Lecture 3

Primitive Types, Reference Types, and Linked Data Structures

CS61B, Fall 2024 @ UC Berkeley

Slides credit: Josh Hug

Goals: Building a List

Lecture 3, CS61B, Fall 2024

Goals: Building a List
Primitive Types
Reference Types
Parameter Passing
Instantiation of Arrays
IntList and Linked Data Structures

Lists

- Unlike Python, lists are not built directly into the Java language.

```java
import java.util.List;
import java.util.LinkedList;
List<String> L = new LinkedList<>();
L.add("a");
L.add("b");
```

Today, we'll begin our 3 lecture journey towards building our own list implementation.

- We'll exploit recursion to allow our list to grow infinitely large.
- But first we need to solve… the mystery of the walrus.

Primitive Types

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Quiz

```
Walrus a = new Walrus(1000, 8.3);
Walrus b;
b = a;
b.weight = 5;
System.out.println(a);
System.out.println(b);
```

Will the change to b affect a?

A. Yes

B. No

```
weight: 5, tusk size: 8.30
weight: 5, tusk size: 8.30
```

Answer: Visualizer

```
int x = 5;
int y;
y = x;
x = 2;
System.out.println("x is: " + x);
System.out.println("y is: " + y);
```

Will the change to x affect y?

A. Yes

B. No

```
x is: 2
y is: 5
```

Bits

Your computer stores information in “memory”.

- Information is stored in memory as a sequence of ones and zeros.
  - Example: 72 stored as 01001000
  - Example: 205.75 stored as … 01000011 01001101 11000000 00000000
  - Example: The letter H stored as 01001000 (same as the number 72)
  - Example: True stored as 00000001

Each Java type has a different way to interpret the bits:

- 8 primitive types in Java: byte, short, **int**, long, float, **double**, boolean, char
- We won’t discuss the precise representations in much detail in 61B.
  - Covered in much more detail in 61C.

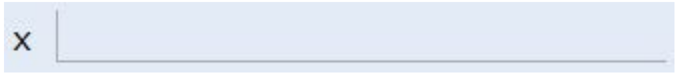
Note: Precise representations may vary from machine to machine.

Declaring a Variable (Simplified)

When you declare a variable of a certain type in Java:

- Your computer sets aside exactly enough bits to hold a thing of that type.
  - Example: Declaring an int sets aside a “box” of 32 bits.
  - Example: Declaring a double sets aside a box of 64 bits.
- Java creates an internal table that maps each variable name to a location.
- Java does NOT write anything into the reserved boxes.
  - For safety, Java will not let you access a variable that is uninitialized.

```
int x;
double y;
x = -1431195969;
y = 567213.112;
```



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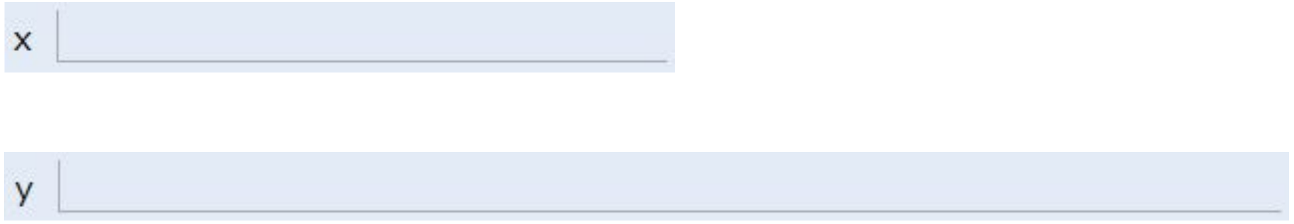

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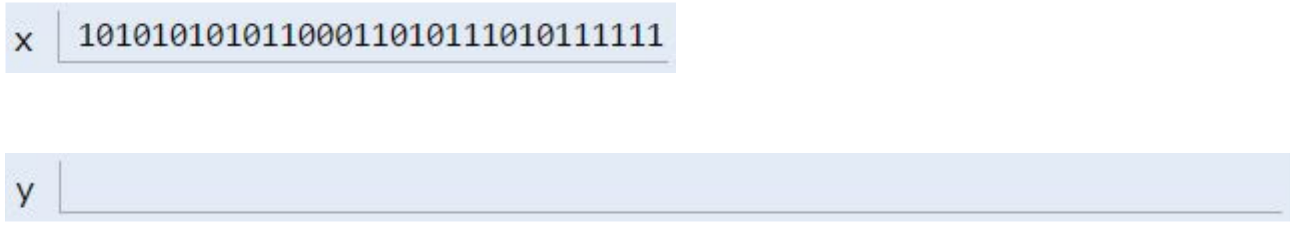

