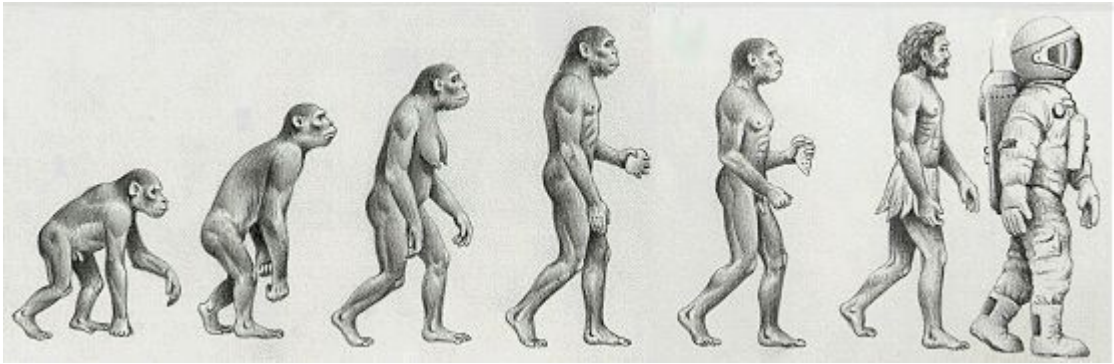


# CS61B, 2021

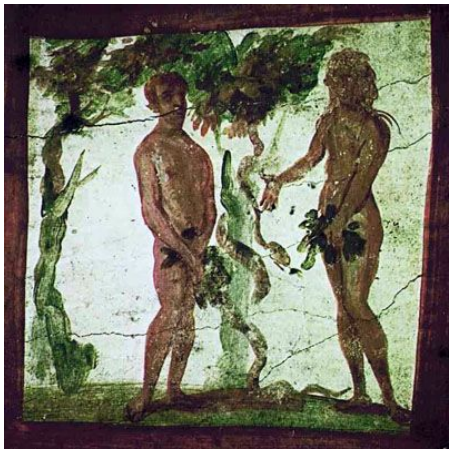
Lecture 5: Node Based Lists

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

# From IntList to SLList

# 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;
    }
}
```

IntNode is now dumb, has no methods.

```
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);
    }
    ...
}
```

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

# The Basic SLList and Helper IntNode Class

```
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);
   }

   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:

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

# SLLists vs. IntLists

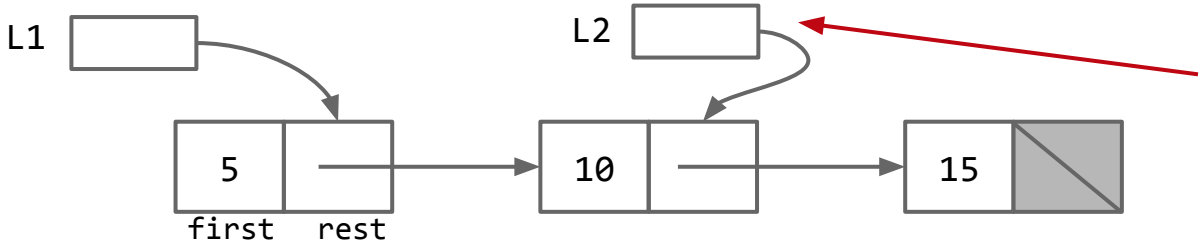
```
SLList L = new SLList(15);
L.addFirst(10);
L.addFirst(5);
int x = L.getFirst();
```

