csci 210: Data Structures

Linked lists

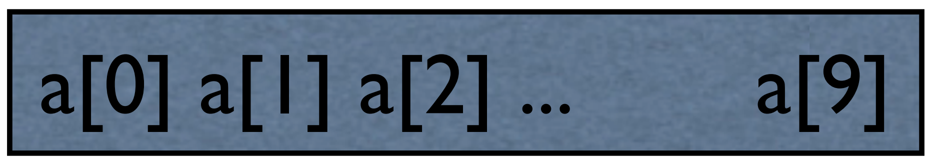
Summary

- Today
  - linked lists
  - single-linked lists
  - double-linked lists
  - circular lists

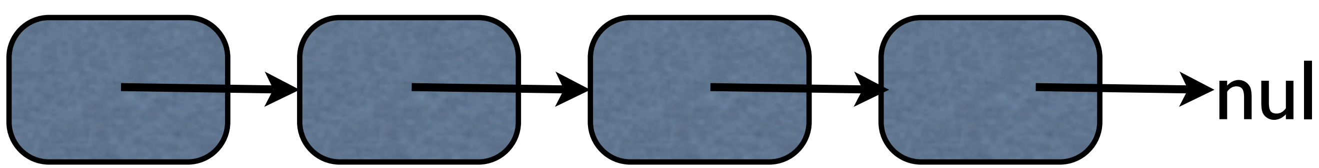
- READING:
  - GT textbook chapter 3.2. 3.3. 3.4

Arrays vs. Linked Lists

- We've seen arrays:
  - int[] a = new int[10];
  - a is a chunk of memory of size 10 x sizeof(int)
  - a has a fixed size



- A linked list is fundamentally different way of storing collections
  - each element stores a reference to the element after it

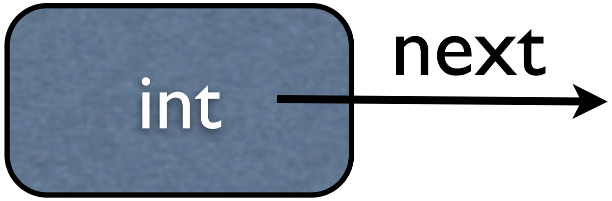


Arrays vs. Lists

- Arrays
  - have a pre-determined fixed size
  - easy access to any element a[i] in constant time
  - no space overhead
    - Size = n x sizeof(element)

- Linked lists
  - no fixed size; grow one element at a time
  - space overhead
    - each element must store an additional reference
    - Size = n x sizeof (element) + n x sizeof(reference)
  - no easy access to i-th element wrt the head of the list
    - need to hop through all previous elements

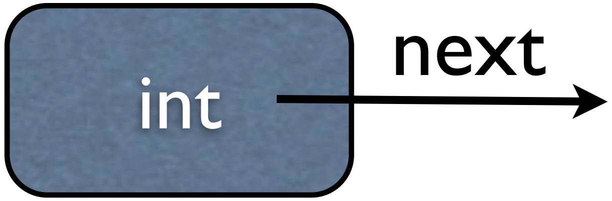
The Node class




```java
/** Node of a singly linked list of integers */
public class Node {

    private int element; // we assume elements are ints
    private Node next;
```

