

CS61B, 2021

Lecture 4: References and Recursion

- Primitive Types
- Reference Types
- Linked Data Structures

Primitive Types

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
```

```
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
```

Answer: [Visualizer](#)

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 access a variable that is uninitialized.

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

x

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

x

y

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

x 10101010101100011010111010111111

y

Declaring a Variable (Simplified)

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```
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;
```

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

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](#)

Walrus instance

32 bits {	weight	1000
64 bits {	tuskSize	8.3

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.

[illegible]

```
→ 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

[illegible]

2384723423

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

Walrus instance

32 bits {	weight	1000
64 bits {	tuskSize	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**).

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

64 bits

someWalrus


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

Walrus instance

96 bits

weight	1000
--------	------

tuskSize 8.3

64 bits

someWalrus

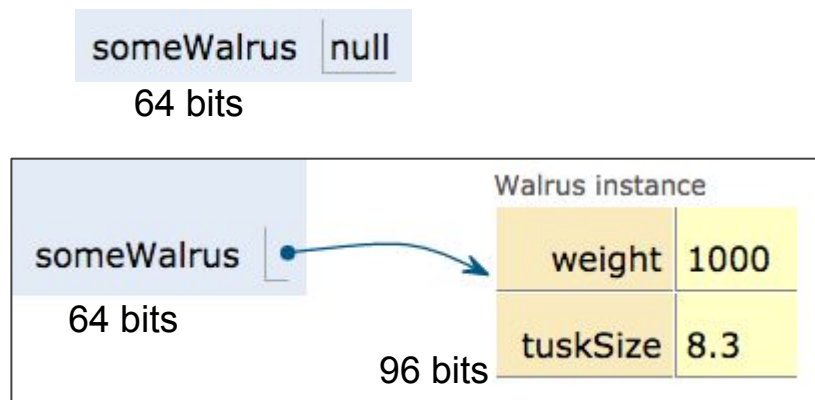
0100011000011100001001111100000100011101110111000001111000111111

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.

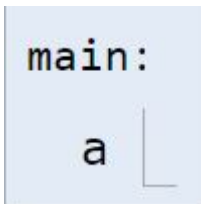


Reference Types Obey the Golden Rule of Equals

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.

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



a is 64 bits

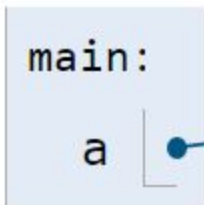
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```
Walrus a;  
a = new Walrus(1000, 8.3);  
Walrus b;  
b = a;
```



a is 64 bits

The Walrus shown is 96 bits.

Walrus instance

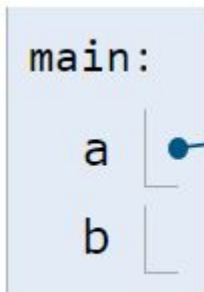
weight	1000
tuskSize	8.3

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.

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



a and b are 64 bits

The Walrus shown is 96 bits.
Walrus instance

weight	1000
tuskSize	8.3

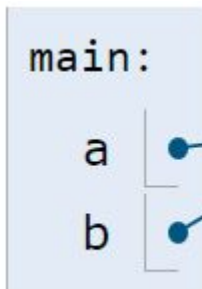
Note: b is currently
undefined, not null!

Reference Types Obey the Golden Rule of Equals

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- 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.

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Walrus a;  
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Walrus b;  
→ b = a;
```



a and b are 64 bits

The Walrus shown is 96 bits.
Walrus instance

weight	1000
tuskSize	8.3

Parameter Passing

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);  
}
```

main

x	5.5
---	-----

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    double x = 5.5;  
    → double y = 10.5;  
    double avg = average(x, y);  
}
```

main	
x	5.5
y	10.5

The Golden Rule of Equals (and Parameter Passing)

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}
```

main	
x	5.5
y	10.5

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.

```
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);  
}
```

average	
a	5.5
b	10.5

main	
x	5.5
y	10.5

The Golden Rule: Summary

There are 9 types of variables in Java:

