20-0: **Linked List**

- Previous Practical Example:
  - `removeAt(int index)`
  - `remove(Object o)`

20-1: **removeAt**

- First need to get to node *before* the one we want to remove
- We can then use the next pointer of the previous node to do removal (example on board)

20-2: **Special Cases**

- Two special cases:
  - Removing from an empty list
  - Removing the first element in the list
- Why do we need these two special cases?

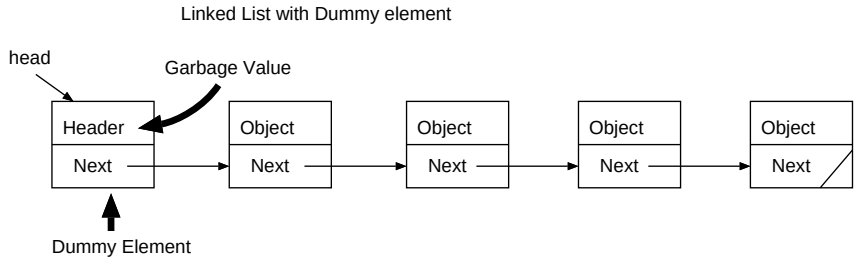
20-3: **removeAt**

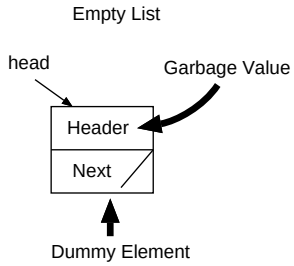
```
public class LinkedList
{
   private ListNode head;
   public void removeAt(int index)
   {
      if (head == null)
         return null;  // May want to throw an execption here instead ...
      if (index == 0)
      {
         head = head.next;
      }
      else
      {
         ListNode tmp = head;
         for (int i = 0; i < index - 1; i++)
         {
            tmp = tmp.next;
         }
         tmp.next = tmp.next.next;
      }
   }
}
```

20-4: **Special Cases**

- Two special cases:
  - Removing from an empty list
  - Removing the first element in the list
- We can remove these special cases by using a dummy element

20-5: **Dummy Element**





20-6: **Dummy Element**

```
class LinkedList
{
   ListNode head;

   LinkedList()
   {
      head = new ListNode(null, null);
   }

   // Other methods ...

}
```

20-7: **find, Dummy Element**

```
class LinkedList
{
   ListNode head;

   LinkedList()
   {
      head = new ListNode(null, null);
   }

   boolean find(Object o) { ... }
}
```

20-8: **find, Dummy Element**

```
class LinkedList
{
   ListNode head;

   boolean find(Object o)
   {
      for (ListNode tmp = head.next; tmp != null; tmp = tmp.next)
      {
         if (tmp.data.equals(o))
         {
            return true;
         }
      }
      return false;
   }
}
```

20-9: **RemoveAt, Dummmy Element**

```
public class LinkedList
{
   private ListNode head;

   LinkedList()
   {
      head = new ListNode(null, null);
```

```
   }

   public void removeAt(int index) { ... }

}
```

20-10: **RemoveAt, Dummmy Element**

```
public class LinkedList
{
   private ListNode head;
   public void removeAt(int index)
   {
      ListNode tmp = head;
      for (int i = 0; i < index; i++)
      {
         tmp = tmp.next;
      }
      tmp.next = tmp.next.next;
   }
}
```

20-11: **Append**

- Append an element to the end of our list
- How would we do it?

20-12: **Append**

- Append an element to the end of our list
- How would we do it?
  - Get a pointer to the last element of the list
  - (start from the front, advance unti last element reached)
  - Append element using this pointer

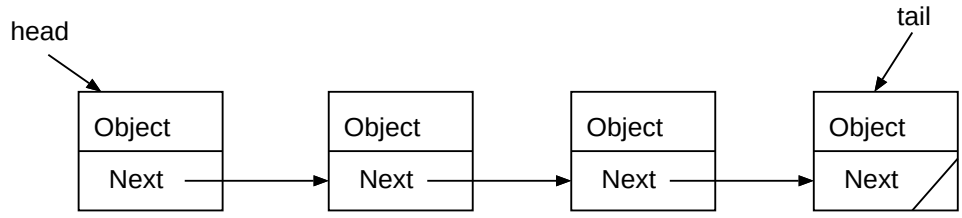
20-13: **Append**

```
public class LinkedList
{
   private ListNode head;
   public void append(Object obj)
   {
      ListNode last = head;
      while (last.next != null)
      {
         last = last.next;
      }
      last.next = new ListNode(obj, null);
   }
}
```

20-14: **Speed up Appending**

- To append an element to the end of a linked list, need to move a temp pointer to the end of the list
- How could we do this more quickly
  - We can add things to our data structure ...