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- Java does NOT write anything into the reserved boxes.
  - For safety, Java will not let you access a variable that is uninitialized.

```java
int x;
double y;
x = -1431195969;
y = 567213.112;
```

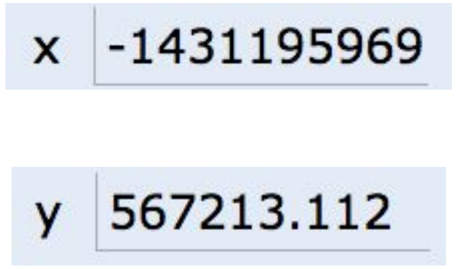
```
x  10101010101100011010111010111111

y  0100000100100001010011110101101000111001010110000001000001100010
```

Simplified Box Notation

We'll use simplified box notation from here on out:

- Instead of writing memory box contents in binary, we'll write them in human readable symbols.

```
int x;
double y;
x = -1431195969;
y = 567213.112;
```



The Golden Rule of Equals (GRoE)

Given variables y and x:

- y = x **copies** all the bits from x into y.

Example from earlier: Link

Reference Types

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Goals: Building a List

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IntList and Linked Data Structures

Reference Types

There are 8 primitive types in Java:

- byte, short, **int**, long, float, **double**, boolean, char

Everything else, including arrays, is a **reference type**.

Class Instantiations

When we instantiate an Object (e.g. Dog, Walrus, Planet):

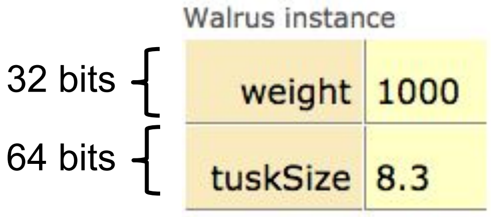
- Java first allocates a box of bits for each instance variable of the class and fills them with a default value (e.g. 0, null).
- The constructor then usually fills every such box with some other value.

```
public static class Walrus {
   public int weight;
   public double tuskSize;

   public Walrus(int w, double ts) {
      weight = w;
      tuskSize = ts;
   }
}
```

```
new Walrus(1000, 8.3);
```

Demo Link



Class Instantiations

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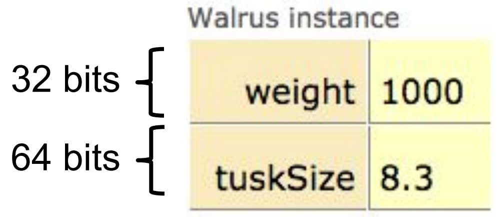
- Java first allocates a box of bits for each instance variable of the class and fills them with a default value (e.g. 0, null).
- The constructor then usually fills every such box with some other value.

```
....00000000000000000000000000000000000000000
000000000000000000000000000000000000000000000
000000000000000000000000000000000000000000000
000000000000000000000000000000000000001111101
000010000000001000001001100110011001100110011 0
```

```java
new Walrus(1000, 8.3);
```



Green is weight, blue is tuskSize.

(In reality, total Walrus size is slightly larger than 96 bits.)

Class Instantiations

Can think of new as returning the address of the newly created object.

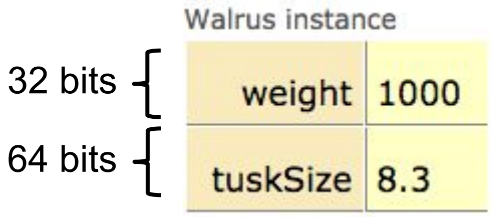
- Addresses in Java are 64 bits.
- Example (rough picture): If object is created in memory location 2384723423, then new returns 2384723423.

