csci 210: Data Structures

Linked lists

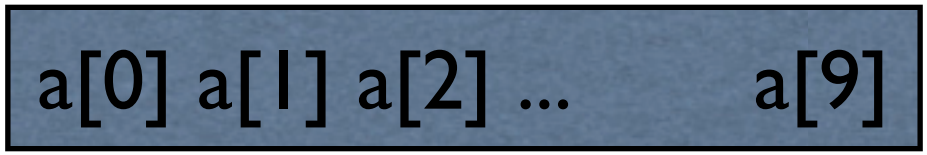
Summary

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

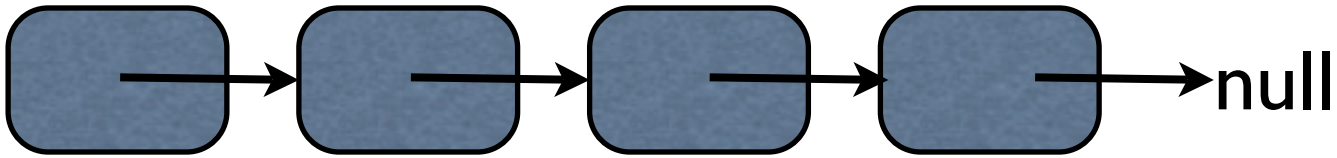
- READING:
  - GT textbook chapter 3

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

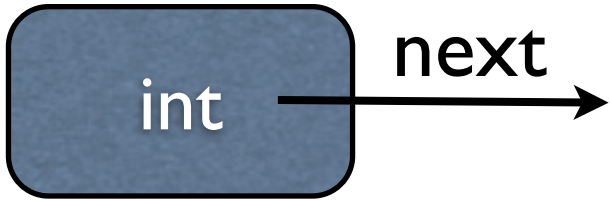


Arrays vs. Lists

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

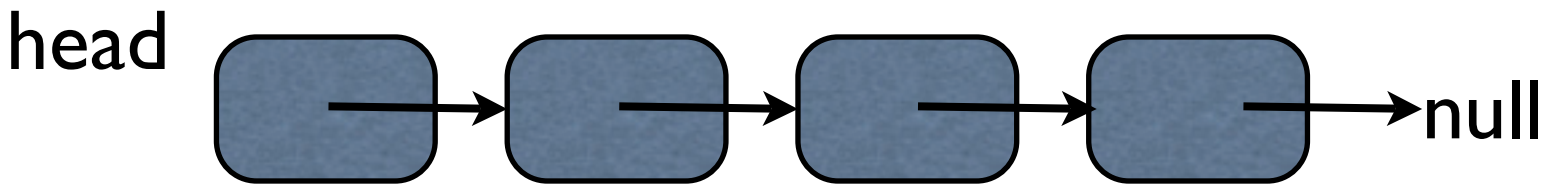
- Linked lists
  - no fixed size; grow one element at a time
  - space overhead
    - each element must store an additional reference
    - S = n x sizeof (element) + n x sizeof(reference)
  - no easy access to i-th element wrt the head of the list
    - need to hop through all previous elements

The Node class




```
/** 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; }
}
```

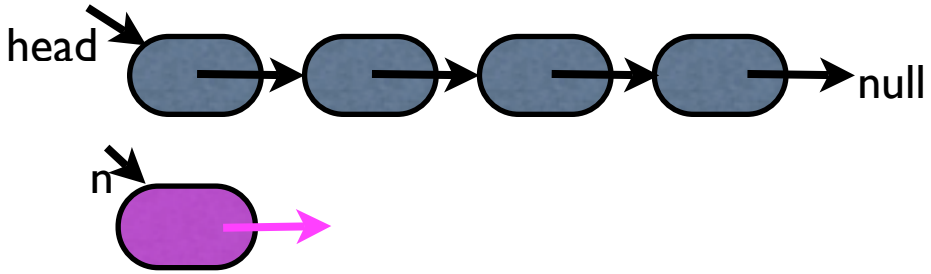
A Single-Linked-List class




```
/** 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;
  }


}
```