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

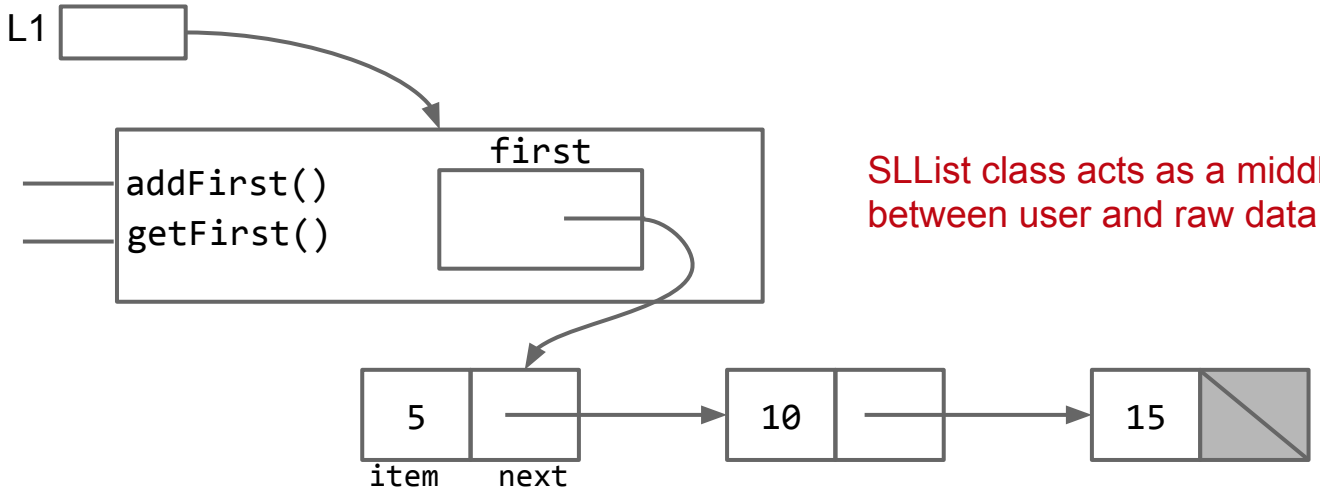
While functional, “naked” linked lists like the `IntList` class are hard to use.

- Users of `IntList` are need to know Java references well, and be able to think recursively.
- `SLList` 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.

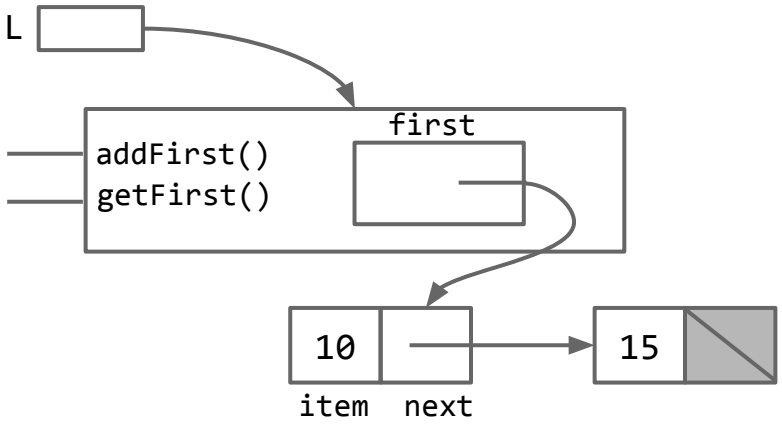



SLList class acts as a middle man between user and raw data structure.

# Public vs. Private Nested Classes

# The SLList So Far

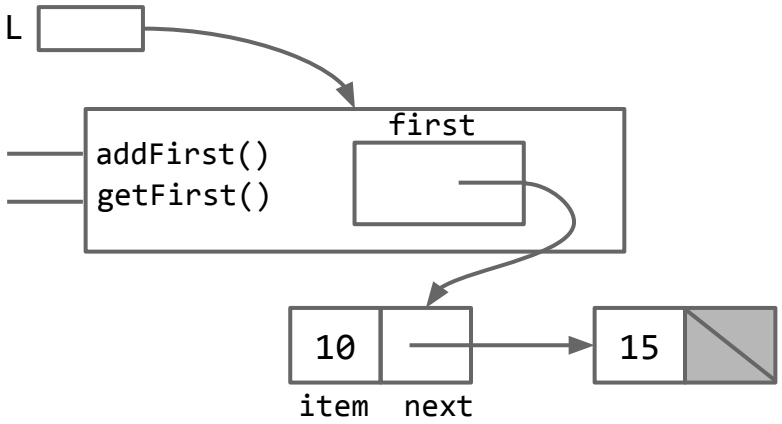
```
public class SLList {
   public IntNode first;

   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);
   }

   ...
}
```

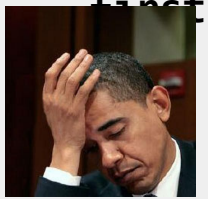


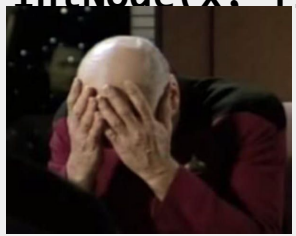

Users of our class might be tempted to try to manipulate our secret IntNode directly in uncouth ways!