20-15: **Tail Pointer**



20-16: **Tail Pointer**

```
public class LinkedList
{
   private ListNode head;
   private ListNode tail;

   public LinkedList()
   {
      head = null;
      tail = null;
   }

   public void insert(Object o) { ... }
}
```

20-17: **Tail Pointer**

```
public class LinkedList
{
   private ListNode head;
   private ListNode tail;

   public LinkedList()
   {
      head = null;
      tail = null;
   }

   public void insert(Object o)
   {
      head = new ListNode(o, head);
      if (tail == null)
         tail = head;
   }
}
```

20-18: **Tail Pointer**

```
public class LinkedList
{
   private ListNode head;
   private ListNode tail;

   public LinkedList()
   {
      head = null;
      tail = null;
   }

   public void append(Object o) { ... }
}
```

20-19: **Tail Pointer**

```
public class LinkedList
{
   private ListNode head;
   private ListNode tail;

   public void append(Object o)
   {
      if (tail != null)
      {
         tail.next = new ListNode(o);
         tail = tail.next
      }
      else
      {
         head = new ListNode(o, head);
         tail = head;
      }
   }
}
```

20-20: **Doubly Linked List**

- Deleting from (and inserting into!) a linked list can be challenging because you need to find the node *before* the node you are looking for
- Once you've found the node, it's too late – can't follow pointers backwards to get to the previous node

20-21: **Doubly Linked List**

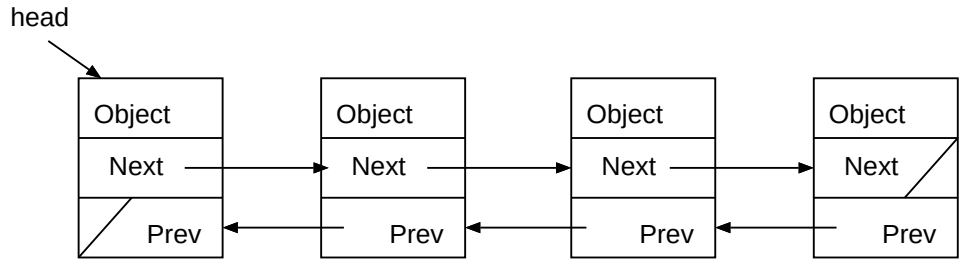
- Deleting from (and inserting into!) a linked list can be challenging because you need to find the node *before* the node you are looking for

- Once you've found the node, it's too late – can't follow pointers backwards to get to the previous node
  - ... unless you keep a pointer to the previous node in the list, too!

20-22: **Doubly Linked List Node**

```
public class DoubleLinkedListNode
{
   Object data;
   DoubleLinkedListNode next;
   DoubleLinkedListNode previous;
   public DoubleLinkedListNode (int data)
   {
      this.data = data;
      this.next = null;
      this.previous = null;
   }
   public DoubleLinkedListNode (int data, DoubleLinedListNode next)
   {
      this.data = data;
      this.next = next;
      this.previous = null;
   }
   public DoubleLinkedListNode (int data, DoubleLinkedListNode next,
                                DoubleLinkedListNode previous)
   {
      this.data = data;
      this.next = next;
      this.previous = previous;
   }
}
```

20-23: **Doubly Linked List**



20-24: **Doubly Linked List**

- Advantages
  - Don't need to be "one off" to do deletions
  - Don't need as many special cases (with some modifications)
- Disadvantages
  - Uses more space (two pointers per node)
  - Need to update both previous/next when changing list

20-25: **Linked Lists**

```
public class LinkedList
{
   private ListNode head;

   public LinkedList()
   {
      head = null;
   }

   public void insert(Object o)
   {
      head = new DoubleLinkedListNode(o, head);
      if (head.next != null)
      {
         head.next.previous = head;
      }
   }
}
```

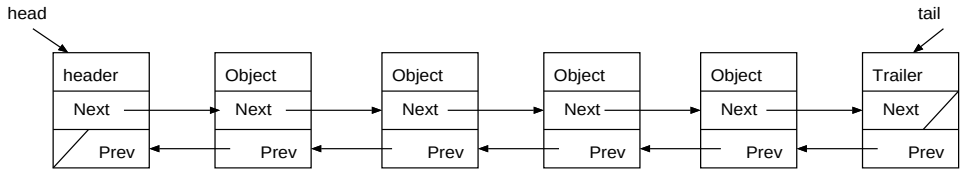
20-26: **remove, Doubly Linked**

```
   public void remove(Object o)
   {
      DoubleLinkedListNode tmp = head;
      while (tmp != null && !tmp.data.equals(o))
         tmp = tmp.next;
      if (tmp != null)
      {
         if (tmp.previous != null) // {} omitted to fit on slide!
             tmp.previous.next = tmp;
         else
             head = tmp;
         if (tmp.next != null)
         {
             tmp.next.previous = tmp;
         }
         return true;
      }
      return false;
}
```

20-27: **Dummy Element II**

- We still needed special cases for deleting from begining / end of the list
- We could avoid these special cases by adding two dummy elements – to front and end of list

20-28: **Doubly Linked List**



20-29: **Dummy Element**

```
class LinkedList
{
   DoublyLinkedListNode head;
   DoublyLinkedListNode tail;

   LinkedList()
   {
      head = new ListNode(null, null, null); // Dummy header
      tail = new ListNode(null, null, head); // Dummy trailer
      head.next = tail;
   }

   // Other methods ...

}
```

20-30: **Dummy Element II**

- We need to change the traversal a bit
  - Don’t want to compare anything to the dummy element

20-31: **remove, Doubly Linked**

```
public class LinkedList
{
   private DoubleLinkedListNode head;
   public void remove(Object o)
   {
      DoubleLinkedListNode tmp = head;
      while (tmp.next != null && !tmp.data.equals(o))
      {
         tmp = tmp.next;
      }
      if (tmp.next != null)
      {
         tmp.previous.next = tmp;
         tmp.next.previous = tmp;
         return true;
      }
      else
      {
      return false;
      }
}
```

20-32: **Next Project**

- Go over next project / lab on website