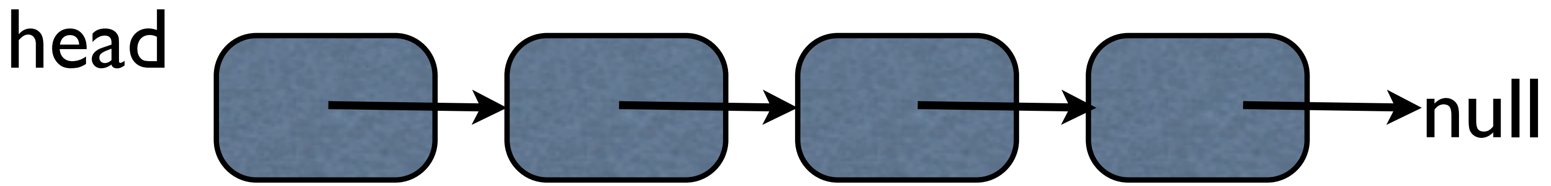
self-referential definition

The Node class



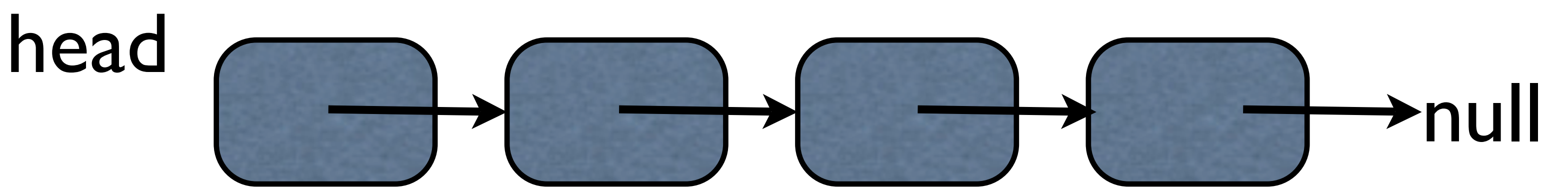

```
/** Node of a singly linked list of integers */
public class Node {
  private int element;   // we assume elements are ints
  private Node next;


  /** Creates a node with the given element and next node. */
  public Node(Int s, Node n) {
    element = s;
    next = n;
  }

  /** Returns the element of this node. */
  public int getElement() { return element; }

  /** Returns the next node of this node. */
  public Node getNext() { return next; }

  // Modifier methods:
  /** Sets the element of this node. */
  public void setElement(int newElem) { element = newElem; }

  /** Sets the next node of this node. */
  public void setNext(Node newNext) { next = newNext; }
}
```

A Single-Linked-List class




```java
/** Singly linked list .*/
public class SLinkedList {
  protected Node head;       // head node of the list
  protected long size;       // number of nodes in the list


  /** Default constructor that creates an empty list */
  public SLinkedList() {
    head = null;
    size = 0;
  }
```

A Single-Linked-List class




```java
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  /** Default constructor that creates an empty list */
  public SLinkedList() {
    head = null;
    size = 0;
  }


}
```
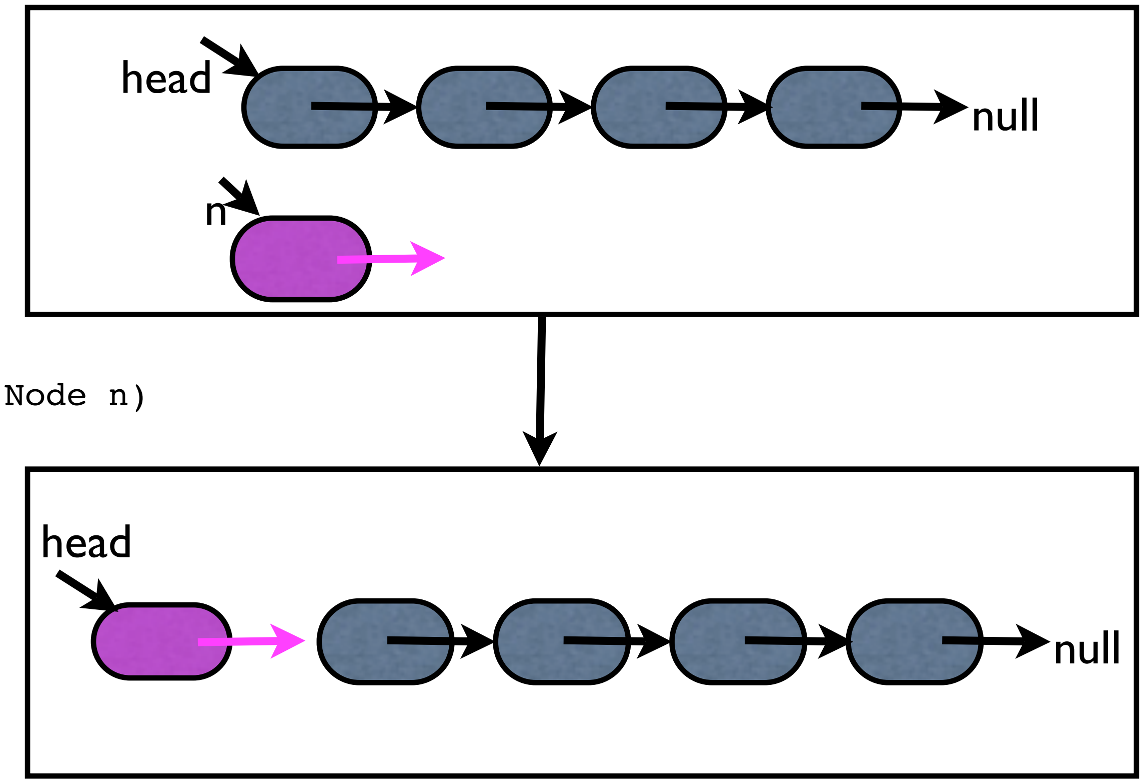

