Memory

Lecture 12

CS106A, Summer 2019
Sarai Gould && Laura Cruz-Albrecht

Announcements

- SCPD OH only for SCPD students
- Midterm in 1 week…
  - In-Person Review Session on Friday, at 10:30am in Gates B01
  - Midterm will be 7pm - 9pm in Bishop

Plan for Today

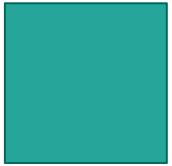
- Review: Pass by Reference vs. Value, Eclipse Debugger
- Equality: Primitives and Objects
- Primitives on the Stack
- Objects on the Heap
- Why This Matters!

Pass by Reference vs Value

Pass by Reference

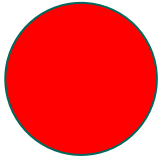
Objects are passed by **reference.**

A few examples:



`GRect`

`GImage`



`GOval`

Pass by Value

Primitives are passed by **value**.

A few examples:

`char`

`int`

`double`

`boolean`

Pass by Reference vs Value

What does this mean?

If something is passed by ***reference***, it ***can*** be altered simply by passing it into a method.

If something is passed by ***value***, it ***cannot*** be altered simply by passing it into a method.

Types of Errors

Syntax Errors:

A programming “typo”. Usually causes a red squiggly line in code.

Execution Errors:

Something that crashes the program *after* you run it.

Logic Errors:

All of your code runs, but it produces unexpected results.

How Can We Debug Errors?

Using the Eclipse Debugger!

Debugger Commands

Suspend. Stops the program immediately as if it had hit a breakpoint.

Terminate. Exits from the program entirely.

Step Into. Executes one statement of the program and then stops again. If that statement includes a method call, the program will stop at the first line of that method. As noted below, this option is not as useful as **Step Over**.

Step Over. Executes one statement of the program at this level and then stops again. Any method calls in the statement are executed through to completion unless they contain explicit breakpoints.

Step Return. Continues to execute this method until it returns, after which the debugger stops in the caller (the method that called the current method).

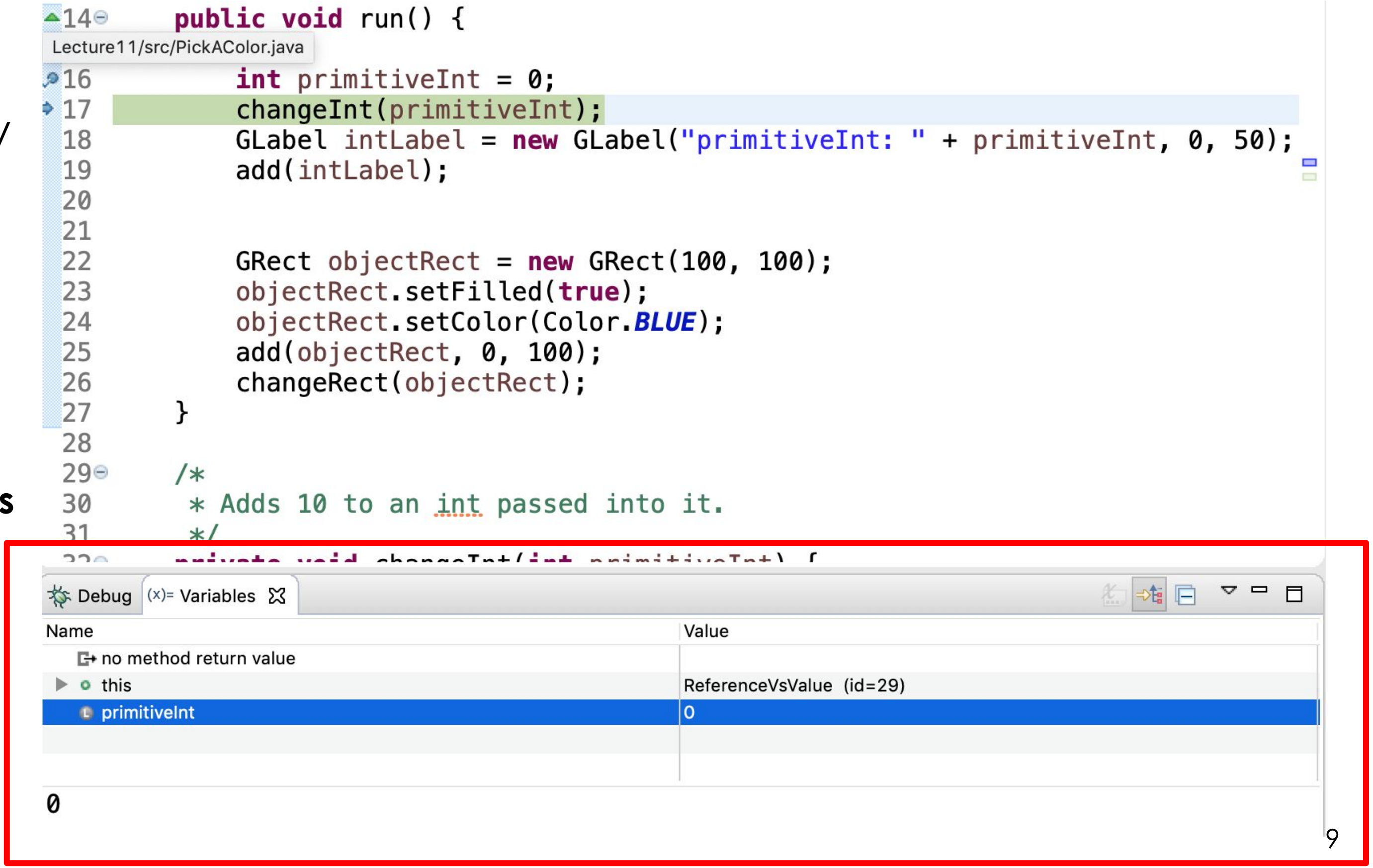
The debugger allows you to step through the execution of a program, one line at a time.

Variables View

I can view what my variables are currently equal to by opening the “Variables” View.

How?

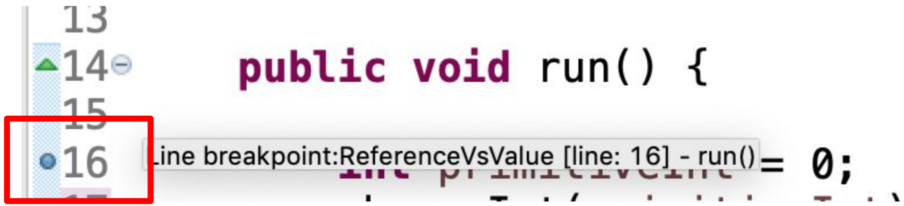
- Click **Window**
- Click **Show View**
- Click **Other…**
- Search for **Variables**
- Click **Variables**



Setting a Breakpoint

To start the debugger, it helps to set a breakpoint. Double click next to the line number where you want to set a breakpoint. This will create a little blue dot, or **breakpoint**.