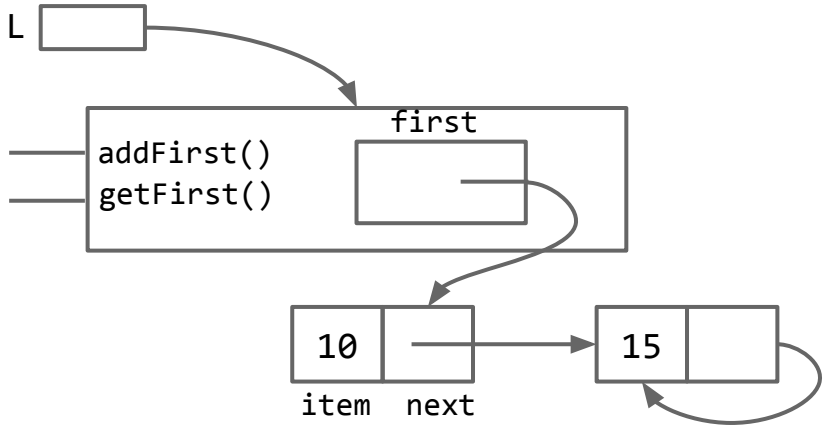
```
SLList L = new SLList(15);
L.addFirst(10);
L.first.next.next = L.first.next;
```

# A Potential SLList Danger

```
public class SLList {
    public IntNode first;

    publ                x) {
        f           tNode
    }

    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 | |
|---|---|---|
| `addFirst(int x)` | #1 | Rebranding: `IntList` → `IntNode` |
| `getFirst` | #2 | Bureaucracy: `SLList` |
| | #3 | Access Control: `public` → `private` |
| | #4 | Nested Class: Bringing `IntNode` into `SLList` |

Answers not shown in slides. See fa20-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).

```
private IntNode first;

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

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

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.

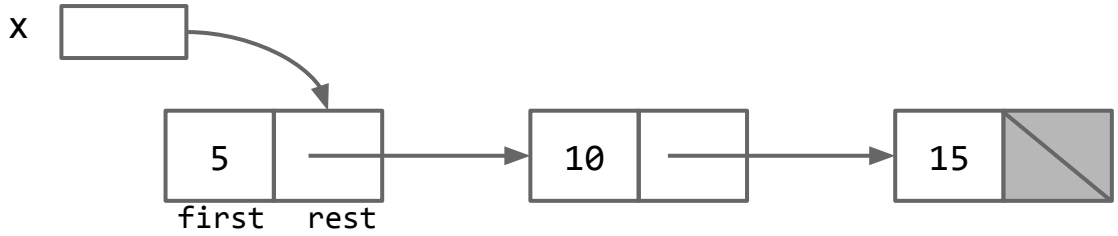
- Caching: putting aside data to speed up retrieval.

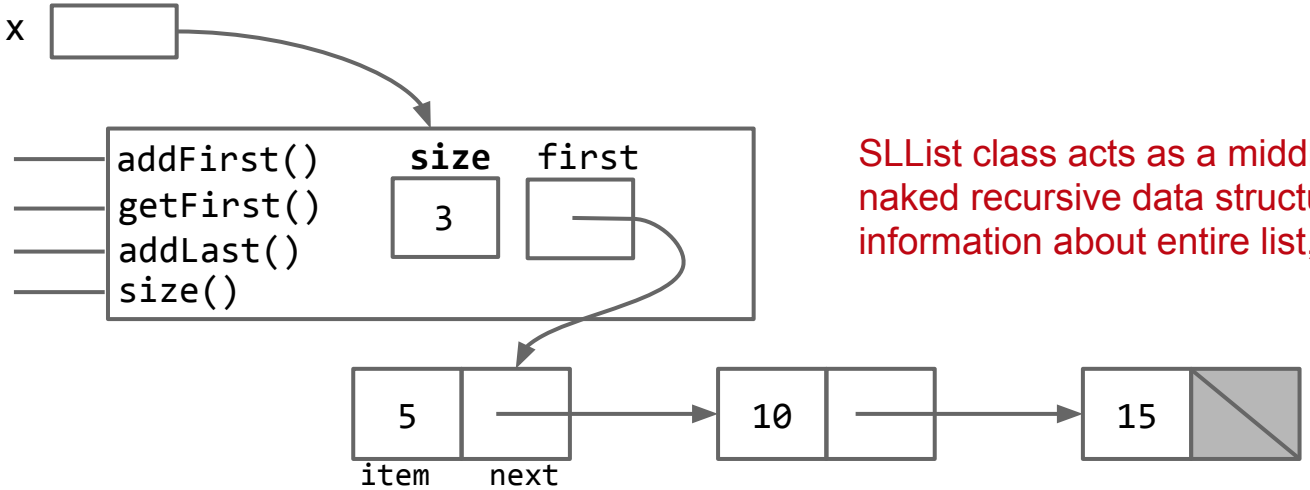
TANSTAAFL: There ain't no such thing as a free lunch.