2384723423th bit

```
....00000000000000000000000000000000000000000
000000000000000000000000000000000000000000000
000000000000000000000000000000000000000000000
000000000000000000000000000000000000001111101
000010000000010000010011001100110011001100110
011001100110011001101000000000000000000000000
000000000000000000000000000000000000000000000
000000000000000000000000000000000000000000000
000000000000000000000000000000000000000000000
000000000000000000000000000000000000000000000
000000000000000000000000000000000000000000000
000000000000000000000000000000000000000000000
000000000000000000000000....
```

2384723423

```
new Walrus(1000, 8.3);
```

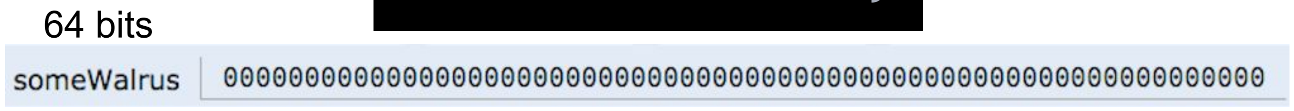


Reference Type Variable Declarations

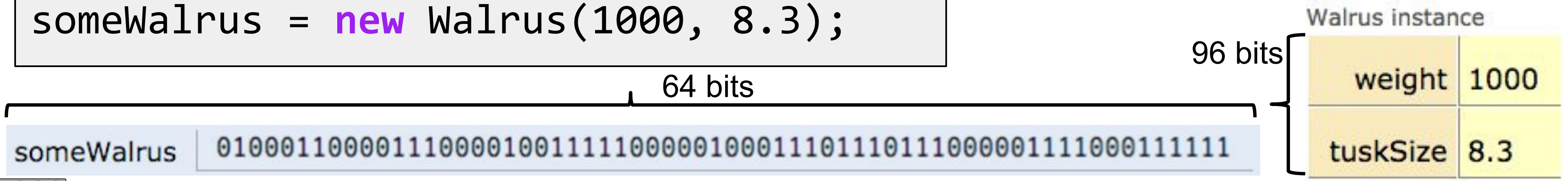
When we declare a variable of any reference type (Walrus, Dog, Planet):

- Java allocates exactly a box of size 64 bits, no matter what type of object.
- These bits can be either set to:
  - Null (all zeros).
  - The 64 bit “address” of a specific instance of that class (returned by **new**).

```java
Walrus someWalrus;
someWalrus = null;
```



```java
Walrus someWalrus;
someWalrus = new Walrus(1000, 8.3);
```

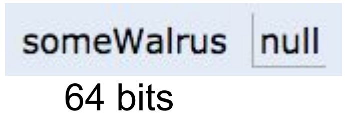


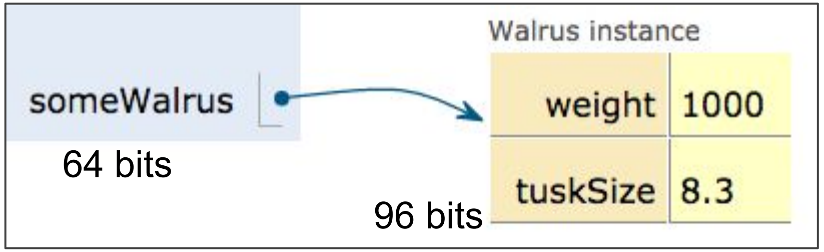
Reference Type Variable Declarations

The 64 bit addresses are meaningless to us as humans, so we’ll represent:

- All zero addresses with “null”.
- Non-zero addresses as arrows.

This is sometimes called “box and pointer” notation.



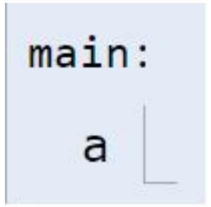


Reference Types Obey the Golden Rule of Equals

Just as with primitive types, the equals sign copies the bits.

- In terms of our visual metaphor, we "copy" the arrow by making the arrow in the b box point at the same instance as a.

```java
Walrus a;
a = new Walrus(1000, 8.3);
Walrus b;
b = a;
```



a is 64 bits

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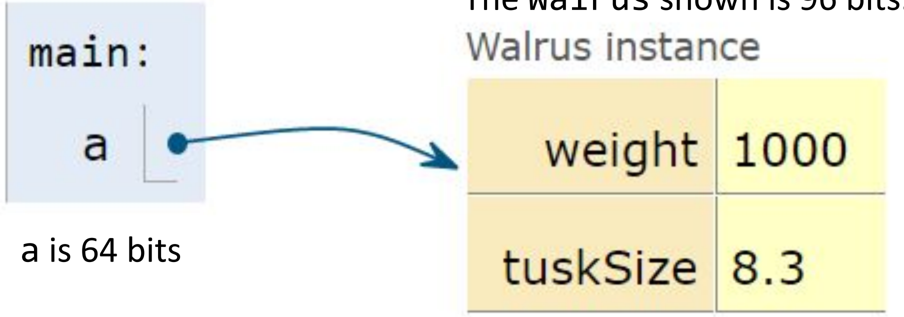
```
Walrus a;
a = new Walrus(1000, 8.3);
Walrus b;
b = a;
```

The `Walrus` shown is 96 bits.