Your code will stop and start the debugger when it sees the breakpoint.



Are They Equal?

```
public void run(){

    int num1 = 12;
    int num2 = 12;

    if(num1 == num2){
        println(“These integers are equal!”);
    } else {
        println(“Actually, these integers are not equal.”);
    }
}
```

Are They Equal?

```
public void run(){

    GRect rect1 = new GRect(100, 100);
    GRect rect2 = new GRect(100, 100);

    if(rect1 == rect2){
        println("These rectangles are equal!");
    } else {
        println("Actually, these rectangles are not equal.");
    }
}
```

Are They Equal?

```
public void run(){

    GRect rect3 = new GRect(100, 100);

    if(rect3 == rect3){
        println(“This rectangle is equal to itself!”);
    } else {
        println(“Actually, this rectangle is not equal to itself.”);
    }
}
```

What’s Going On Here?

Can you have **two different versions** of the same number?

Can one number 12 be different from another number 12?

What's Going On Here?

Can you have **two different versions** of the same number?
Can one number 12 be different from another number 12?

Can you have **two different versions** of the same rectangle?
Can one rectangle with a width and height of 100 be different from another rectangle with a width and height of 100?

What's Going On Here?

You **can** have two different rectangles with the same properties, but you **can't** have two different number 12s.

Being the same thing is different from having the same properties.

Are They Equal?

```
public void run(){

    GRect rect3 = new GRect(100, 100);

    if(rect3 == rect3){
        println(“This rectangle is equal to itself!”);
    } else {
        println(“Actually, this rectangle is not equal to itself.”);
    }
}
```

This will only evaluate to true if it’s the exact same rectangle! Let’s look into why.

Memory!

Hey Duke!

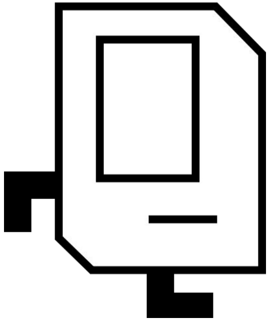
Karel! So good to see you.
um, will Sarai delete us?

Well, you'll always be in my memory

Heap or stack?

Heap ofc

Now that's true friendship <3



What Happened: Primitive

```
public void run(){
     int primitiveInt = 0;
     changeInt(primitiveInt);
```

```
private void changeInt(int primitiveInt){
     primitiveInt += 10;
}
```

Remember, in Thursday's example, when we called a new method, we put a box representing our method **on top of** the box representing **run()**.

We created a **stack**.

What Happened: Primitive

```
public void run(){
     int primitiveInt = 0;
     changeInt(primitiveInt);
```

```
private void changeInt(int primitiveInt){
     primitiveInt += 10;
}
```

We created a **stack**.

The computer does the same thing!

It creates a stack of things to keep track of in its temporary memory.

What Happened: Primitive

```
public void run(){
    int primitiveInt = 0;
    changeInt(primitiveInt);
```

```
private void changeInt(int primitiveInt){
    primitiveInt += 10;
}
```

The computer creates a stack of things to keep track of in its temporary memory.

And when the computer is done with something on the stack?

What Happened: Primitive

```
public void run(){
     int primitiveInt = 0;
     changeInt(primitiveInt);
     println(“primitiveInt: “ + primitiveInt, 0, 50);

     ...
```

The old item in memory is removed from the **stack**!

An Example: Stack

```
public void run(){
    firstMethodCall()

    ...
}
```

The **stack** stores method calls and local variables in our program.

Right now run() is on the top of the stack.

An Example: Stack

```
public void run(){
    firstMethodCall()
```

```
public void firstMethodCall(){
    secondMethodCall()

    ...
}
```

The **stack** stores method calls and local variables in our program.

Right now `firstMethodCall()` is on the top of the stack.

An Example: Stack

```
public void run(){
    firstMethodCall()
```

```
public void firstMethodCall(){
    secondMethodCall()
```

```
public void secondMethodCall(){
    thirdMethodMethodCall()

    ...

}
```

Right now `secondMethodCall()` is on the top of the stack.

And so it continues.

An Example: Stack

```
public void run(){
     int num1 = 18;
     int num2 = 13;
     double answer = average(num1, num2);
}
```

run

Right now `run()` is on the top of the stack.

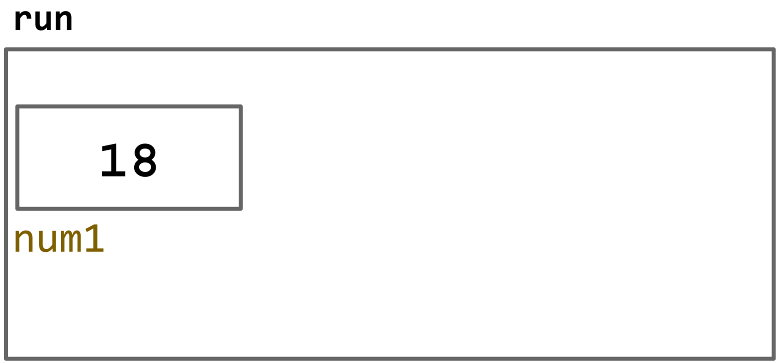
We will create a new **stack frame** for it.

An Example: Stack

```
public void run(){
    int num1 = 18;
    int num2 = 13;
    double answer = average(num1, num2);
}
```

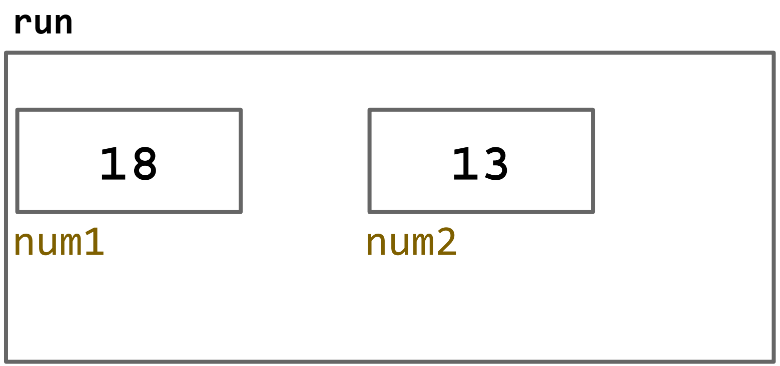
As we create **local variables**, they are added to our stack as well.

