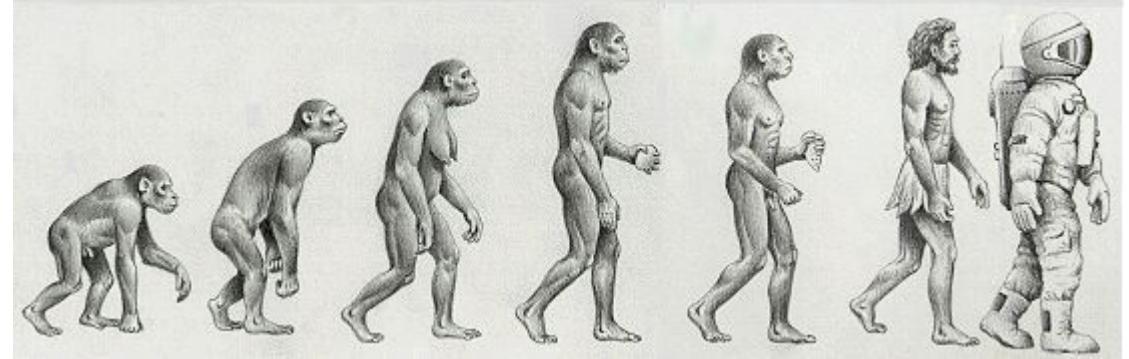


## Pre-announcements

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- Info session at Kresge Library at 6:30 PM tomorrow 1/31 if you want to help out with autonomous underwater vehicles.
- No experience needed all are welcome.



# CS61B: 2019

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## Lecture 4: Node Based Lists

- From IntList to SLList
  - The private keyword
  - Nested classes
  - Recursive private helper methods
  - Caching
  - Sentinel nodes

# From IntList to SLLList

# Last Time in 61B: Recursive Implementation of a List

---

```
public class IntList {  
    public int first;  
    public IntList rest;  
  
    public IntList(int f, IntList r) {  
        first = f;  
        rest = r;  
    }  
    ...  
}
```



While functional, “naked” linked lists like the one above are hard to use.

- Users of this class are probably going to need to know references very well, and be able to think recursively. Let’s make our users’ lives easier.

## Improvement #1: Rebranding and Culling

```
public class IntNode {  
    public int item;  
    public IntNode next;  
  
    public IntNode(int i, IntNode n) {  
        item = i;  
        next = n;  
    }  
}
```

IntNode is now dumb, has no methods. We will reintroduce functionality in the coming slides.



Not much of an improvement obviously, but this next weird trick will be more impressive.

## Improvement #2: Bureaucracy

```
public class IntNode {  
    public int item;  
    public IntNode next;  
  
    public IntNode(int i, IntNode n) {  
        item = i;  
        next = n;  
    }  
}
```

```
IntList X = new IntList(10, null);  
SLList Y = new SLList(10);
```

SLList is easier to instantiate (no need to specify null), but we will see more advantages to come.

```
public class SLList {  
    public IntNode first;  
  
    public SLList(int x) {  
        first = new IntNode(x, null);  
    }  
    ...  
}
```

IntNode is now dumb, has no methods.

Next: Let's add addFirst and getFirst methods to SLList.

# The Basic SLLList and Helper IntNode Class

```
public class SLLList {  
    public IntNode first;  
  
    public SLLList(int x) {  
        first = new IntNode(x, null);  
    }  
  
    public void addFirst(int x) {  
        first = new IntNode(x, first);  
    }  
  
    public int getFirst() {  
        return first.item;  
    }  
}
```

```
public class IntNode {  
    public int item;  
    public IntNode next;  
  
    public IntNode(int i, IntNode n) {  
        item = i;  
        next = n;  
    }  
}
```

Example  
usage:

```
SLLList L = new SLLList(15);  
L.addFirst(10);  
L.addFirst(5);  
int x = L.getFirst();
```

