# LinkedLists

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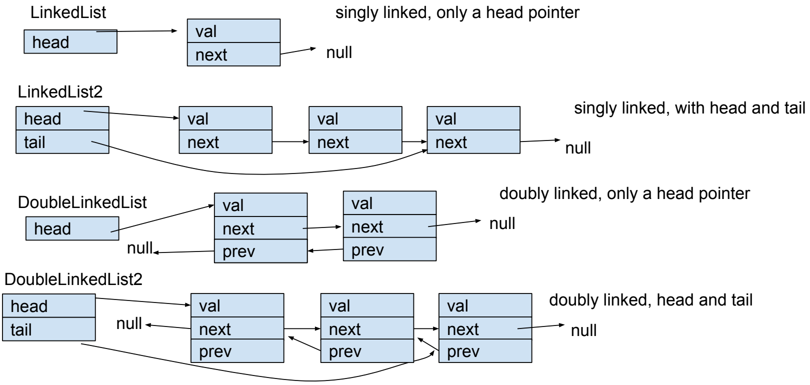
# Introduction

A linked list is a data structure

- Composed of individual nodes
- Each with pointers to the next (sometimes also previous)
- The linked list can either point to the first (head) or head and tail

# Four kinds of LinkedList



# LinkedLists vs. Dynamic Arrays

There is no "best" list

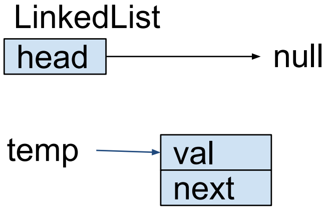
**DynamicArrays**

- Faster sequential append to end
- Less overall memory used

**LinkedList**

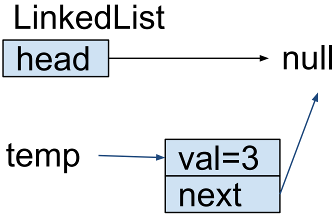
- Efficient insertion and deletion in the beginning and middle

# LinkedList addStart(3)




allocate new node

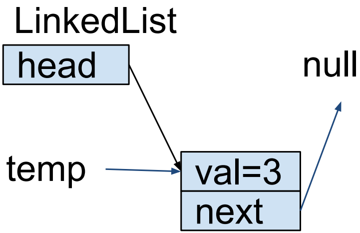
# LinkedList addStart(3)




temp.val = 3
temp.next = head

set value and next pointer

# LinkedList addStart(3)



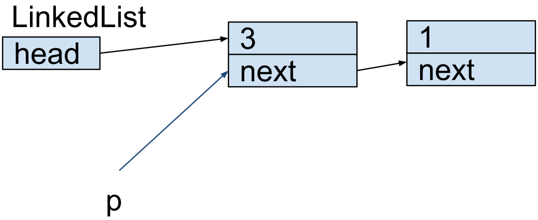

set head to point to the new node

# Complexity of LinkedList addStart(v)

```
Node* temp = new Node();   // O(1)
temp->val = v;             // O(1)
temp->next = head;         // O(1)
head = temp;               // O(1)
```