Local variables are variables created within our current scope.



An Example: Stack

```
public void run(){
     int num1 = 18;
     int num2 = 13;
     double answer = average(num1, num2);
}
```



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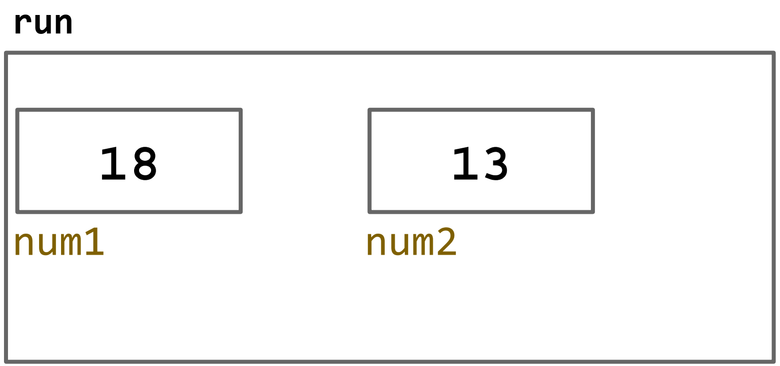
Local variables are variables created within our current scope.

An Example: Stack

```
public void run(){
     int num1 = 18;
     int num2 = 13;
     double answer = average(num1, num2);
}
```

Look, we see a new method!

Remember, we always **evaluate the right side first!**



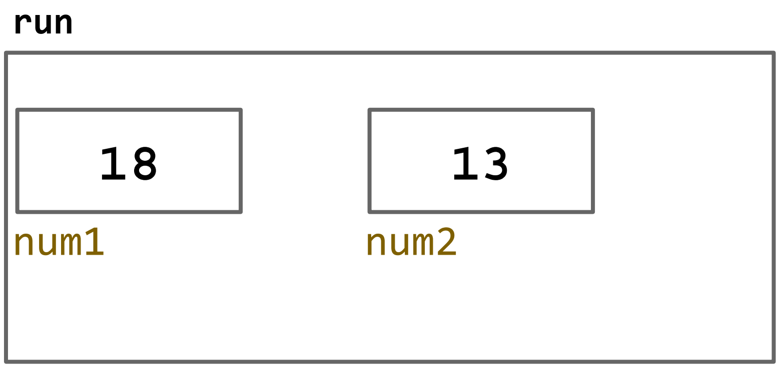
An Example: Stack

```
public void run(){
    int num1 = 18;
    int num2 = 13;
    double answer = average(num1, num2);
}
```

Look, we see a new method!

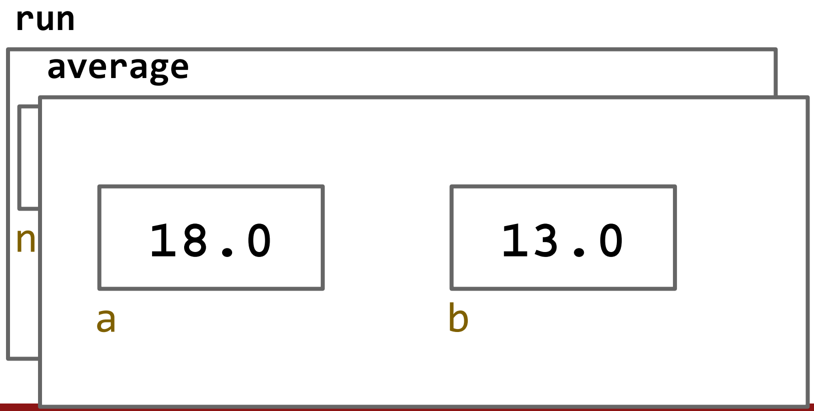
(Remember, we always **evaluate the right side first!**)

What do we do now?



An Example: Stack

```
public void run(){
private double average(double a, double b){

    double sum = a + b;
    return sum / 2;
}
}
```



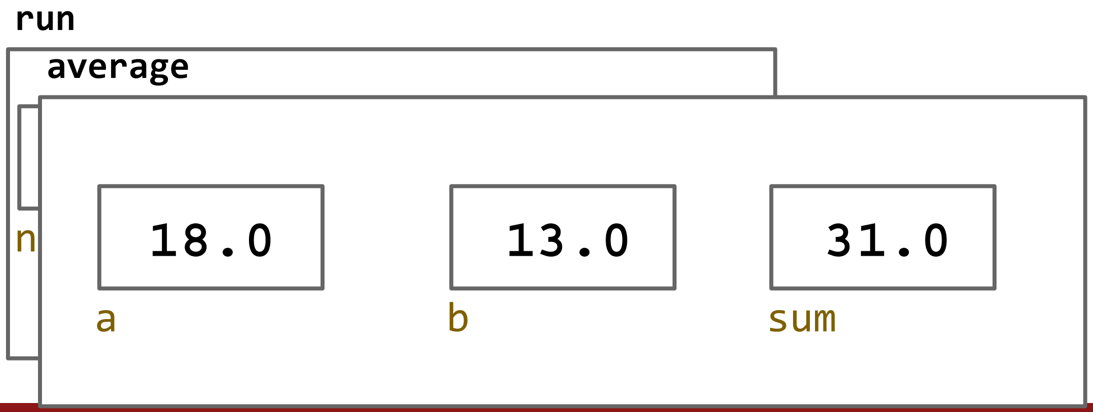
Create a new stack frame!

Every time a new method is called we create a new **stack frame** and copy the **parameter values** that were passed in!

An Example: Stack

```
public void run(){
}
```

```
private double average(double a, double b){

    double sum = a + b;
    return sum / 2;
}
```

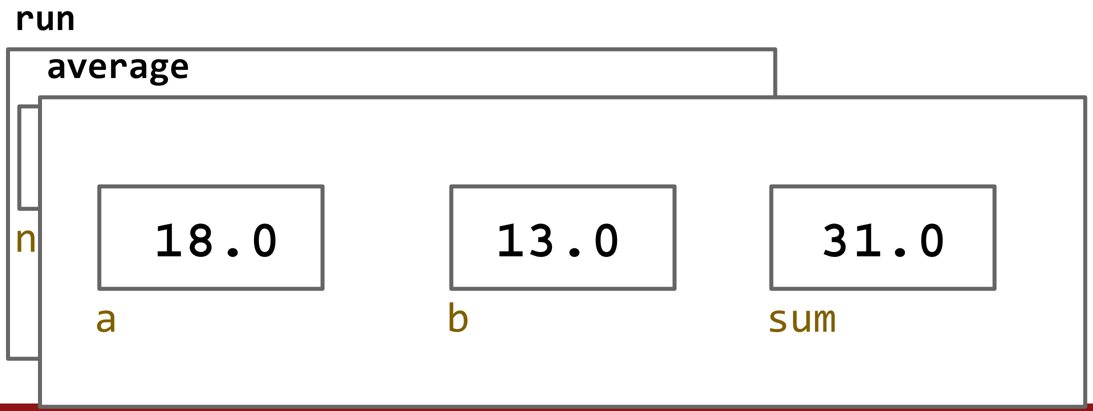


As new **local variables** are created, we created new boxes for them and **add them to the stack as well**!