# SLLLists vs. IntLists

---

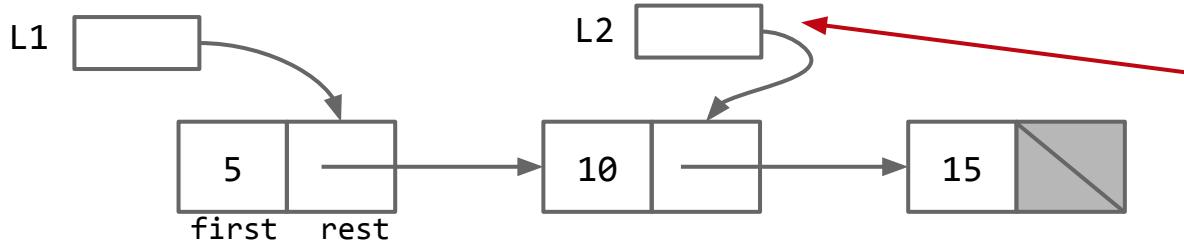
```
SLLList L = new SLLList(15);
L.addFirst(10);
L.addFirst(5);
int x = L.getFirst();
```

```
IntList L = new IntList(15, null);
L = new IntList(10, L);
L = new IntList(5, L);
int x = L.first;
```

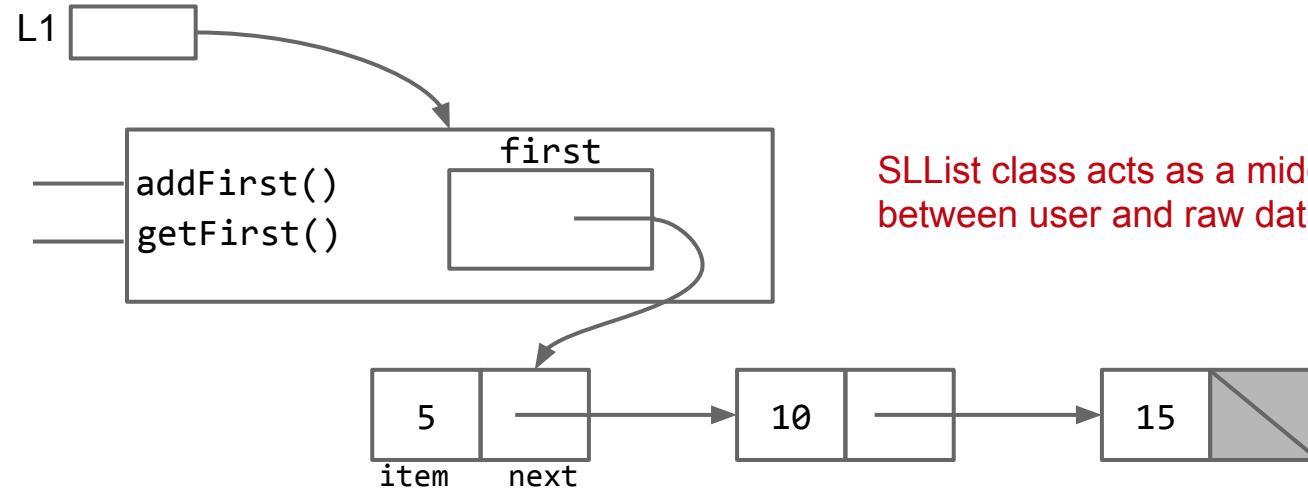
While functional, “naked” linked lists like the `IntList` class are hard to use.

- Users of `IntList` are need to know Java references well, and be able to think recursively.
- `SLLList` is much simpler to use. Simply use the provided methods.
- Why not just add an `addFirst` method to the `IntList` class? Turns out there is no efficient way to do this. See exercises in `lectureCode` repository.

# Naked Linked Lists (IntList) vs. SLLists



Naked recursion: Natural for IntList user to have variables that point to the middle of the IntList.



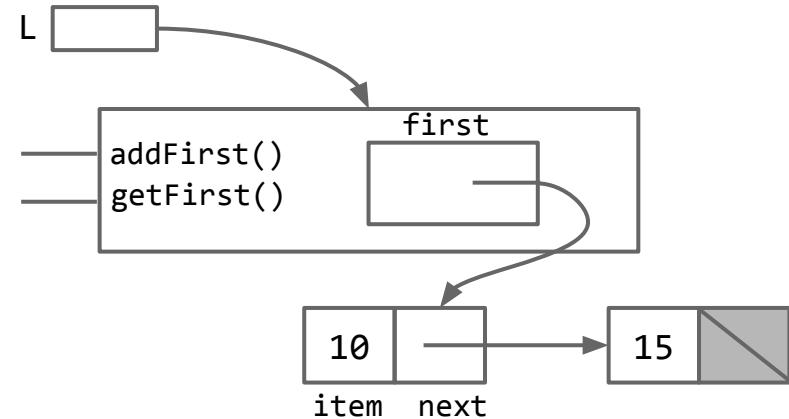
SLList class acts as a middle man between user and raw data structure.