- we'll discuss the following methods
  - addFirst(Node n)
  - addAfter(Node n)
  - Node get(int i)
  - Node removeFirst()
  - addLast(Node n)
  - removeLast(Node n)

Inserting at head

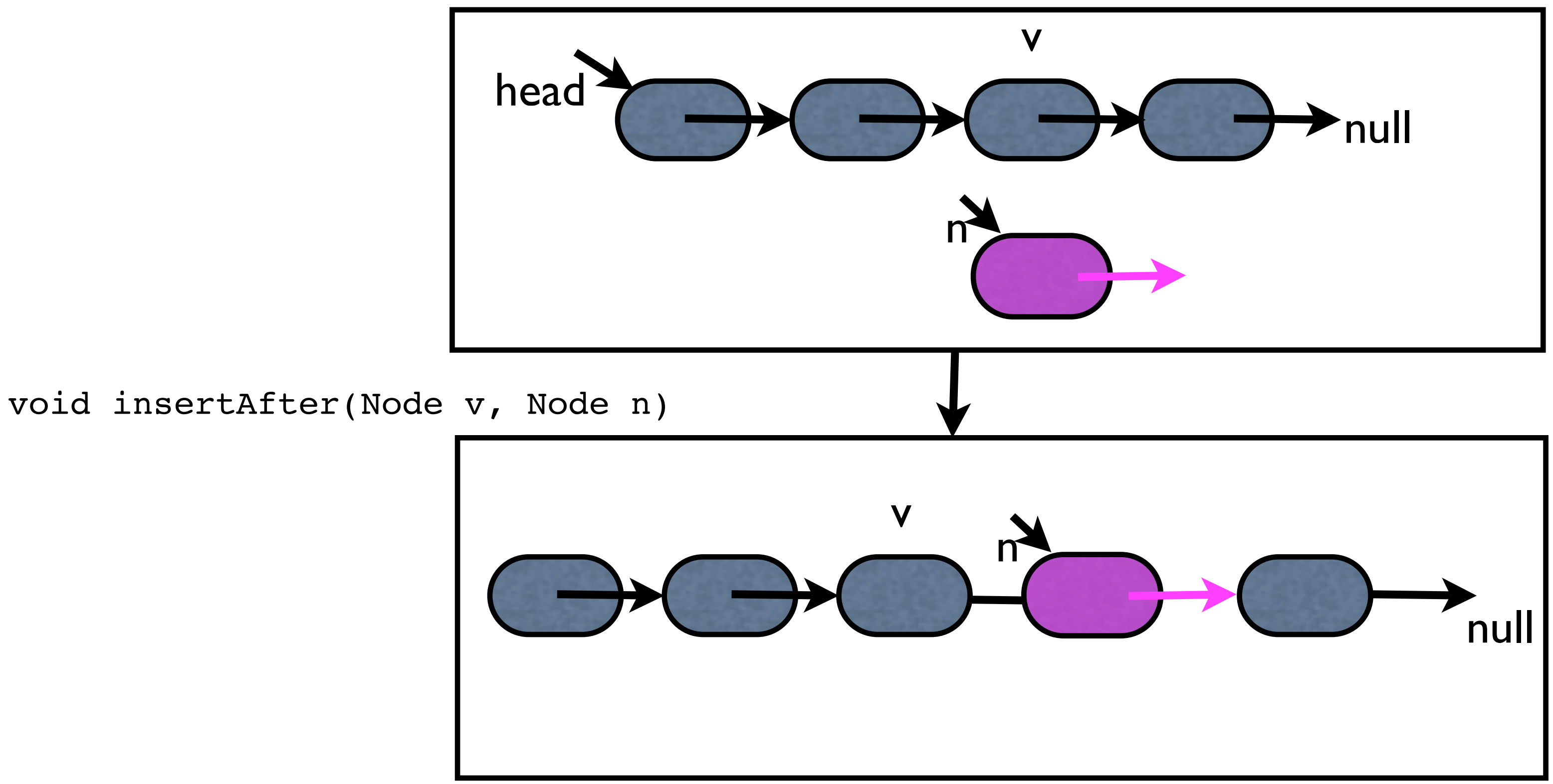


void addFirst(Node n)

```
void addFirst(Node n) {
    n.setNext(head);
    head = n;
    size++;
}
```