An Example: Stack

```java
public void run(){

}
```

```java
private double average(double a, double b){

    double sum = a + b;
    return sum / 2;
}
```

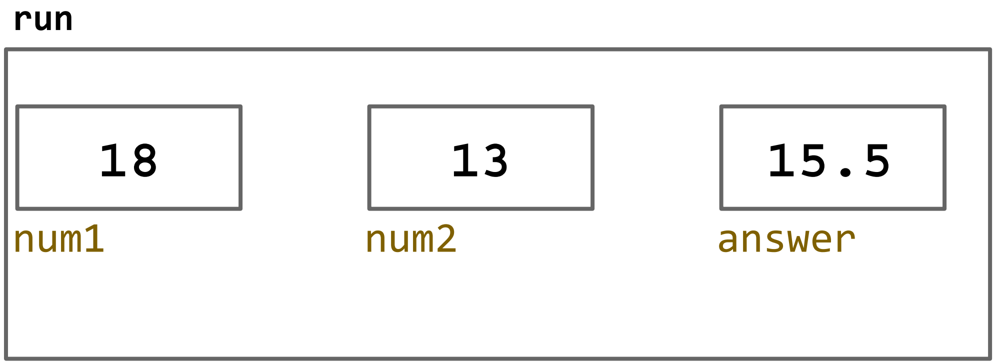


When we **return** this allows a method to pass information back to the **caller**.

The **caller** is the method that called our current method.

An Example: Stack

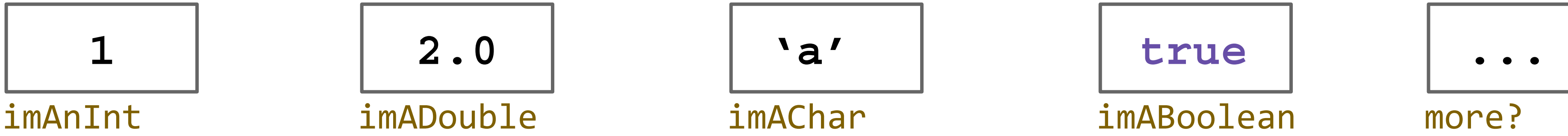
```
public void run(){
     int num1 = 18;
     int num2 = 13;
     double answer = average(num1, num2);
}
```



When **average** returned, we removed it from the stack frame!

This removed it from memory as well as all of the local variables it created!

Primitives



All of the primitive variables we create in memory have a fixed size.

All **`int`**s receive the same amount of space, all **`double`**s receive the same amount of space, etc...

Primitives

`1`	`2.0`	`'a'`	`true`	`...`
`imAnInt`	`imADouble`	`imAChar`	`imABoolean`	`more?`

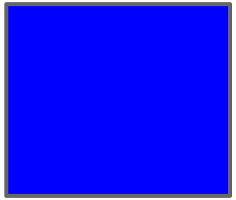
`int`s receive 4 bytes.

`double`s receive 8 bytes.

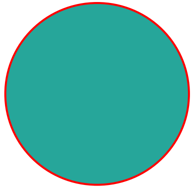
`char`s receive 2 bytes.

`boolean`s are less precisely defined, but still a primitive!

Objects



`imARect`



`imAnOval`

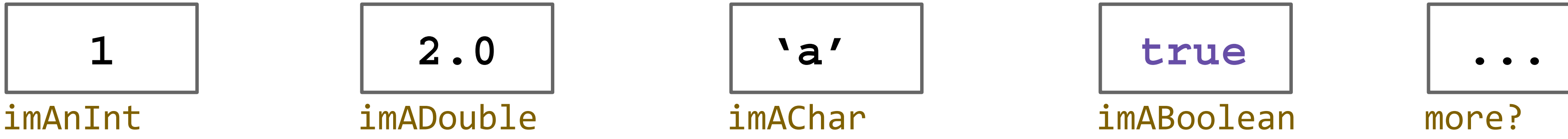
`imAnImage`

...

`more...`

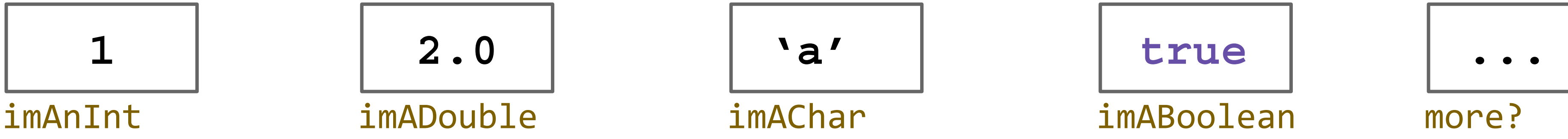
What about objects?

Primitives

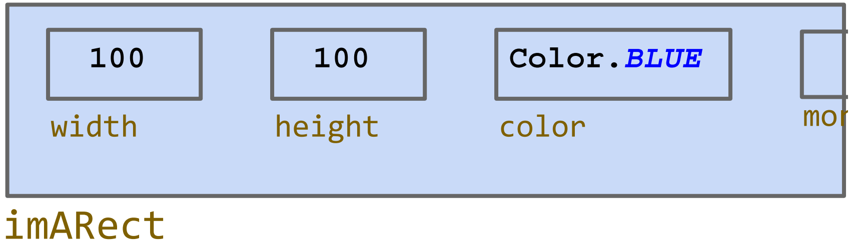


Primitives receive a set amount of space on the stack when they are created! They store a small amount of data.

Primitives

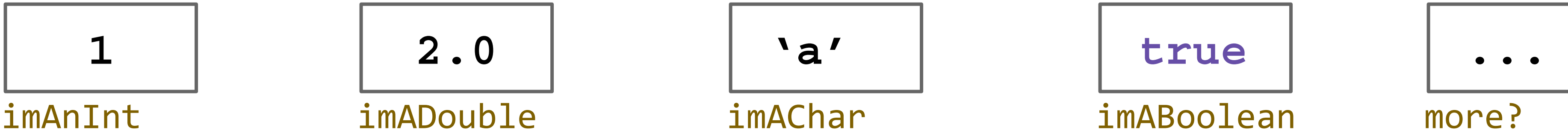


Primitives receive a set amount of space on the stack when they are created! They store a small amount of data.