# Public vs. Private Nested Classes



# The SLList So Far

```
public class SLList {  
    public IntNode first;  
  
    public SLList(int x) {  
        first = new IntNode(x, null);  
    }  
  
    public void addFirst(int x) {  
        first = new IntNode(x, first);  
    }  
    ...  
}
```

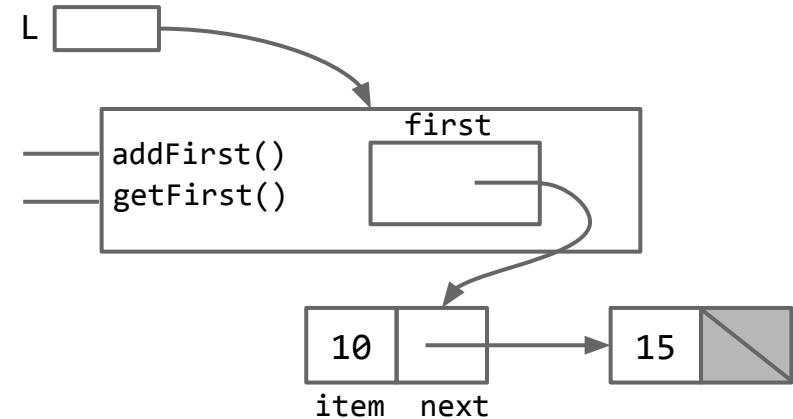


```
SLList L = new SLList(15);  
L.addFirst(10);
```

# A Potential SLList Danger

```
public class SLList {  
    public IntNode first;  
  
    public SLList(int x) {  
        first = new IntNode(x, null);  
    }  
  
    public void addFirst(int x) {  
        first = new IntNode(x, first);  
    }  
    ...  
}
```

Users of our class might be tempted to try to manipulate our secret IntNode directly in uncouth ways!



```
SLList L = new SLList(15);  
L.addFirst(10);  
L.first.next.next = L.first.next;
```

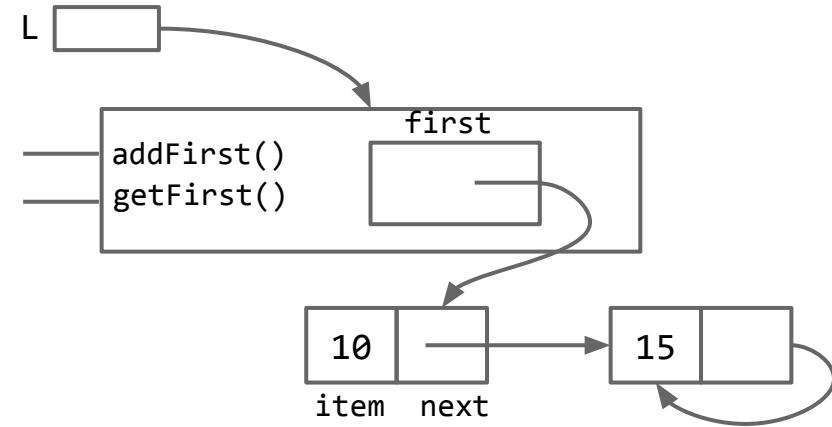
# A Potential SLList Danger

```
public class SLList {  
    public IntNode first;  
  
    public f  
    }  
  
    public void addFirst(int x) {  
        first = new IntNode(x, first);  
    }  
}
```



}

Users of our class might be tempted to try to manipulate our secret IntNode directly in uncouth ways!



```
SLList L = new SLList(15);  
L.addFirst(10);  
L.first.next.next = L.first.next;
```

# Access Control

---

```
public class SLList {  
    public IntNode first;  
  
    public SLList(int x) {  
        first = new IntNode(x, null);  
    }  
  
    public void addFirst(int x) {  
        first = new IntNode(x, first);  
    }  
  
    ...  
}
```

We can prevent programmers from making such mistakes with the **private** keyword.