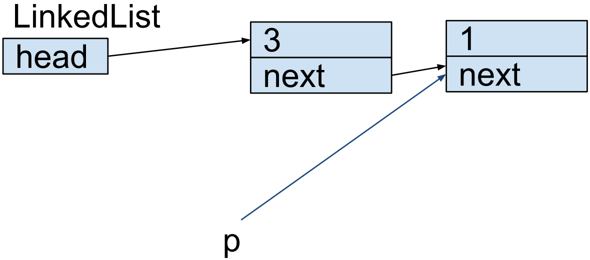
**Complexity of addStart is O(1)**

# LinkedList addEnd(4)



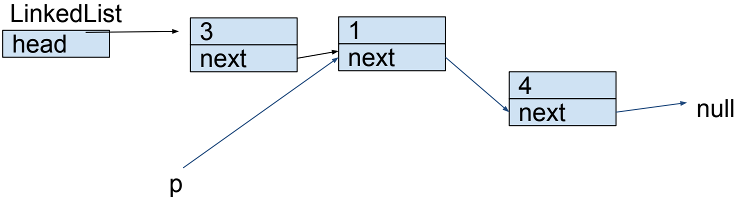

point to first element in list

# LinkedList addEnd(4)




… find last element in list

# LinkedList addEnd(4)




add new node to the end and set its value to 4 and next pointer to null

# LinkedList addEnd(4) steps

In C++

```
Node* p = head;
while (p->next != nullptr)
  p = p->next;
Node* temp = new Node();
temp->val = 4;
value->next = nullptr;
p->next = temp;
```

Note: Not while (p != null)

Otherwise at the end of the loop, p is null, and all you know is, you arrived at the end!

# LinkedList addEnd(4) Complexity

In C++

```
Node* p = head;                     //O(1)
while (p->next != nullptr)          //O(n)
   p = p->next;
Node* temp = new Node();            //O(1)
temp->val = 4;                      //O(1)
value->next = nullptr;              //O(1)
p->next = temp;                     //O(1)
```

# LinkedList removeStart() Complexity

```
Node* p = head;            //O(1)
head = p->next;            //O(1)
delete p;                  //O(1)
```

There are many classes where the word "Node" is used

Generally, nest the class Node inside so it does not collide with the other nodes

Also, just because a class is nested inside does not mean its private components are accessible to the outer class. Make everything in Node public

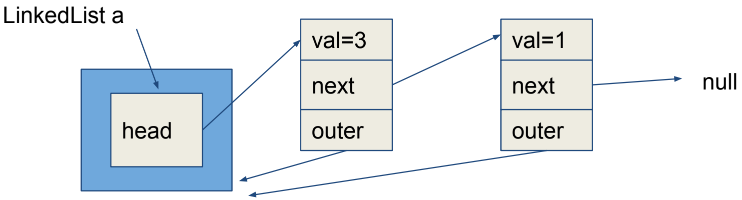
```
class LinkedList {
  class Node {
    int val;
    Node* next; // this is all private by default!
  };
  Node* head;
  // class LinkedList cannot access val and next inside Node
```

# C++ LinkedList Overview

```
class LinkedList {
private:
  class Node {// no one else needs to know about
Node but me!
  public: // everything in Node is accessible to
LinkedList
    int val;
    Node* next;
  };
  Node* head; // pointer to first Node
  ...
}
```

# Implementation Issues: Java

In Java, a class Node declared within the outer class is called an inner class Inner classes are completely available to the outer class They also have an extra pointer to the outer class. The following diagram shows the situation



# Memory Allocation Overhead

A system to allocate memory requires overhead to track the blocks of memory.

- In C++ each block of memory is preceded by one 64-bit number.

Overhead of memory allocation is 8 bytes

- In Java, every object incurs 12 bytes overhead
- No inline objects, so there is also a 4-byte pointer to the block

Allocating a single contiguous chunk of memory is much faster than many separate chunks

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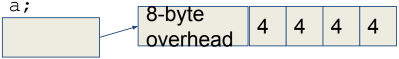
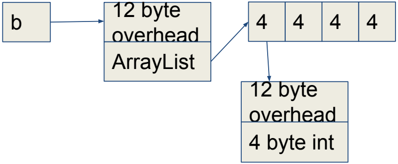
# Example: C++ vector<int> vs. Java ArrayList<Integer>

```
vector<int> a;
```




size = 8 + n * sizeof(int)
sizeof(int) = 4

```
ArrayList<Integer> b = new ArrayList<>();
```

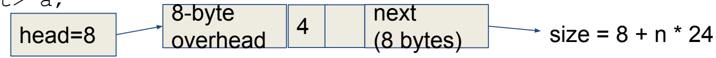



including the variable b
size = 20 + n * 20

this is 5 times larger

# Example: C++ list<int> vs. Java LinkedList<Integer>

```
list<int> a;
```




C++ Pointers are 64-bit (8 bytes each)