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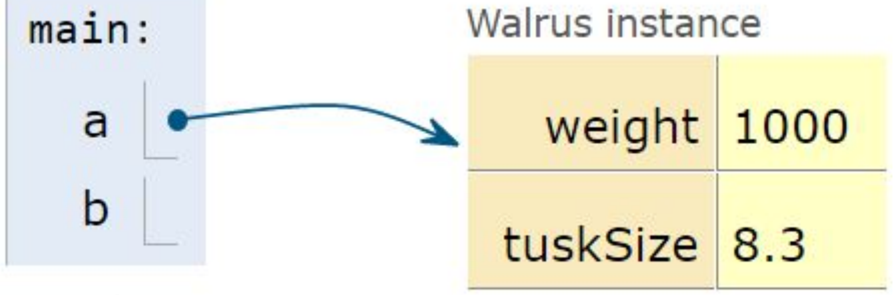

a and b are 64 bits

Note: b is currently undefined, not null!

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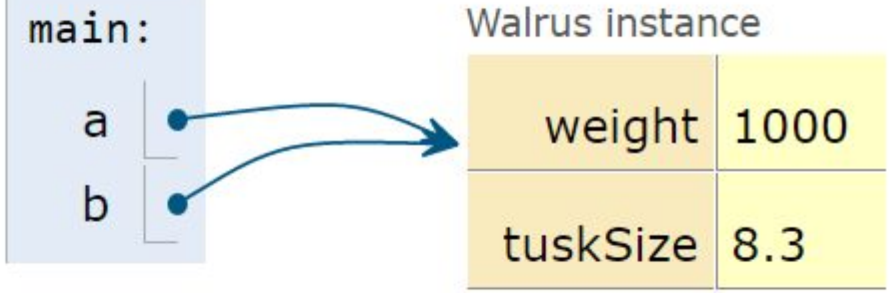

a and b are 64 bits

Parameter Passing

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The Golden Rule of Equals (and Parameter Passing)

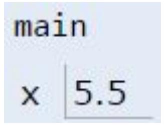
Given variables b and a:

- `b = a` **copies** all the bits from a into b.

Passing parameters obeys the same rule: Simply **copy the bits** to the new scope.

```
public static double average(double a, double b) {
   return (a + b) / 2;
}

public static void main(String[] args) {
   double x = 5.5;
   double y = 10.5;
   double avg = average(x, y);
}
```



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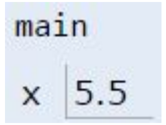
```



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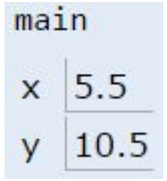

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   double y = 10.5;
 → double avg = average(x, y);
}
```

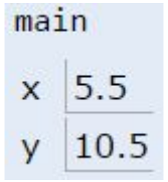

The Golden Rule of Equals (and Parameter Passing)

Given variables b and a:

- `b = a` **copies** all the bits from a into b.

This is also called pass by value.

Passing parameters obeys the same rule: Simply **copy the bits** to the new scope.

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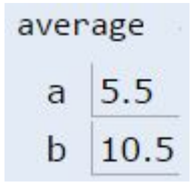
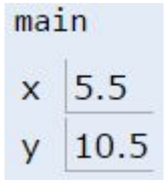




The Golden Rule: Summary

There are 9 types of variables in Java:

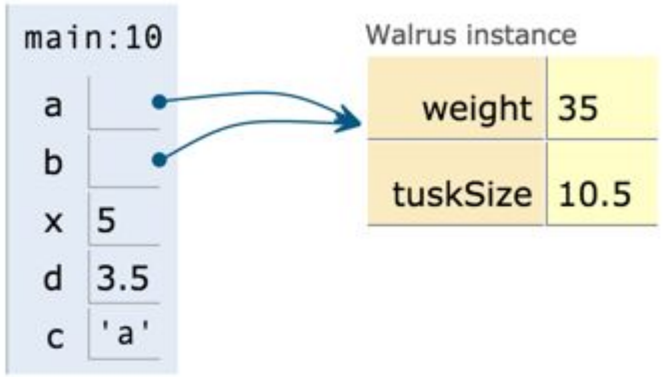
- 8 primitive types (byte, short, int, long, float, double, boolean, char).
- The 9th type is references to Objects (an arrow). References may be null.