## Improvement #3: Access Control

```
public class SLList {  
    private IntNode first;  
  
    public SLList(int x) {  
        first = new IntNode(x, null);  
    }  
  
    public void addFirst(int x) {  
        first = new IntNode(x, first);  
    }  
  
    ...  
}
```

Use the **private** keyword to prevent code in other classes from using members (or constructors) of a class.

```
SLList L = new SLList(15);  
L.addFirst(10);  
L.first.next.next = L.first.next;
```

```
jug ~/Dropbox/61b/lec/lists2  
$ javac SLListUser.java  
SLListUser.java:8: error: first has private access in SLList  
        L.first.next.next = L.first.next;
```

## Why Restrict Access?

---

Hide implementation details from users of your class.

- Less for user of class to understand.
- Safe for you to change private methods (implementation).

Car analogy:

- **Public:** Pedals, Steering Wheel    **Private:** Fuel line, Rotary valve
- Despite the term ‘access control’:
  - Nothing to do with protection against hackers, spies, and other evil entities.

## Improvement #4: Nested Classes

Can combine two classes into one file pretty simply.

```
public class SLList {  
    public class IntNode { ←  
        public int item;  
        public IntNode next;  
        public IntNode(int i, IntNode n) {  
            item = i;  
            next = n;  
        }  
    }  
  
    private IntNode first; ←  
    public SLList(int x) {  
        first = new IntNode(x, null);  
    } ...
```

Nested class definition.

Could have made IntNode a private nested class if we wanted.

Instance variables, constructors, and methods of SLList typically go below nested class definition.

# Why Nested Classes?

---

Nested Classes are useful when a class doesn't stand on its own and is obviously subordinate to another class.

- Make the nested class private if other classes should never use the nested class.

In my opinion, probably makes sense to make `IntNode` a nested private class.

- Hard to imagine other classes having a need to manipulate `IntNodes`.

# Static Nested Classes

If the nested class never uses any instance variables or methods of the outer class, declare it static.

- Static classes cannot access outer class's instance variables or methods.
- Results in a minor savings of memory. See book for more details / exercise.

```
public class SLList {  
    private static class IntNode { ←  
        public int item;  
        public IntNode next;  
        public IntNode(int i, IntNode n) {  
            item = i;  
            next = n;  
        }  
        ...  
    }  
}
```

We can declare IntNode static, since it never uses any of SLList's instance variables or methods.

Analogy: Static methods had no way to access "my" instance variables. Static classes cannot access "my" outer class's instance variables.

Unimportant note: For private nested classes, access modifiers are irrelevant.

# **addLast() and size()**



# Adding More SLList Functionality

To motivate our remaining improvements, and to give more functionality to our `SLList` class, let's add:

- `.addLast(int x)`
- `.size()`

See study guide for starter code!



Recommendation: Try writing them yourself before watching how I do it.

Methods	Non-Obvious Improvements	
<code>addFirst(int x)</code>	#1	Rebranding: <code>IntList</code> → <code>IntNode</code>
<code>getFirst</code>	#2	Bureaucracy: <code>SLList</code>
	#3	Access Control: <code>public</code> → <code>private</code>
	#4	Nested Class: Bringing <code>IntNode</code> into <code>SLList</code>

Answers not shown in slides. See `sp19-lectureCode` or video for answers.

# Private Recursive Helper Methods

To implement a recursive method in a class that is not itself recursive (e.g. SLList):

- Create a private recursive helper method.
- Have the public method call the private recursive helper method.

```
public class SLList {  
    private int size(IntNode p) {  
        if (p.next == null) {  
            return 1;  
        }  
  
        return 1 + size(p.next);  
    }  
  
    public int size() {  
        return size(first);  
    }  
}
```

# Efficiency of Size: <http://yellkey.com/design>

How efficient is size?

- Suppose size takes 2 seconds on a list of size 1,000.
  - How long will it take on a list of size 1,000,000?
- 
- a. 0.002 seconds.
  - b. 2 seconds.
  - c. 2,000 seconds.
  - d. 2,000,000 seconds.

```
public class SLList {  
    private int size(IntNode p) {  
        if (p.next == null) {  
            return 1;  
        }  
  
        return 1 + size(p.next);  
    }  
  
    public int size() {  
        return size(first);  
    }  
}
```

## Improvement #5: Fast size()

Your goal:

- Modify SLList so that the execution time of size() is always fast (i.e. independent of the size of the list).