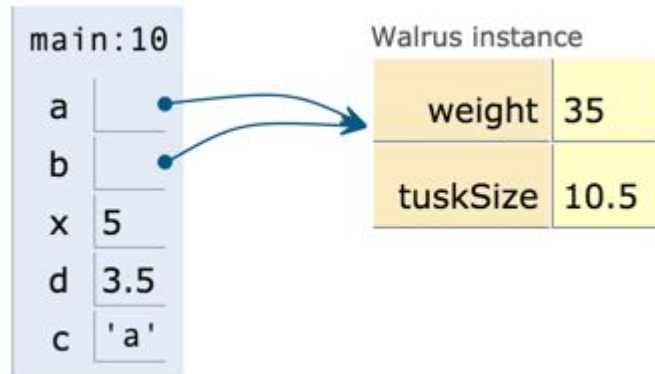
- 8 primitive types (byte, short, int, long, float, double, boolean, char).
- The 9th type is references to Objects (an arrow). References may be null.

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/others

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;  
}
```

Try to convince neighbor of your answer: yellkey.com/public

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- D. Both will decrease.

```
public static void doStuff(Walrus W, int x) {  
    W = new Walrus(W);  
    W.weight = W.weight - 100;  
    x = x - 5;  
}
```

Answer: <http://goo.gl/ngsxkq>

Instantiation of Arrays

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!

array				
0	1	2	3	4
0	1	2	95	4

Assignment of Arrays

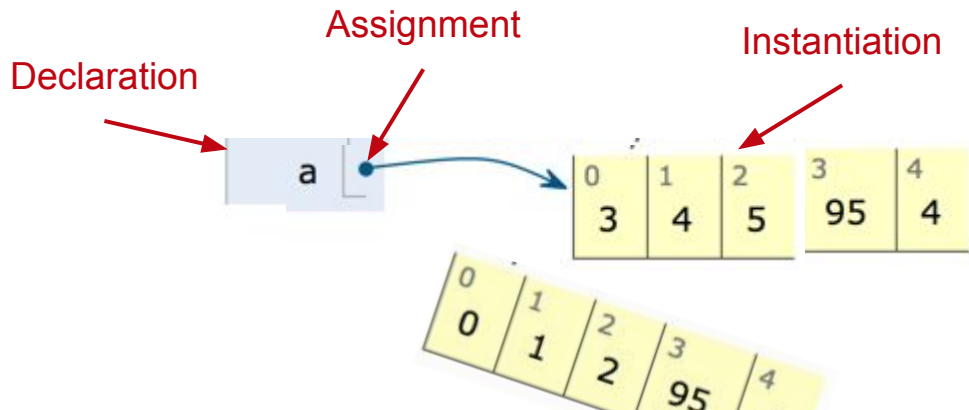
Declaration, instantiation,
and assignment.

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

- 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

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()`

Challenge

See the video online for a solution:

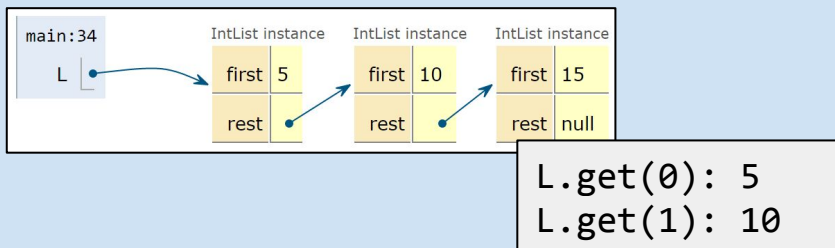
https://www.youtube.com/watch?v=qnmxD_21DNk

Write a method `int get(int i)` that returns the *i*th 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)



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

Question: yellkey.com/iterate

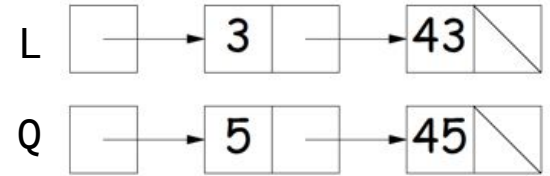
What is your comfort level with recursive data structure code?

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

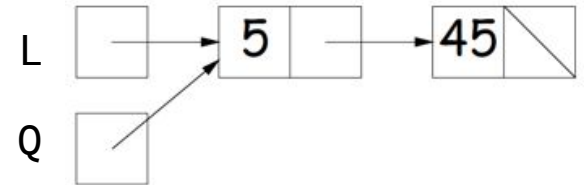
ExtraIntListPractice.java

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).



This week's discussion also features optional IntList problems.

Old Deprecated Slides

Quick Aside on Class Instantiation

Any class that we've created so far in 61B can be instantiated.

- Would be silly (but possible) to instantiate HelloWorld.

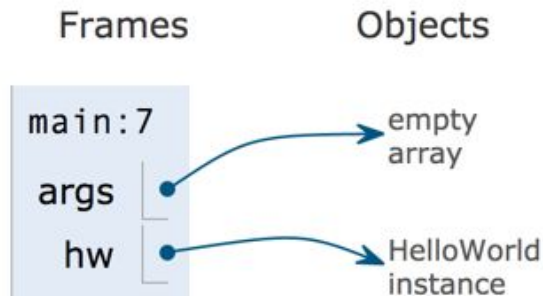
```
public class HelloWorld {  
    public static void main(String[] args) {  
        System.out.println("Hello World.");  
    }  
}
```

\$ java HelloWorld
Hello World.