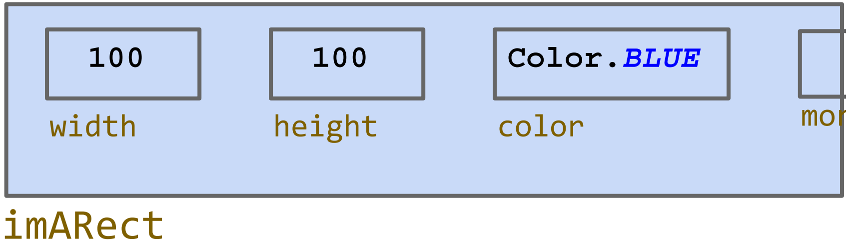


Objects store LOTS of data!

Primitives



Primitives receive a set amount of space on the stack when they are created! They store a small amount of data.



Objects store LOTS of data! Java chooses to store **objects** on the **heap**.

The Heap??

The **Heap** is more permanent memory. Things on the heap don't disappear as methods are called or returned.

Why do we care that objects are stored on the heap?

Remember: Are They Equal?

```
public void run(){

    GRect rect3 = new GRect(100, 100);

    if(rect3 == rect3){
        println("This rectangle is equal to itself!");
    } else {
        println("Actually, this rectangle is not equal to itself.");
    }
}
```

Remember: This will only evaluate to true if it's the exact same rectangle! **This has something to do with how objects are stored in memory.**

Objects

```java
public void run(){
     GRect rect = new GRect(100, 100);
     rect.setFilled(true);
     rect.setColor(Color.BLUE);
     add(rect, 100, 100);
}
```

Like before, we'll put `run()` on our stack!

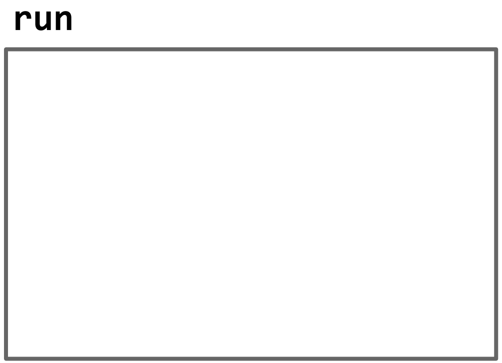
run

Objects

```
public void run(){
     GRect rect = new GRect(100, 100);
     rect.setFilled(true);
     rect.setColor(Color.BLUE);
     add(rect, 100, 100);
}
```

We'll create a GRect.

Remember: we evaluate the right-hand side first!



Objects

```
public void run(){
    GRect rect = new GRect(100, 100);
    rect.setFilled(true);
    rect.setColor(Color.BLUE);
    add(rect, 100, 100);
}
```

Wait a second! Why did it create a GRect outside of `run()`?

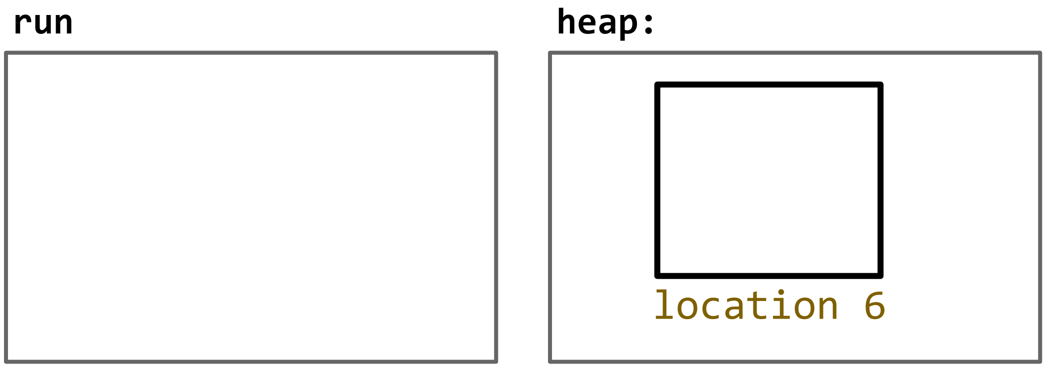
run

Objects

```
public void run(){
     GRect rect = new GRect(100, 100);
     rect.setFilled(true);
     rect.setColor(Color.BLUE);
     add(rect, 100, 100);
}
```

Wait a second! Why did it create a GRect outside of `run()`?

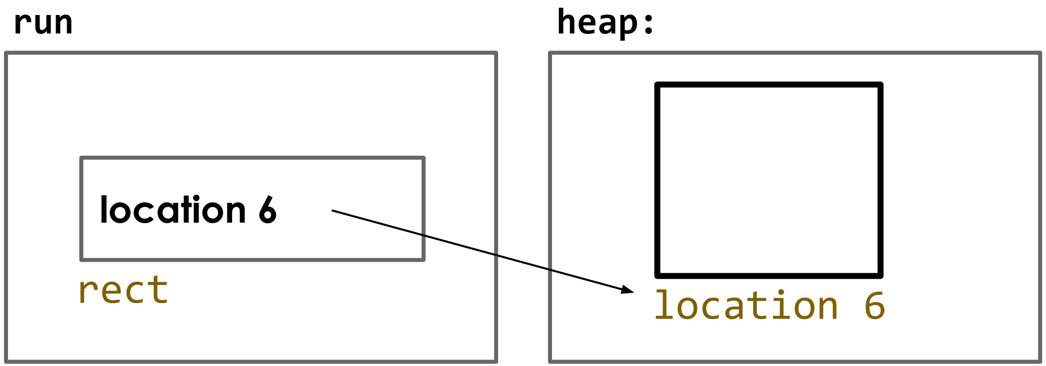
It created our GRect on the heap!



Objects

```
public void run(){
    GRect rect = new GRect(100, 100);
    rect.setFilled(true);
    rect.setColor(Color.BLUE);
    add(rect, 100, 100);
}
```

rect becomes equal to the **location in memory** where our GRect is.