- Notes
  - Special cases: works when head is null, i.e. list is empty
  - Efficiency: O(1) time (i.e. constant time)

Inserting in the middle




```
//insert node n after node v
void insertAfter(Node v, Node n)
    n.setNext(v.getNext());
    v.setNext(n);
    size++;
}
```

- Notes:
  - Efficiency: O(1) (constant time)
  - Special cases
    - does not work if v or n are null
      - null pointer exception

Get the i-th element

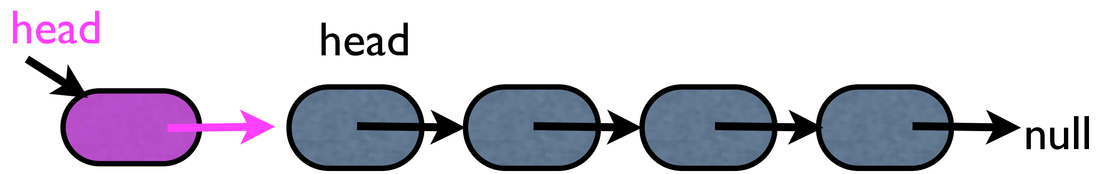
```
//return the i-th node
Node get(int i)
```

Get the i-th element

```
//return the i-th node
Node get(int i) {
    if (i >= size) print error message and return null
    Node ptr = head;
    for (int k=0; k<i; k++)
        ptr = ptr.getNext();
    return ptr;
}
```

- Notes
  - Special cases
    - does it work when list is empty?
  - Efficiency: takes O(i) time
    - constant time per element traversed
    - unlike arrays, accessing i-th element is not constant time

Remove at head




```
Node removeFirst() {
    Node n = head;
    head = head.getNext();
    n.setNext(null);
    return n;
}
```

- Notes:
  - Special cases
    - does it work when list is empty?
      - Nope.
      - How to fix it?
  - Efficiency: O(1)

Insert at tail

```
void addLast(Node n) {
    insertAfter (get(size), n);
}
```

- Notes
  - Special cases
    - does it work when list is empty?
      - Nope (first node in insertAfter is null).
      - How to fix it?
  - Efficiency: takes O(size) time

Delete at tail

- Remove at end: similar
  - need to get to the last element from the head
  - O(size) time

Linked lists

- Single-linked lists support insertions and deletions at head in O(1) time.
  - insertions and deletion at the tail can be supported in O(size) time.

  - addFirst: O(1) time (constant time)
  - removeFirst: O(1) time (constant time)
  - addLast: O(size) time
  - removeLast: O(size) time

- Why? because we keep track of the head.
  - To access the tail in constant time, need to keep track of tail as well.

Linked-list with tail

```
/** Singly linked list .*/
public class SLinkedList {

  private Node head, tail;   // head and tail nodes of the list
  private long size;         // number of nodes in the list



void SLinkedList() {
    head = tail = null;
    size = 0;
}

void addFirst(Node n)  {...}

Node removeFirst() {...}

....
}
```

all methods must update tail

Insert at tail

- Special cases: list is empty

```
void addLast(Node n) {

    //if list is empty the new element is head and tail
    if (tail == null) {
        n.setNext(null);
        head = tail = n;
    } else {
        //the list is not empty: link tail to n and n becomes the new tail
        tail.setNext(n);
        n.setNext(null);
        tail = n;
        }
    //increment size
    size++
}
```

- Efficiency: O(1)

Remove at tail

- What we want: delete the last element and set the new tail
- Is that possible?

Remove at tail

- What we want: delete the last element and set the new tail
- Is that possible?

- Remove at tail
  - set the tail to the node BEFORE the tail
  - need the node before the tail: O(size)

- To remove an element from a list you need the node BEFORE it as well

```
remove(Node n) {
    //link n.before to n.next
}
```

- To remove a node efficiently need to keep track of `previous` node

Doubly-linked lists


```
/** Node of a doubly linked list of integers */
public class DNode {
  protected int element;     //element stored by a node
  protected DNode next, prev;     // Pointers to next and previous nodes



  /** Constructor that creates a node with given fields */
  public DNode(int e, DNode p, DNode n) {
    element = e;
    prev = p;
    next = n;
  }
  /** Returns the element of this node */
  public int getElement() { return element; }
  /** Returns the previous node of this node */
  public DNode getPrev() { return prev; }
  /** Returns the next node of this node */
  public DNode getNext() { return next; }
  /** Sets the element of this node */
  public void setElement(Int newElem) { element = newElem; }
  /** Sets the previous node of this node */
  public void setPrev(DNode newPrev) { prev = newPrev; }
  /** Sets the next node of this node */
  public void setNext(DNode newNext) { next = newNext; }
}
```