Also I have a gift giveaway:  
Accidentally some CDs from  
KALX 10 years ago. Come take  
one from the front if you want  
one.

```
private IntNode first;

public SLList(int x) {
    first = new IntNode(x, null);
}

public void addFirst(int x) {
    First = new IntNode(x, front);
}

private int size(IntNode p) {
    if (p.next == null)
        return 1;
    return 1 + size(p.next);
}

public int size() {
    return size(first);
}
```

## Improvement #5: Fast size()

Solution: Maintain a special size variable that **caches** the size of the list.

- Caching: putting aside data to speed up retrieval.

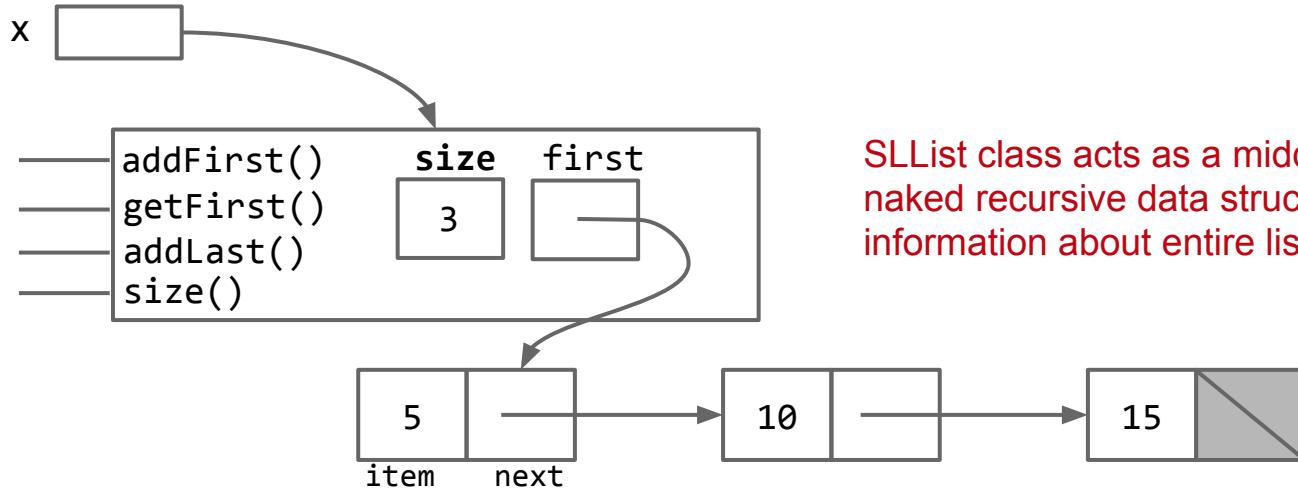
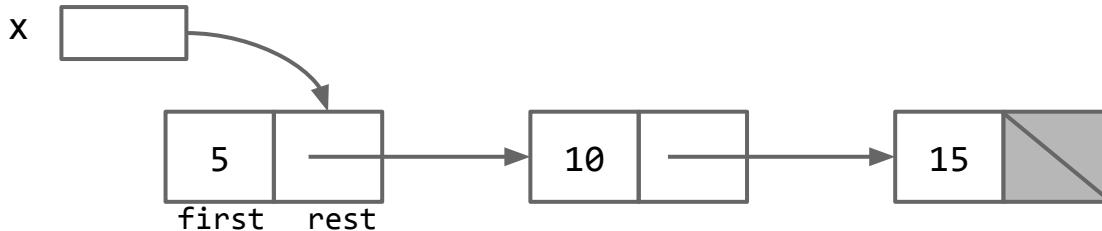
TANSTAAFL: There ain't no such thing as a free lunch.

- But spreading the work over each add call is a net win in almost any circumstance.



<http://www.ensler.us/ensler.us/images/nolnchsmalla.jpg>

# Naked Linked Lists (IntList) vs. SLLists



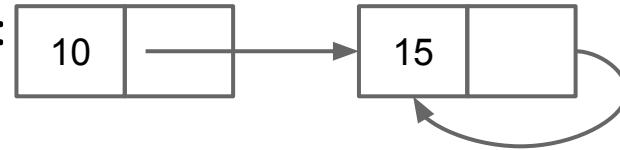
SLList class acts as a middle man between user and the naked recursive data structure. Allows us to store meta information about entire list, e.g. `size`.