In box-and-pointer notation, each variable is drawn as a labeled box and values are shown in the box.

- Addresses are represented by arrows to object instances.

The golden rule:

- b = a **copies the bits** from a into b.
- Passing parameters **copies the bits**.



Test Your Understanding: yellkey.com/however

Does the call to doStuff(walrus, x) have an affect on `walrus` and/or main's x?

A. Neither will change.
B. `walrus` will lose 100 lbs, but main's x will not change.
C. `walrus` will not change, but main's x will decrease by 5.
D. Both will decrease.

```
public static void main(String[] args) {
   Walrus walrus = new Walrus(3500, 10.5);
   int x = 9;
   doStuff(walrus, x);
   System.out.println(walrus);
   System.out.println(x);
}
public static void doStuff(Walrus W, int x) {
   W.weight = W.weight - 100;
   x = x - 5;
}
```

Answer: http://goo.gl/ngsxkq

Instantiation of Arrays

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Declaration and Instantiation of Arrays

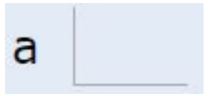
Arrays are also Objects. As we've seen, objects are (usually) instantiated using the ***new*** keyword.

- `Planet p = new Planet(0, 0, 0, 0, 0, “blah.png”);`
- `int[] x = new int[]{0, 1, 2, 95, 4};`

```
int[] a;
```

Declaration

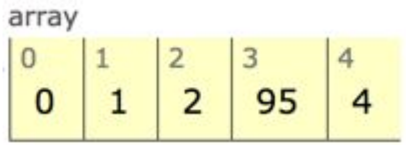
- Declaration creates a 64 bit box intended only for storing a reference to an int array. **No object is instantiated.**



```
new int[]{0, 1, 2, 95, 4};
```

Instantiation (HW0 covers this syntax)

- Instantiates a new Object, in this case an int array.
- Object is anonymous!



Minor technical note: I'm abusing the term instantiate a little by applying it to arrays.

Assignment of Arrays

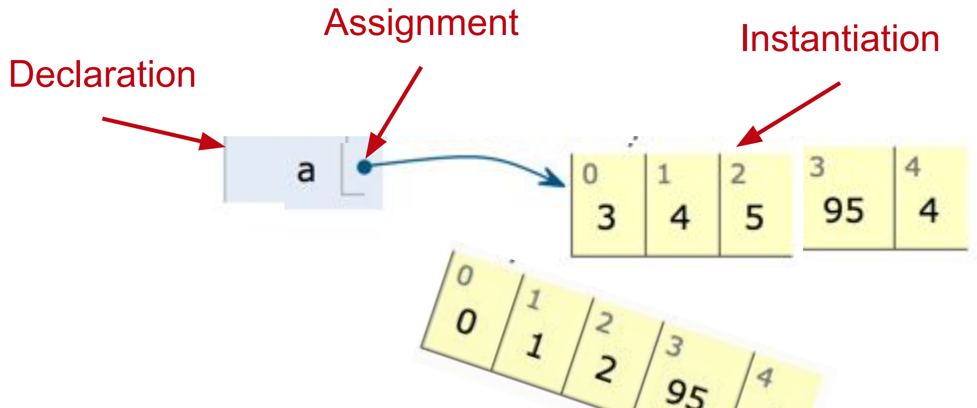
```
int[] a = new int[]{0, 1, 2, 95, 4};
```

Declaration, instantiation, and assignment.

- Creates a 64 bit box for storing an int array address. (declaration)
- Creates a new Object, in this case an int array. (instantiation)
- Puts the address of this new Object into the 64 bit box named a. (assignment)

Note: Instantiated objects can be lost!

- If we were to reassign a to something else, we'd never be able to get the original Object back!