Doubly-linked lists

```
/** Doubly linked list with nodes of type DNode  */
public class DList {

  protected int size;             // number of elements
  protected DNode head, tail;

 void addFirst(Node n);
 void addLast(Node n);
 Node deleteFirst();
 Node deleteLast();
 void delete(Node n);
}
```

- Operations on doubly linked lists
  - `addFirst():    O(1) time`
  - `addLast():     O(1) time`
  - `deleteFirst(): O(1) time`
  - `deleteLast():  O(1) time`
  - `delete():      O(1) time`
  - `get(i):        O(i) time`

Insert at head

```
void addFirst(Node n) {

    n.setNext(head);
    n.setprev(null);
    head.setPrev(n);
    head = n;
    size++;
}
```

Does this work?

Insert at head

```
void addFirst(Node n) {
    n.setNext(head);
    n.setprev(null);
    head.setPrev(n);
    head = n;
    size++;
}
```

- Special cases?
  - empty list: head is null; need to set tail too

```
void addFirst(Node n) {
    if (head==null)  {
        //this is the first element: set both head and tail to it
        head = tail = n;
        n.setPrev(null);  n.setNext(null);
        }
    else {
    n.setNext(head);  n.setprev(null);
    head.setPrev(n);
    head = n;
    }
    size++;
}
```

- Efficiency: O(1)

Insert at tail

```
void addLast(Node n) {
    tail.setNext(n);
    n.setprev(tail);
    n.setNect(null);
    tail = n;
    size++;
}
```

Does this work ?

Insert at tail

```
void addLast(Node n) {
    tail.setNext(n);
    n.setprev(tail);
    n.setNect(null);
    tail = n;
    size++;
}
```

- Special cases?
  - empty list: tail is null; need to set head too

```
void addLast(Node n) {
    if (tail == null) {
        head = tail = n; n.setPrev(null); n.setNext(null);
    }
    else {
        tail.setNext(n); n.setprev(tail);  n.setNect(null);
        tail = n;
    }
    size++;
}
```

- Efficiency: O(1)

Doubly-linked lists

- Class work: Sketch the following methods for doubly-linked lists, and analyze their efficiency.
  - `Node removeFirst()`
  - `Node removeLast()`
  - `void remove(Node n)`
  - `Node search(int k)`

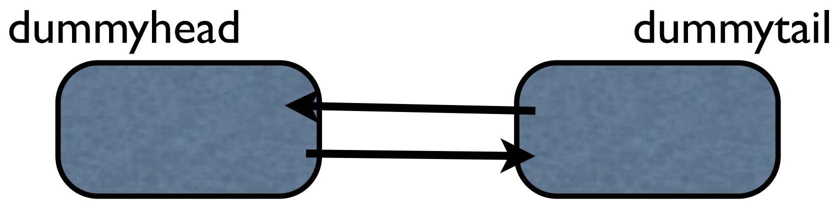
Sentinels

- Sentinels for singly-linked list: keep a dummy head
  - an empty list is one node: the dummy head
- Sentinels for doubly-linked lists
  - dummy head and dummy tail
- Why? elegant. Unifies special cases when head or tail are null

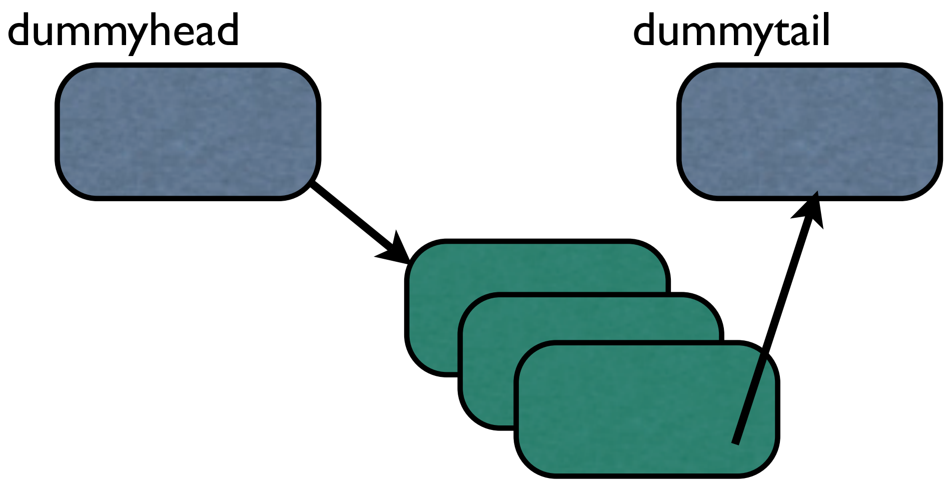
DLLists with Sentinels

```
public class DList {

    protected int size;              // number of elements
    protected DNode header, trailer;// sentinels


    /** Constructor that creates an empty list */
    public DList() {
      size = 0;
      header = new DNode(null, null, null);  // create header
      trailer = new DNode(null, header, null);    // create trailer
      // make header and trailer point to each other
      header.setNext(trailer);

  }
```