- 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



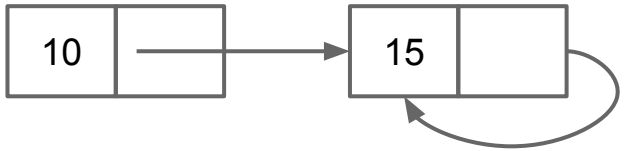




SLList class acts as a middle man between user and the naked recursive data structure. Allows us to store meta information about entire list, e.g. **`size`**.

# Improvement #6a: Representing the Empty List

Benefits of `SLList` vs. `IntList` so far:

- Faster `size()` method than would have been convenient for `IntList`.
- User of an `SLList` 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!!)

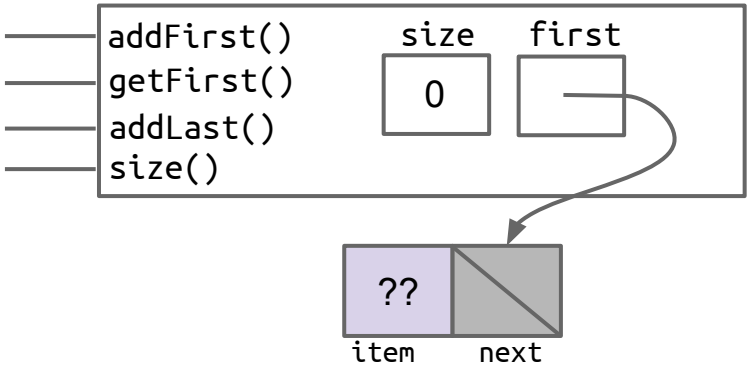
How can we avoid special cases?