Let's Revisit

```
public void run(){

     GRect rect1 = new GRect(100, 100); // rect1 = location 4
     GRect rect2 = new GRect(100, 100); // rect2 = location 5

     // is the memory address of rect1 equal to the memory address of rect2?
     if(rect1 == rect2){
          println("These rectangles are equal!");
     } else {
          println("Actually, these rectangles are not equal.");
     }
}
```

Let's Revisit

```
public void run(){

    GRect rect1 = new GRect(100, 100); // rect1 = location 4
    GRect rect2 = new GRect(100, 100); // rect2 = location 5

    // is the memory address of rect1 equal to the memory address of rect2?
    if(rect1 == rect2){
        println("These rectangles are equal!");
    } else {
        // no! They're at different locations in memory!
        println("Actually, these rectangles are not equal.");
    }
}
```

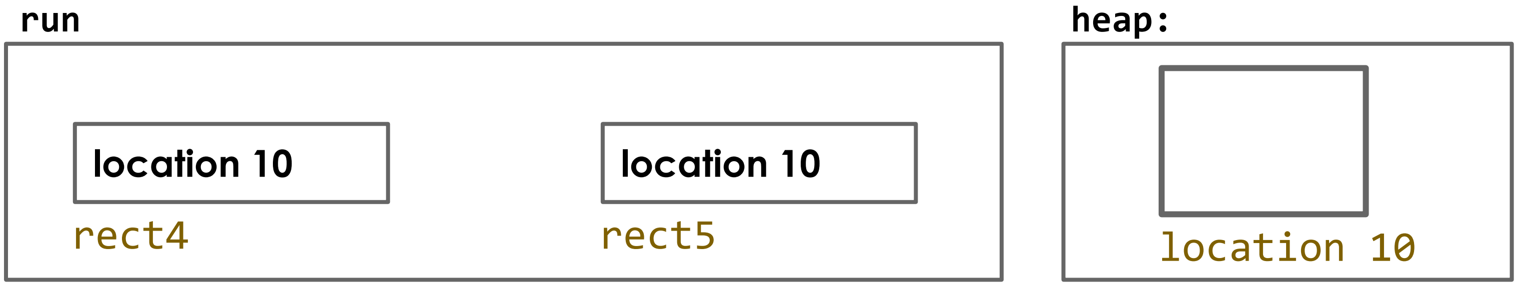
We cannot create two different GRects in the same location in memory.

Another Example

```
public void run(){

    GRect rect4 = new GRect(100, 100); // rect4 = location 10
    GRect rect5 = rect4;

    // is the memory address of rect4 equal to the memory address of rect5?
    if(rect4 == rect5){
        println("These rectangles are equal!");
    } else {
        println("Actually, these rectangles are not equal.");
    }
}
```

Another Example

```
public void run(){

      GRect rect4 = new GRect(100, 100); // rect4 = location 10
      GRect rect5 = rect4;

      // is the memory address of rect4 equal to the memory address of rect4?
      if(rect4 == rect5){
            // They are equal! They both point to the same place in memory!
            println("These rectangles are equal!");
      } else {
            println("Actually, these rectangles are not equal.");
      }
}
```



What's Going On Here?

Can you have **two different versions** of the same number? Can one number 12 be different from another number 12?

No. Two primitive ***values*** will always be equal if they're the same. Their values are stored on the stack.

What's Going On Here?

Can you have **two different versions** of the same rectangle? Can one rectangle with a width and height of 100 be different from another rectangle with a width and height of 100?

Yes. Two rectangles are only the same if the **value of their memory addresses** are the same. Each rectangle is stored on the heap while the value of their memory address can be stored on the stack.

Pass by Reference vs Value

If something is passed by ***reference***, it ***can*** be altered simply by passing it into a method. This is because we are passing in a **reference to its location in memory**, not a copy of the object.

If something is passed by ***value***, it ***cannot*** be altered simply by passing it into a method. This is because we are a passing in a **copy of its value**.

What Happens Here?

```
public void run(){
      int size = 250;
      GRect rect1 = new GRect(size, size);
      GRect rect2 = rect1;
      changeSize(rect2, size);
      add(rect1, 100, 100);
}

private void changeSize(GRect rect, double size){
      size += 250;
      rect.setSize(size, size);
}
```