## Improvement #6a: Representing the Empty List

---

Benefits of **SLLList** vs. **IntList** so far:

- Faster `size()` method than would have been convenient for **IntList**.
- User of an **SLLList** never sees the **IntList** class.
  - Simpler to use.
  - More efficient `addFirst` method (see exercises).
  - Avoids errors (or malfeasance):



Another benefit we can gain:

- Easy to represent the empty list. Represent the empty list by setting `first` to null. Let's try!

# How Would You Fix addLast?

Your goal:

- Fix addLast so that we do not get a null pointer exception when we try to add to the back of an empty SLList:

```
SLList s1 = new SLList();
s1.addLast(5);
```

See study guide for starter code if you want to try on a computer.

```
public class SLList {
    private IntNode first;
    private int size;

    public SLList() {
        first = null;
        size = 0;
    }

    public void addLast(int x) {
        size += 1;
        IntNode p = first;
        while (p.next != null) {
            p = p.next;
        }
        p.next = new IntNode(x, null);
    } ...
```

# One Solution

One possible solution:

- Add a special case for the empty list.

But there are other ways...

```
public void addLast(int x) {  
    size += 1;  
  
    if (first == null) {  
        first = new IntNode(x, null);  
        return;  
    }  
  
    IntNode p = first;  
    while (p.next != null) {  
        p = p.next;  
    }  
  
    p.next = new IntNode(x, null);  
}
```

# Sentinel Nodes



# Tip For Being a Good Programmer: Keep Code Simple

As a human programmer, you only have so much working memory.

- You want to restrict the amount of complexity in your life!
- Simple code is (usually) good code.
  - Special cases are not ‘simple’.



```
public void addLast(int x) {  
    size += 1;  
  
    if (first == null) {  
        first = new IntNode(x, null);  
        return;  
    }  
  
    IntNode p = first;  
    while (p.next != null) {  
        p = p.next;  
    }  
  
    p.next = new IntNode(x, null);  
}
```

# addLast's Fundamental Problem

The fundamental problem:

- The empty list has a null **first**. Can't access **first.next**!

Our fix is a bit ugly:

- Requires a special case.
- More complex data structures will have many more special cases (gross!!)

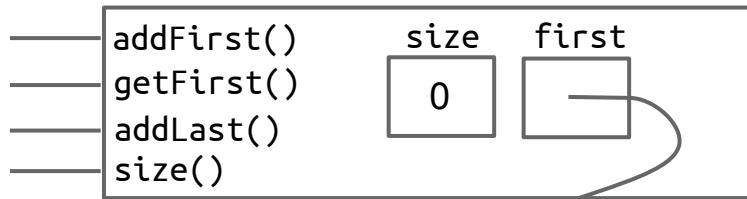
How can we avoid special cases?

- Make all **SLLists** (even empty) the “same”.

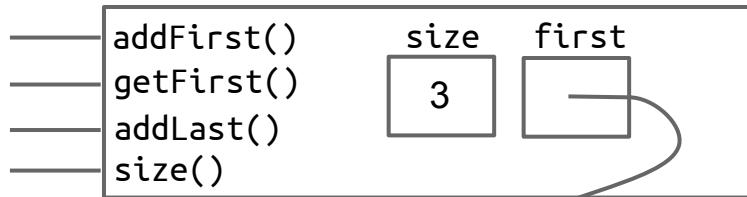
```
public void addLast(int x) {  
    size += 1;  
  
    if (first == null) {  
        first = new IntNode(x, null);  
        return;  
    }  
  
    IntNode p = first;  
    while (p.next != null) {  
        p = p.next;  
    }  
  
    p.next = new IntNode(x, null);  
}
```

## Improvement #6b: Representing the Empty List Using a Sentinel

Create a special node that is always there! Let's call it a “sentinel node”.



The empty list is just the sentinel node.