IntList and Linked Data Structures

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IntList

Let's define an `IntList` as an object containing two member variables:

- `int first;`
- `IntList rest;`

And define two versions of the same method:

- `size()`
- `iterativeSize()`

Coding Demo: Adding to End of IntList

IntList.java

```
public class IntList {
   public int first;
   public IntList rest;









}
```

Coding Demo: Adding to End of IntList

IntList.java

```java
public class IntList {
   public int first;
   public IntList rest;

   public static void main(String[] args) {
      IntList L = new IntList();
      L.first = 5;
      L.rest = null;








   }
}
```

Coding Demo: Adding to End of IntList

IntList.java

```
public class IntList {
   public int first;
   public IntList rest;

   public static void main(String[] args) {
      IntList L = new IntList();
      L.first = 5;
      L.rest = null;

      L.rest = new IntList();
      L.rest.first = 10;




   }
}
```

Coding Demo: Adding to End of IntList

IntList.java

```java
public class IntList {
   public int first;
   public IntList rest;

   public static void main(String[] args) {
      IntList L = new IntList();
      L.first = 5;
      L.rest = null;

      L.rest = new IntList();
      L.rest.first = 10;

      L.rest.rest = new IntList();
      L.rest.rest.first = 15;

   }
}
```

Java Visualizer

Coding Demo: Adding to Start of IntList

IntList.java

```java
public class IntList {
   public int first;
   public IntList rest;













}
```

Coding Demo: Adding to Start of IntList

IntList.java

```java
public class IntList {
   public int first;
   public IntList rest;

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









}
```

Coding Demo: Adding to Start of IntList

IntList.java

```java
public class IntList {
   public int first;
   public IntList rest;

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

   public static void main(String[] args) {
      IntList L = new IntList(15, null);
      L = new IntList(10, L);
      L = new IntList(5, L);


   }
}
```

Java Visualizer

Coding Demo: IntList size

IntList.java

```java
public class IntList {
   public int first;
   public IntList rest;

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

   public static void main(String[] args) {
      IntList L = new IntList(15, null);
      L = new IntList(10, L);
      L = new IntList(5, L);

      System.out.println(L.size());  // should print out 3
   }
}
```

Coding Demo: IntList size

IntList.java

```java
public class IntList {
   public int first;
   public IntList rest;

   /** Return the size of the list using... recursion! */
   public int size() {




   }






}
```

Coding Demo: IntList size

IntList.java

```
public class IntList {
   public int first;
   public IntList rest;

   /** Return the size of the list using... recursion! */
   public int size() {
      if (rest == null) {

      }

   }






}
```

Coding Demo: IntList size

IntList.java

```
public class IntList {
   public int first;
   public IntList rest;

   /** Return the size of the list using... recursion! */
   public int size() {
      if (rest == null) {
         return 1;
      }

   }




}
```

Coding Demo: IntList size

IntList.java

```java
public class IntList {
   public int first;
   public IntList rest;

   /** Return the size of the list using... recursion! */
   public int size() {
      if (rest == null) {
         return 1;
      }
      return 1 + this.rest.size();
   }







}
```

Java Visualizer

Coding Demo: IntList iterativeSize

IntList.java

```
public class IntList {
   public int first;
   public IntList rest;

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

   public static void main(String[] args) {
      IntList L = new IntList(15, null);
      L = new IntList(10, L);
      L = new IntList(5, L);

      System.out.println(L.iterativeSize());  // should also print out 3
   }
}
```

Coding Demo: IntList iterativeSize

IntList.java

```java
public class IntList {
   public int first;
   public IntList rest;

   /** Return the size of the list using no recursion! */
   public int iterativeSize() {







   }


}
```

Coding Demo: IntList iterativeSize

IntList.java

```
public class IntList {
   public int first;
   public IntList rest;

   /** Return the size of the list using no recursion! */
   public int iterativeSize() {
      IntList p = this;







   }


}
```

Coding Demo: IntList iterativeSize

IntList.java

```
public class IntList {
   public int first;
   public IntList rest;

   /** Return the size of the list using no recursion! */
   public int iterativeSize() {
      IntList p = this;
      int totalSize = 0;





   }


}
```

Coding Demo: IntList iterativeSize

IntList.java

```java
public class IntList {
   public int first;
   public IntList rest;

   /** Return the size of the list using no recursion! */
   public int iterativeSize() {
      IntList p = this;
      int totalSize = 0;
      while (p != null) {


      }

   }


}
```

Coding Demo: IntList iterativeSize

IntList.java

```
public class IntList {
   public int first;
   public IntList rest;

   /** Return the size of the list using no recursion! */
   public int iterativeSize() {
      IntList p = this;
      int totalSize = 0;
      while (p != null) {
         totalSize += 1;

      }

   }


}
```