For speed, 64-bit objects are placed on 8-byte alignment

The blank space in the diagram is 4 bytes wasted in order to align the next pointer

Every time memory is allocated with new or malloc

- 8 bytes (1 pointer) overhead is used

# Example: Java LinkedList<Integer> (Poorly)

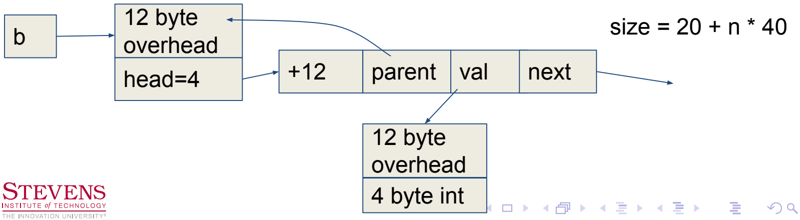
Inner class not declared static

- Each Node has extra pointer to parent
- Integer is a separate object

Java Pointers are 4 bytes not 8

- Size advantage over C++

```
public class LinkedList {
  private class Node {
    Integer val;
    Node    next;
  }
LinkedList<Integer> b = new
LinkedList<>();
```

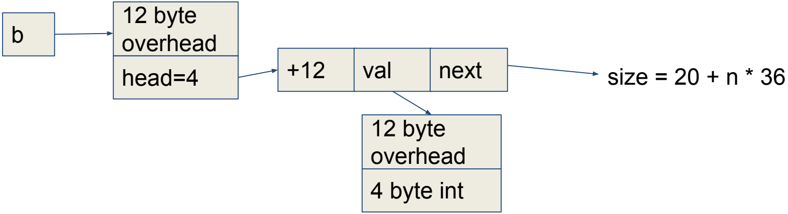


# Example: Java LinkedList<Integer> (Better)

This is slightly better

- Inner node declared static
- Integer is still a separate object
- This is the library implementation

```
public class LinkedList {
  private static class Node {
    Integer val;
    Node    next;
  }
LinkedList<Integer> b = new
LinkedList<>();
```

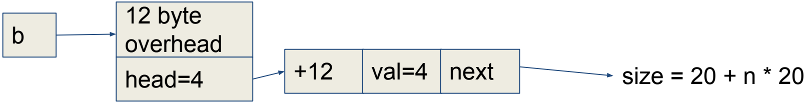


# Example: Java More Efficient LinkedList of int

For int, dramatic space savings are possible

- Inner node declared static
- int is stored in the Node

```
public class IntLinkedList {
  private static class Node {
    int val;
    Node    next;
  }
IntLinkedList b = new IntLinkedList();
```



# Insertion into a LinkedList

$O(1)$ time if you have the pointer to node available

$O(n)$ if you only have the integer position

# Iterators

In order to traverse a list efficiently, we need to know where we are

- For LinkedLists, using an integer position is not efficient
- Integer positions require starting at the beginning and finding the location each time
- A pointer to node is efficient but requires the programmer to know the structure of the list

An Iterator is a popular design pattern

- Tracks position in something complex, hiding the details
- Write an iterator in C++ or Java to maintain optimal efficiency, keep the list simple

# Example of Iterators in C++ Library

```
list<int> a;
for (int i = 0; i < 10; i++)
  a.push_back(i);

for (list<int>::iterator i = a.begin(); i != a.end(); ++i)
 out << *i << ' ';

for (auto i = a.begin(); i != a.end(); ++i)
  out << *i << ' ';
```

# Example of Iterators in Java Library

```
LinkedList<Integer> a = new LinkedList<>();
for (int i = 0; i < 10; i++)
  a.add(i);

for (Iterator i = a.iterator(); i.hasNext(); ) {
  System.out.print(i.next() + " ");
```

# Implementing an Iterator

Implementing an Iterator is beyond the scope of this course

- It involves a knowledge of the implementation language and style
- See EE-553 (C++) or CPE-552(Java) past course videos for examples