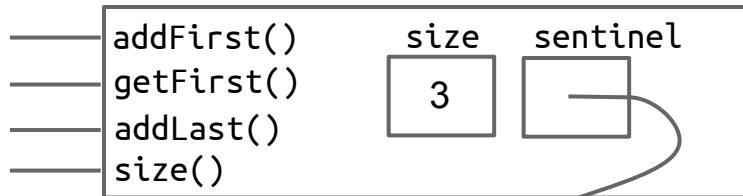
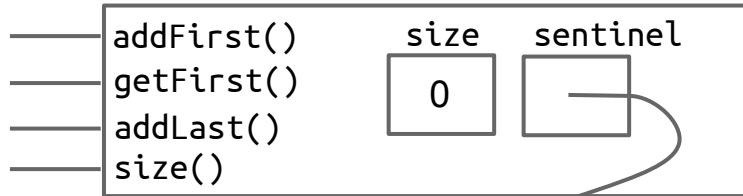
A list with 3 numbers has a sentinel node and 3 nodes that contain real data.

Let's try reimplementing SLList with a sentinel node.



# Sentinel Node

The sentinel node is always there for you.



Notes:

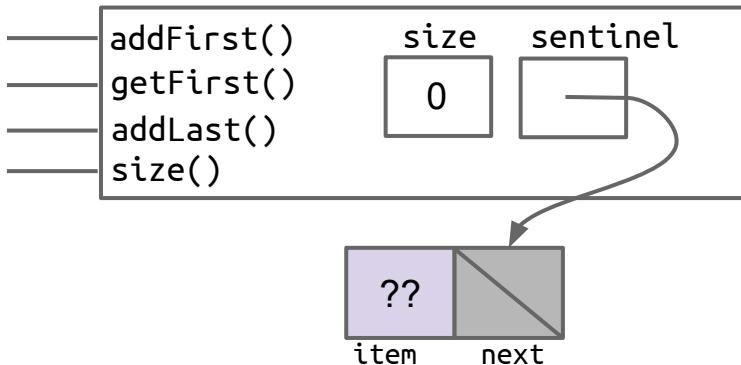
- I've renamed `first` to be `sentinel`.
- `sentinel` is never null, always points to sentinel node.
- Sentinel node's `item` needs to be some integer, but doesn't matter what value we pick.
- Had to fix constructors and methods to be compatible with sentinel nodes.



# addLast (with Sentinel Node)

Bottom line: Having a sentinel simplifies our addLast method.

- No need for a special case to check if `sentinel` is null (since it is never null).



```
public void addLast(int x) {  
    size += 1;  
  
    if (sentinel == null) {  
        sentinel = new IntNode(x, null);  
        return;  
    }  
  
    IntNode p = sentinel;  
    while (p.next != null) {  
        p = p.next;  
    }  
  
    p.next = new IntNode(x, null);  
}
```

# Invariants

---

An invariant is a condition that is guaranteed to be true during code execution (assuming there are no bugs in your code).

An `SLLList` with a sentinel node has at least the following invariants:

- The `sentinel` reference always points to a sentinel node.
- The first node (if it exists), is always at `sentinel.next`.
- The `size` variable is always the total number of items that have been added.

Invariants make it easier to reason about code:

- Can assume they are true to simplify code (e.g. `addLast` doesn't need to worry about nulls).
- Must ensure that methods preserve invariants.

# Summary

---

Methods	Non-Obvious Improvements	
<code>addFirst(int x)</code>	#1	Rebranding: <code>IntList</code> → <code>IntNode</code>
<code>getFirst</code>	#2	Bureaucracy: <code>SLList</code>
<code>size</code>	#3	Access Control: <code>public</code> → <code>private</code>
<code>addLast(int x)</code>	#4	Nested Class: Bringing <code>IntNode</code> into <code>SLList</code>
	#5	Caching: Saving <code>size</code> as an <code>int</code> .
	#6	Generalizing: Adding a <code>sentinel</code> node to allow representation of the empty list.

## For Those Who Were a Bit Bewildered!

---

Don't panic if it felt fast!

The `LinkedListDeque` class that you'll build in project 1 (to be officially released Friday) will give you practice so that you can deeply understand the ideas from today's lecture.

# Old Deprecated Slides



## Improvement #7: Helper Methods

---

Suppose we wanted to write a `getBack()` method.

- Would be quite similar to `insertBack()`
- Make sense to create a `getBackNode()` method that can be used by both `getBack()` and `insertBack()`