new Exception(“error description”)`
- Java provides structured error-handling via *try/catch/finally* blocks
  - *catch* executes only if there is an exception in *try* body
  - *catch* block can specify the type of error it handles
  - Can have multiple *catch* blocks for each *try*
  - *Finally* block executes regardless whether *try* succeeds or fails

# ListExceptions.java: Exceptions can be handled with try/catch/finally blocks

**ListExceptions.java**

```
4  public class ListExceptions {
5      public static void main(String[] args) { // note: no "throws exception", as every method that could is
6
7          SimpleList<String> list = new SinglyLinked<String>();
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9          try {
10             list.add(-1, "?");
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35         catch (Exception e) {
36             System.out.println("why did I catch it again!"); // won't print -- we know this code is fine
37         }
38         finally {
39             System.out.println("finally 2"); // executed whether or not caught an error
40         }
41 }
42 }
43
```

**Create new SinglyLinked List**
**T in SinglyLinked.java now becomes String**

Problems Javadoc Declaration Console Debug Expressions Error Log Console Call Hierarchy

```
<terminated> ListExceptions [Java Application] /Library/Java/JavaVirtualMachines/jdk1.8.0_112.jdk/Contents/Home/bin/java (Apr 6, 2018, 1:20:09 PM)
caught it!
caught it again!
java.lang.Exception: invalid index
finally 1
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**Try block**

**Catch block**
**Only executes if exception in try block**

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**Trying to add at index -1 is an error, the catch block will execute because *add()* throws an exception for negative indices**

Problems Javadoc Declaration Console Debug Expressions Error Log Console Call Hierarchy

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```
public void add(int idx, T item) throws Exception {
  //safety check for valid index (can add at size index)
  if (idx < 0 || idx > size) {
    throw new Exception("invalid index");
  }
  else if (idx == 0) {
    // Insert at head
    head = new Element(item, head);
  }
  else {
     Element e = advance(idx-1);
     e.next = new Element(item, e.next);
}
  size++;
}
```

**SinglyLinked.java**

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**Trying to add at index -1 is an error, the catch block will execute because *add()* throws an exception for negative indices**

**Catch block on line 15 executes because exception thrown on line 10**

**Lines 11 and 12 never execute because exception on line 10 stops execution in try block and starts running in catch block**

**"I never run" and "Neither do I" are not printed**

**If we didn't catch exception, the program would end because *main()* wouldn't have caught the exception (but we did catch it, so *main()* doesn't end execution)**

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```

**Trying to add at index -1 is *still* an error, the catch block will execute**

Problems Javadoc Declaration Console Debug Expressions Error Log Console Call Hierarchy

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43
```

Trying to add at index -1 is ***still*** an error, the catch block will execute

We can see what the exception was by printing e (it is just an object)

```
public void add(int idx, T item) throws Exception {
  //safety check for valid index (can add at size index)
  if (idx < 0 || idx > size) {
    throw new Exception("invalid index");
  }
  else if (idx == 0) {
    //Insert at head
    head = new Element(item, head);
  }
  ...
```

Problems Javadoc Declaration Console Debug Expressions Error Log Console Call Hierarchy

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```
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"invalid index" was the message we included when we threw an error in the add method of SinglyLinked.java

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```

- ***finally*** **always executes, regardless of whether exception in *try* block**
- ***catch*** **only executes if exception occurs in *try* block, otherwise *catch* code does not execute**
- **If exception in *try* block, execution in the *try* block stops at the point of the exception and picks up in first line of *catch* block**
- **Code in the *try* block after the line that caused the exception is not executed**

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```

**This is valid, so *catch* block does not execute**

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**This is valid, so *catch* block does not execute**

***finally* always executes, even if no exception in try block**

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```

# Key points

1. The List ADT specifies a set of operations that must be implemented
2. Those operations can be implemented using a singly linked list
3. Exceptions are used when something unexpected happens
4. The *called* method can tell the *calling* method about the exception
5. The *calling* method can *catch* the exception and continue running