```
public class HelloWorldMaker {  
    public static void main(String[] args) {  
        HelloWorld hw = new HelloWorld();  
    }  
}
```

\$ java HelloWorldMaker

(nothing happens) -- HelloWorld.main does not run!!



null

Java (for better or worse) allows null references.

- Danger lurks: null references do NOT have instance variables.
 - Blame Sir Tony Hoare (more when we talk about Quicksort)

Example:

```
Planet earth = new Planet(6e24, 6.37e6);  
System.out.println(Planet.surfaceGravity(earth));
```

```
Planet x = null;  
System.out.println(Planet.surfaceGravity(x));
```

```
9.862754424315312
```

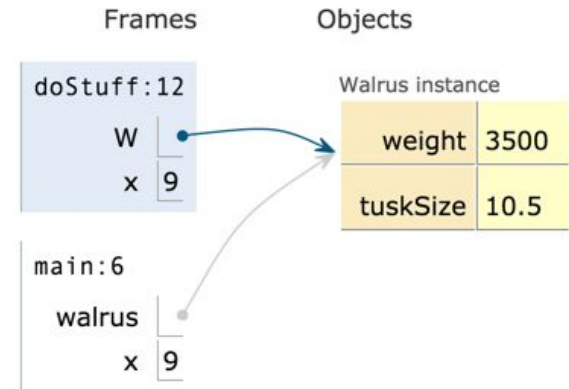
```
Exception in thread "main" java.lang.NullPointerException  
    at Planet.surfaceGravity(Planet.java:17)  
    at Planet.main(Planet.java:36)
```

Java is “Pass by Value”

All method (and constructor) calls are pass by value!

- The exact contents of the container in the outside world are delivered to the containers in the function. If the container has an arrow, so be it.

```
1 public class PassByValueFigure {
2     public static void main(String[] args) {
3         Walrus walrus = new Walrus(3500, 10.5);
4         int x = 9;
5
6         doStuff(walrus, x);
7         System.out.println(walrus);
8         System.out.println(x);
9     }
10
11     public static void doStuff(Walrus W, int x) {
12         W.weight = W.weight - 100;
13         x = x - 5;
14     }
```



Note

`is` in python equivalent to `==` in Java

- These check memory addresses.

`==` in python equivalent to `.equals` in Java

- In python we write a `__eq__` function.
- In Java we write a `equals()` function (see lecture 12).
- These check the boolean return value of a special function written by a class author.

Question: If a class doesn't define `equals`, and you call `equals`, what happens?

- It defaults to the implementation of `equals` in the “object” class (more on this later), but it uses `==`!