What Happens Here?

```java
public void run(){
      int size = 250;
      GRect rect1 = new GRect(size, size);
      GRect rect2 = rect1;
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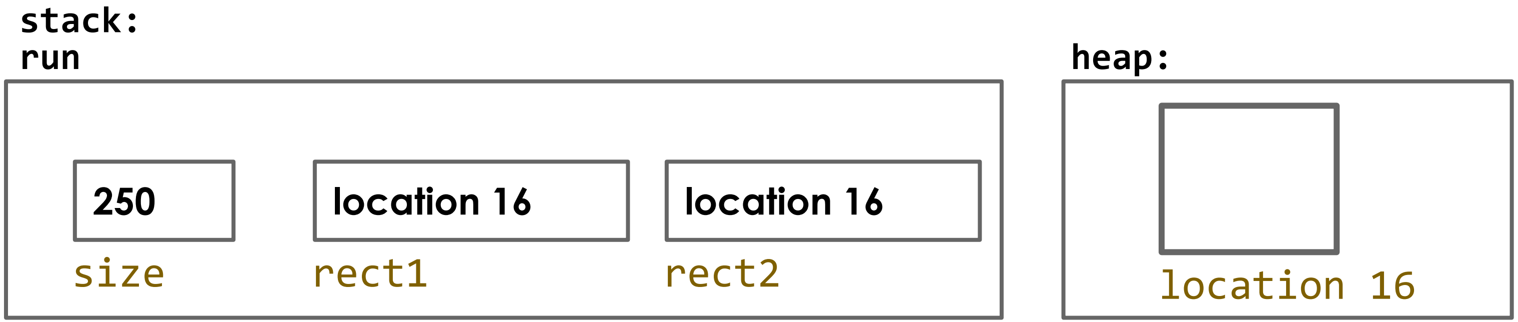

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public void run(){
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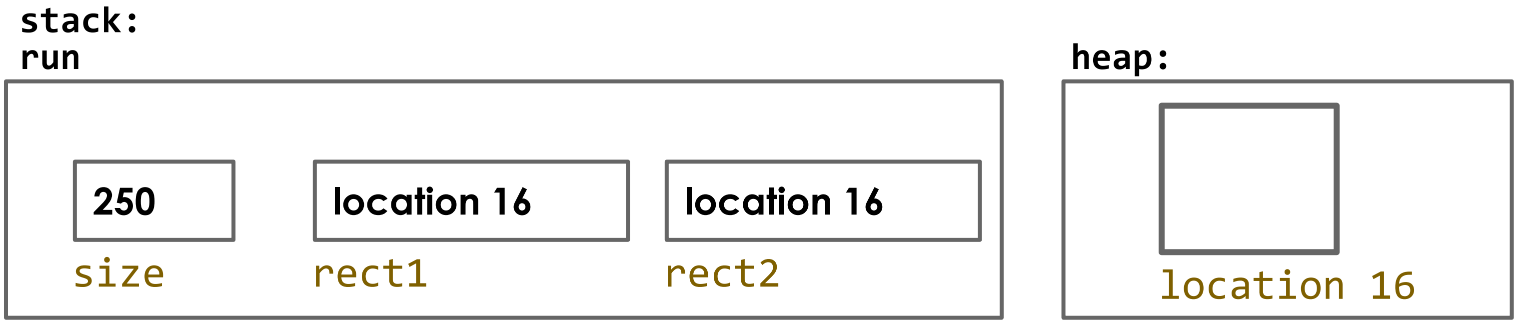

What Happens Here?

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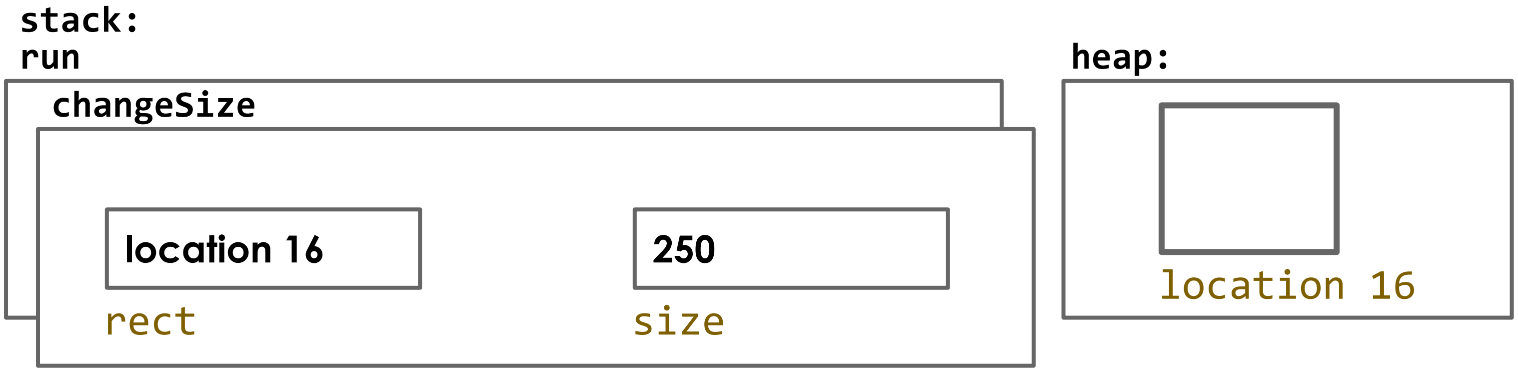

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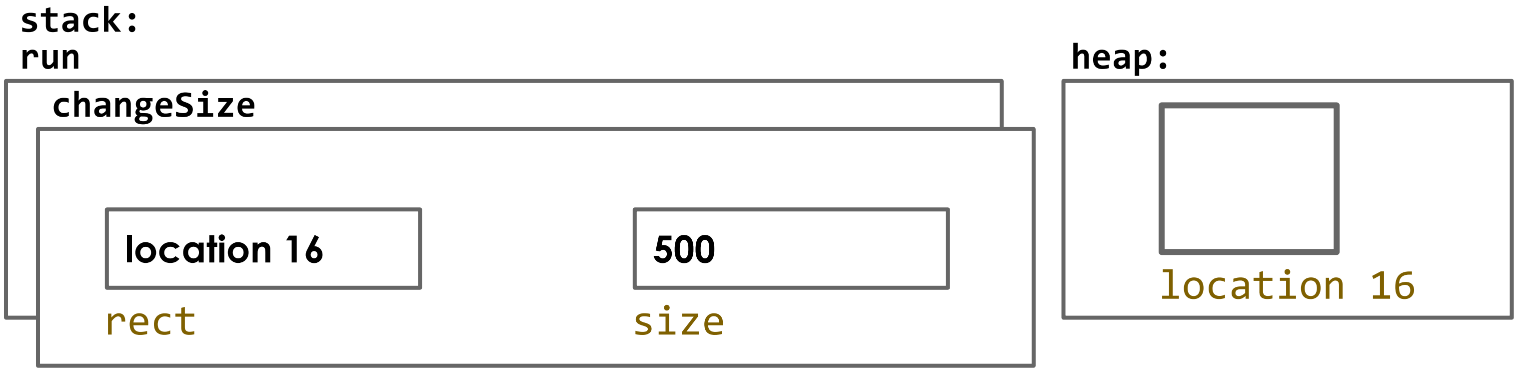

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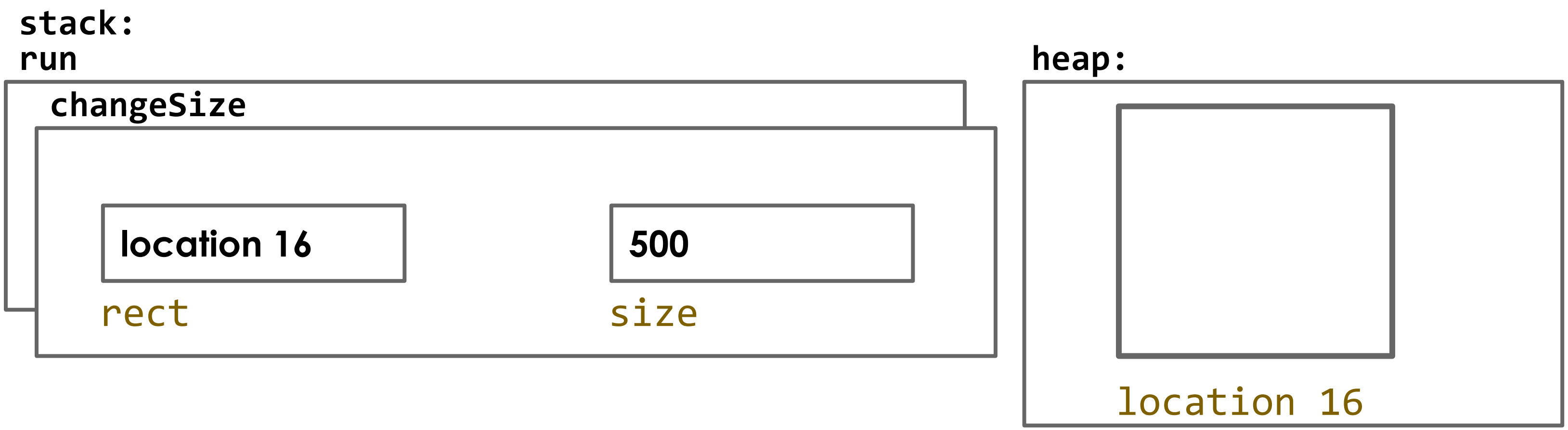

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}
```
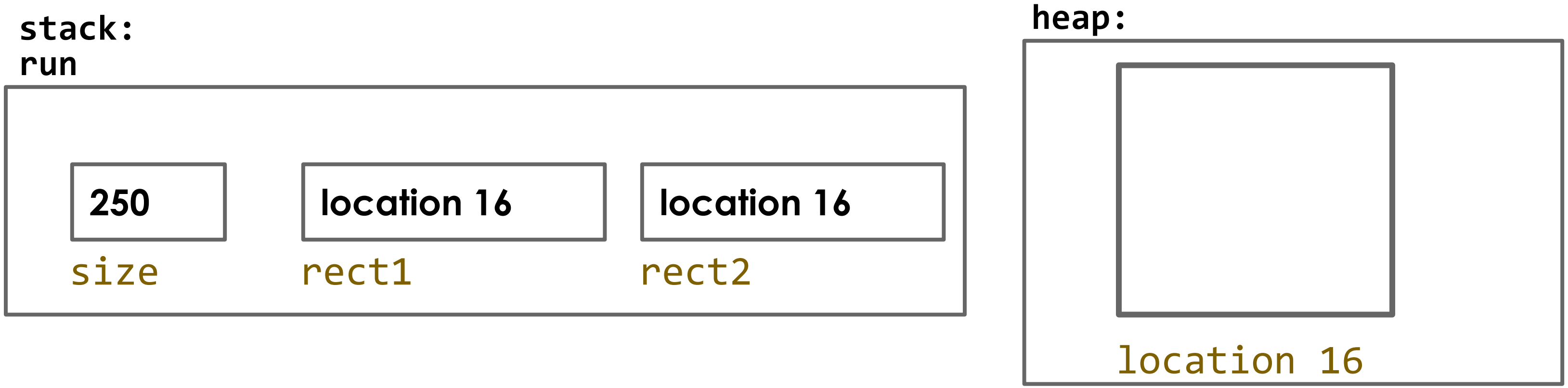
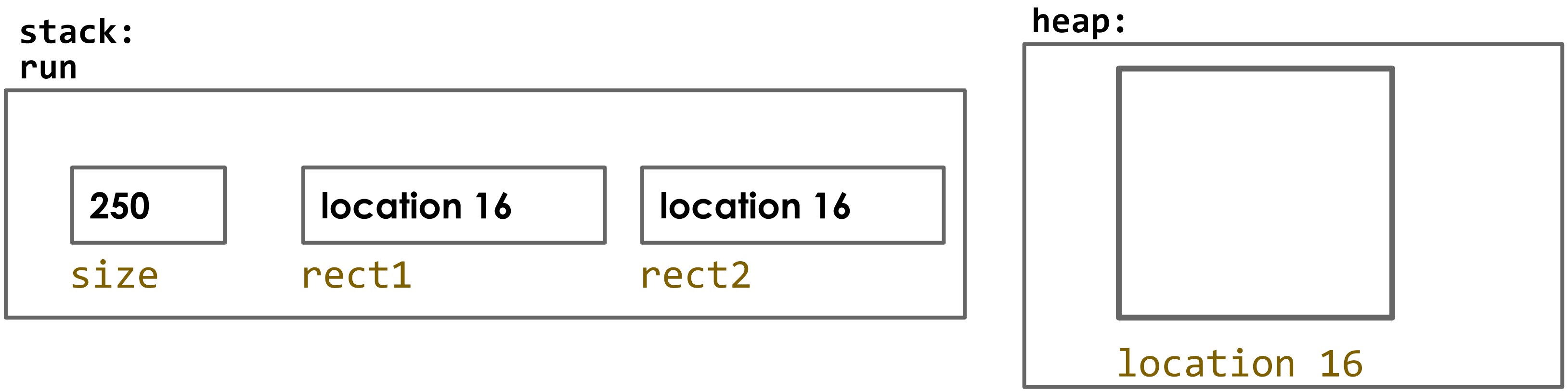