- 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);
}
```

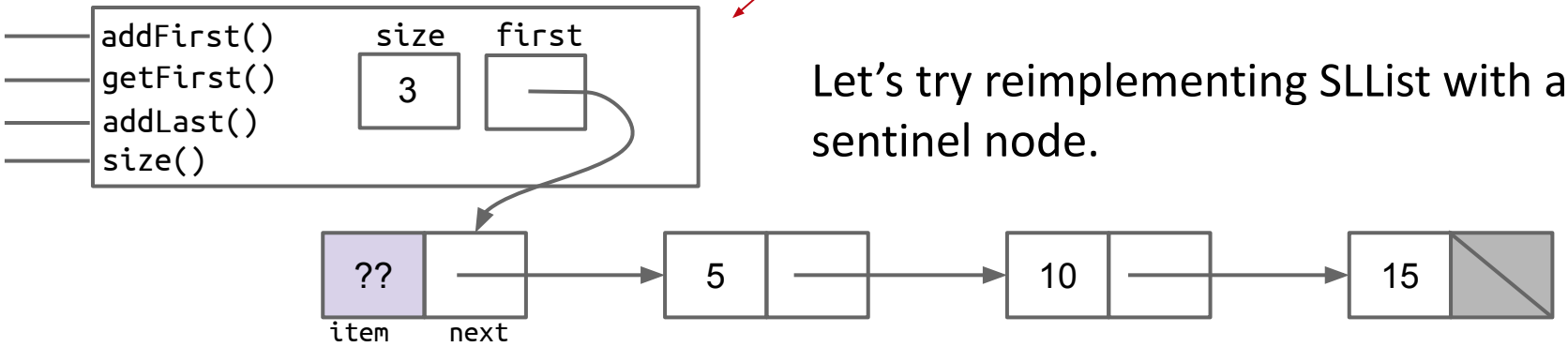
# Improvement #6b: Representing the Empty List Using a Sentinel

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




The empty list is just the sentinel node.

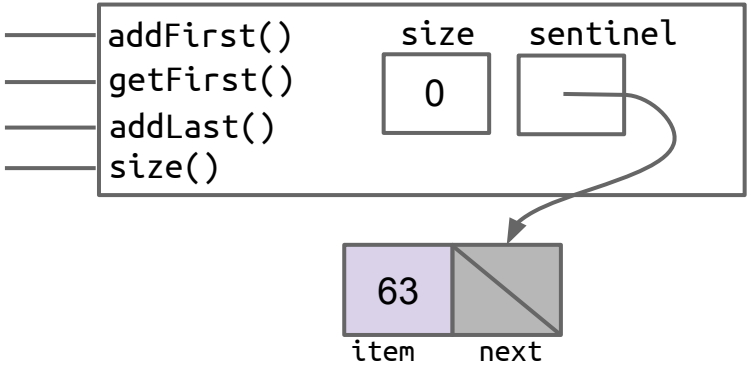
A list with 3 numbers has a sentinel node and 3 nodes that contain real data.

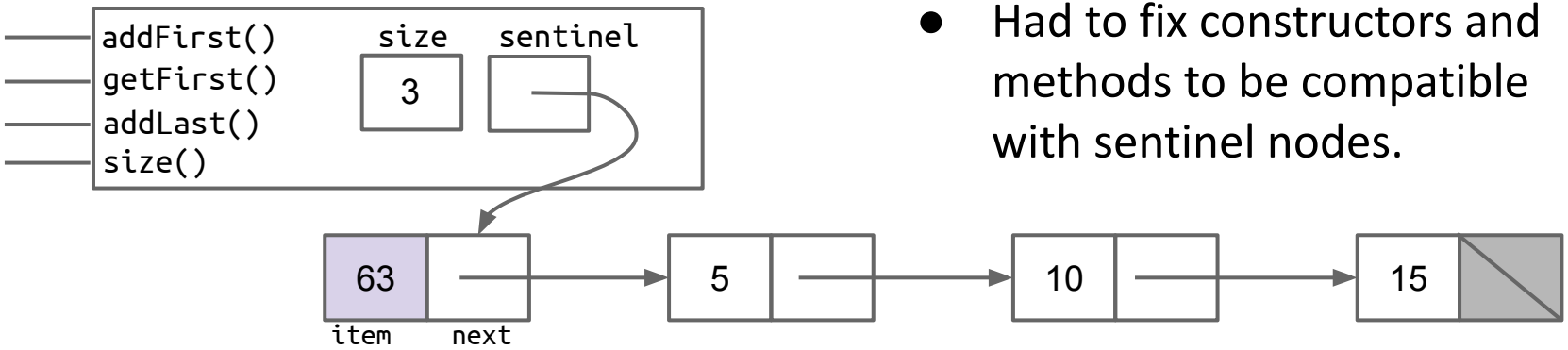



Let's try reimplementing SLList with a sentinel node.

# Sentinel Node

The sentinel node is always there for you.



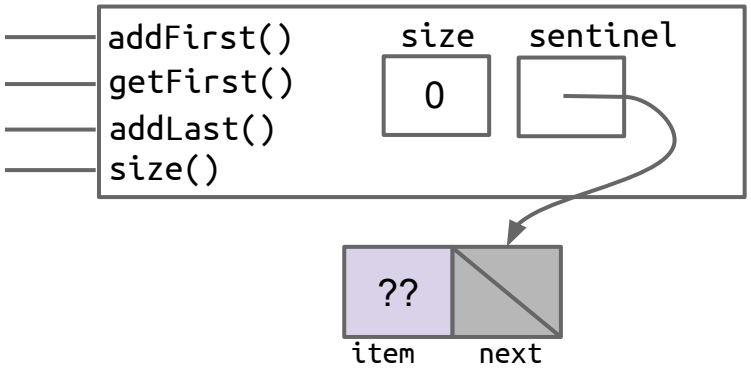

Notes:

- 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 `SLList` 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 | |
|---|---|---|
| `addFirst(int x)` | #1 | Rebranding: `IntList` → `IntNode` |
| `getFirst` | #2 | Bureaucracy: `SLList` |
| `size` | #3 | Access Control: `public` → `private` |
| `addLast(int x)` | #4 | Nested Class: Bringing `IntNode` into `SLList` |
| | #5 | Caching: Saving `size` as an `int`. |
| | #6 | Generalizing: Adding a `sentinel` 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()`