Coding Demo: IntList iterativeSize

IntList.java

```
public class IntList {
   public int first;
   public IntList rest;

   /** Return the size of the list using no recursion! */
   public int iterativeSize() {
      IntList p = this;
      int totalSize = 0;
      while (p != null) {
         totalSize += 1;
         p = p.rest;
      }

   }


}
```

Coding Demo: IntList iterativeSize

IntList.java

```
public class IntList {
   public int first;
   public IntList rest;

   /** Return the size of the list using no recursion! */
   public int iterativeSize() {
      IntList p = this;
      int totalSize = 0;
      while (p != null) {
         totalSize += 1;
         p = p.rest;
      }
      return totalSize;
   }


}
```

Java Visualizer

Challenge

Write a method `int get(int i)` that returns the ith item in the list.

- For simplicity, OK to assume the item exists.
- Front item is the 0th item.

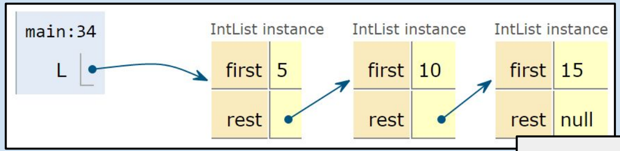
Ways to work:

- Paper (best)
- Laptop (see lectureCode repo)
  - exercises/lists1/IntList.java
- In your head (worst)

See the video online for a solution:
https://www.youtube.com/watch?v=qnmxD_21DNk

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

   /** Return the size of this IntList. */
   public int size() {
      if (rest == null) {
         return 1;
      }
      return 1 + this.rest.size();
   ...
```



```
L.get(0): 5
L.get(1): 10
```

Coding Demo: IntList get

IntList.java

```java
public class IntList {
   public int first;
   public IntList rest;

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

   public static void main(String[] args) {
      IntList L = new IntList(15, null);
      L = new IntList(10, L);
      L = new IntList(5, L);

      System.out.println(L.get(1));  // should print out 10
   }
}
```

Coding Demo: IntList get

IntList.java

```java
public class IntList {
   public int first;
   public IntList rest;

   /** Return the ith item of this IntList. */
   public int get(int i) {




   }






}
```

Coding Demo: IntList get

IntList.java

```
public class IntList {
   public int first;
   public IntList rest;

   /** Return the ith item of this IntList. */
   public int get(int i) {
      if (i == 0) {

      }

   }




}
```

Coding Demo: IntList get

IntList.java

```java
public class IntList {
   public int first;
   public IntList rest;

   /** Return the ith item of this IntList. */
   public int get(int i) {
      if (i == 0) {
         return first;
      }

   }







}
```

Coding Demo: IntList get

IntList.java

```java
public class IntList {
   public int first;
   public IntList rest;

   /** Return the ith item of this IntList. */
   public int get(int i) {
      if (i == 0) {
         return first;
      }
      return rest.get(i - 1);
   }






}
```

Java Visualizer

Question: yellkey.com

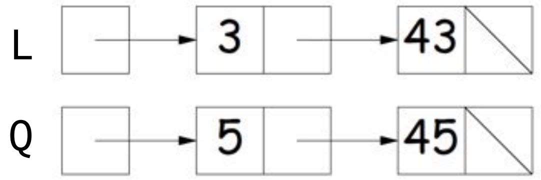
What is your comfort level with recursive data structure code?

A. Very comfortable.
B. Comfortable.
C. Somewhat comfortable.
D. I have never done this.

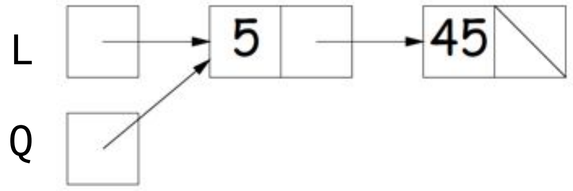
ExtraIntListPractice.java

For further practice with IntLists, fill out the code for the methods listed below in the **lists1/exercises/ExtraIntListPractice.java** in **lectureCode** github directory.

- `public static IntList incrList(IntList L, int x)`
  - Returns an IntList identical to L, but with all values incremented by x.
  - Values in L cannot change!



- `public static IntList dincrList(IntList L, int x)`
  - Returns an IntList identical to L, but with all values incremented by x.
  - Not allowed to use 'new' (to save memory).3



This week's discussion also features optional IntList problems.