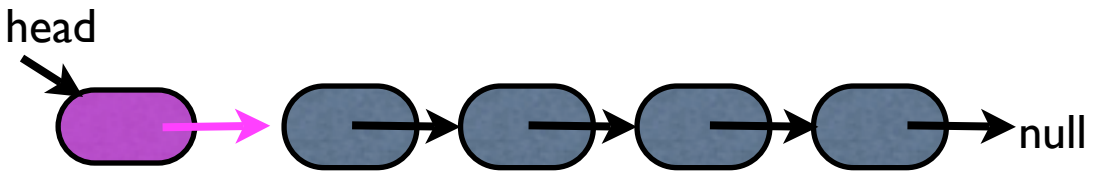
- we'll discuss the following methods
  - addFirst(Node n)
  - addAfter(Node n)
  - Node get(int i)
  - Node removeFirst()
  - addLast(Node n)
  - removeLast(Node n)

Inserting at head



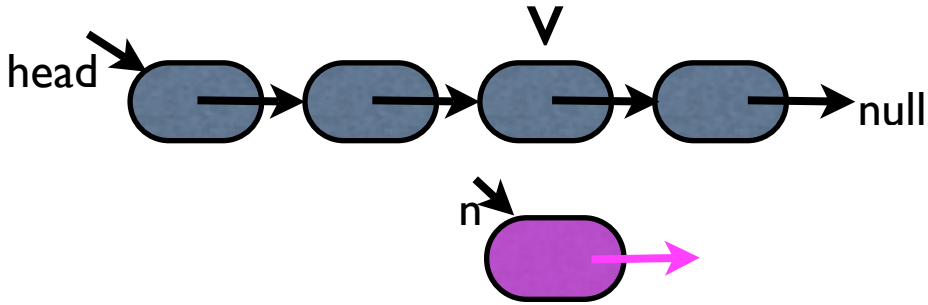

```
void addFirst(Node n) {
    n.setNext(head);
    head = n;
    size++;
}
```

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

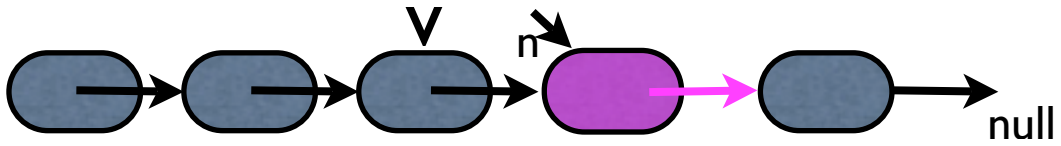


Inserting in the middle

```
//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

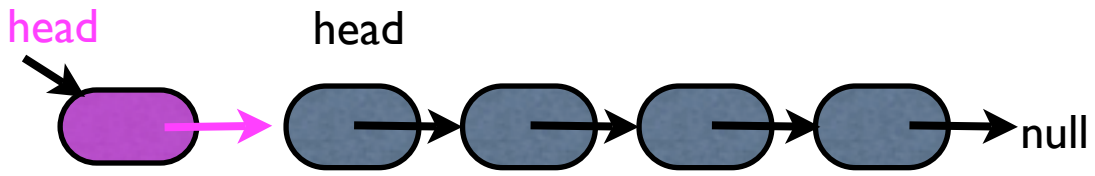
```
//return the i-th node
Node get(int i) {
    if (i >= size) print error message and return null
    Node ptr = head;
    for (int k=0; k<i; k++)
        ptr = ptr.getNext();
    return ptr;
}
```

- 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

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

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

- Single-linked lists support insertions and deletions at head in O(1) time

Insert at tail in O(1) time

- 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
- Insertions at tail can be supported in O(1) if keep track of 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;
}

//must keep track of tail
addFirst(Node n)  {...}
Node removeFirst() {...}


}
```

insert/remove at tail

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

- Efficiency: O(1)
- remove at tail
  - set the tail to the node BEFORE the tail
  - need the node before the tail: O(size)