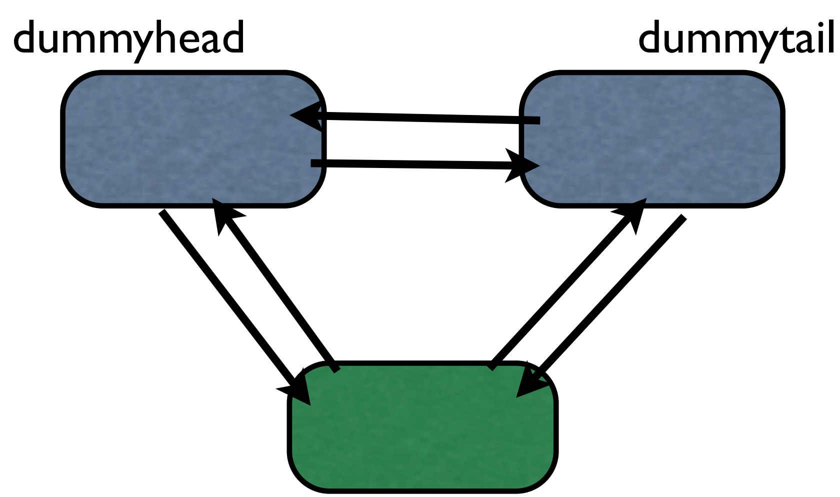
- the empty list:
    - size = 0



DLLists with sentinels



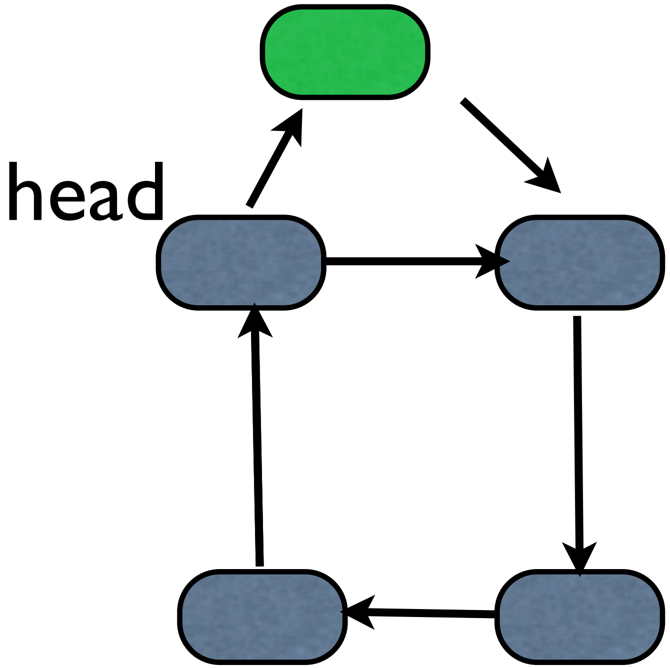

```
insertFirst(Node n) {
    n.setNext(dummyHead.getNext());
    dummyHead.getNext().setPrev(n);
    dummyHead.setNext(n);
    n.setPrev(dummyhead);
    size++;
}
```



- Special cases: none
  - works for empty list

Extensions

- Circular lists
    - make last node point to the first (instead of null)
- class CircularList {
    - SNode head;
    - int size;
- }



- let's say we want to insert at head

```
insertAtHead(Node n) {
    n.setNext(head.getNext());
    head.setNext(n);
}
```

- if head is null?

```
    if (head ==null) {
        n.setNext(n);
        head = n;
    }
```

Linked-lists in Java

- search for class Java Linked List
- has all expected methods and features