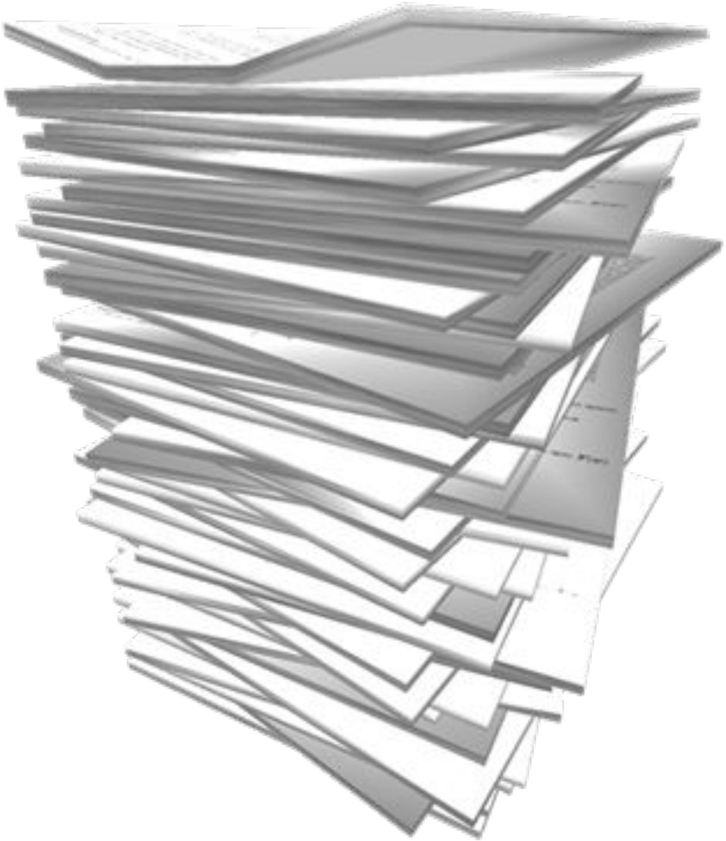
What Happens Here?

Name	Value
no method return value	
this	ChangingSize (id=29)
size	250
rect1	GRect (id=68)
rect2	GRect (id=68)

```
GRect[bounds=(0.0, 0.0, 500.0, 500.0), filled=false, fillColor=BLACK]
```



Stack Too Tall?



What happens if there's too many things on the stack?

Stack Overflow!

Plan for Today

- Review: Pass by Reference vs. Value, Eclipse Debugger
- Equality: Primitives and Objects
- Primitives on the Stack
- Objects on the Heap
- Why This Matters!