- in general, 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 storing strings. */
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();
    delete(Node n);
}
```

- 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++;
}
```

- 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++;
}
```

- 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

- exercises
  - Node removeFirst()
  - Node removeLast()
  - void remove(Node n)
  - Node search(int k)

Sentinels

- singly-linked list: keep a dummy head
  - an empty list is one node: the dummy head
- for doubly-linked lists
  - dummy head and dummy tail

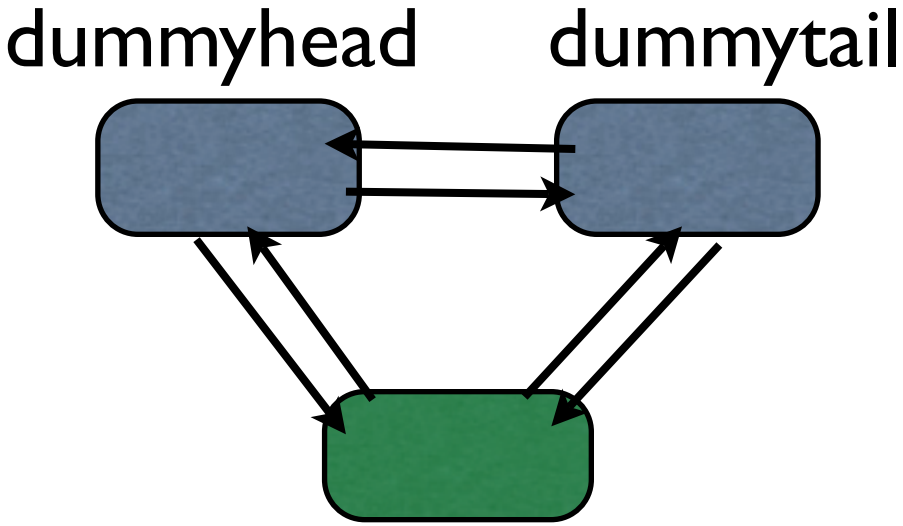
- Why? elegant. Unifies special cases when head or tail are null

- Example

```
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);

  }
```

Sentinels (dummy nodes)

- an empty list

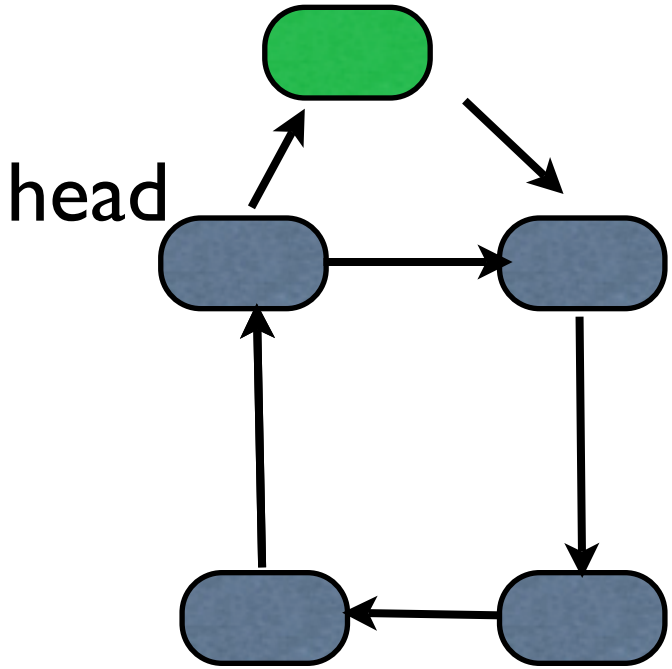



```
insertFirst(Node n) {
        n.setNext(dummyHead.getNext());
        dummyHead.getNext().setPrev(n);
        dummyHead.setNext(n);
        n.setPrev(dummyhead);
        size++;
}
```

- 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 Java Linked List
- has all expected methods and features

-