Memory

Brahm Capoor

```
int x = 42;
int y = 42;

if (x == y) {
   println("These numbers are equal");
} else {
   println("These numbers are different");
}
```

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int x = 42;
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if (x == y) {
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```

```
GRect r1 = new GRect(20, 50);
GRect r2 = new GRect(20, 50);

if (r1 == r2) {
   println("These rectangles are equal");
} else {
   println("These rectangles are different");
}
```

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GRect r1 = new GRect(20, 50);
GRect r2 = new GRect(20, 50);

if (r1 == r2) {
   println("These rectangles are equal");
} else {
   println("These rectangles are different");
}
```

An intuition: You can have different rectangles with the same properties, but you can’t have different 42s

A hot take: being the same thing is different from having the same properties

A hot take: identity and equality are different

A hot take: identity and equality are different

The same thing

The same properties

A hot take: identity and equality are different

The same thing

The same properties

What do we know about variables?

```
public void run() {
    int x = 42;
    int y = 2;
    int z = foo(x, y);
}

private void foo(int a, int b) {
    int x =  a + 2 * b;
    return x + 3;
}
```

run()

Every time a method is called, we make a new stack frame for it

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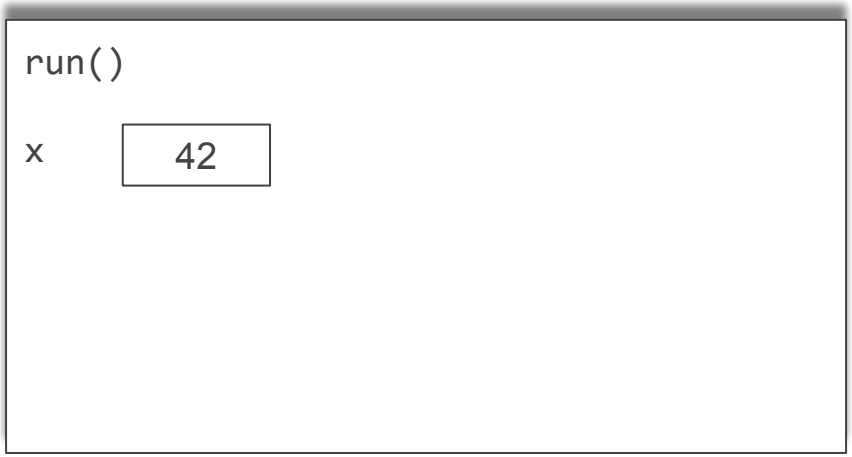

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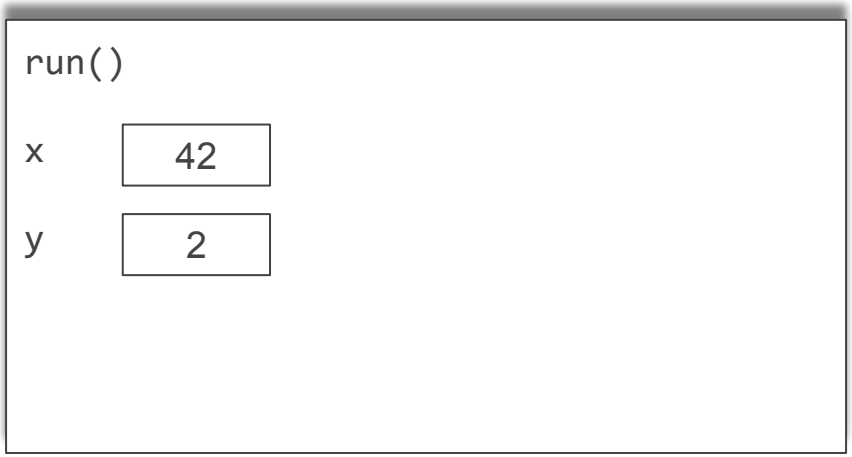

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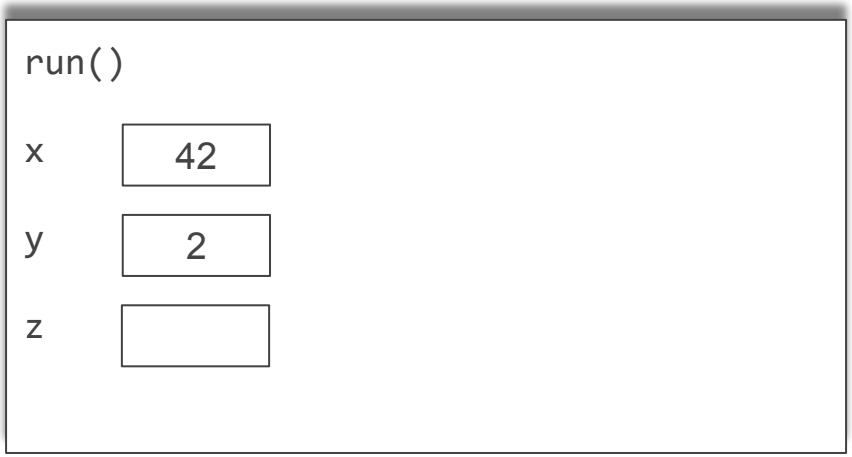

We evaluate the right-hand side **before** the left-hand side

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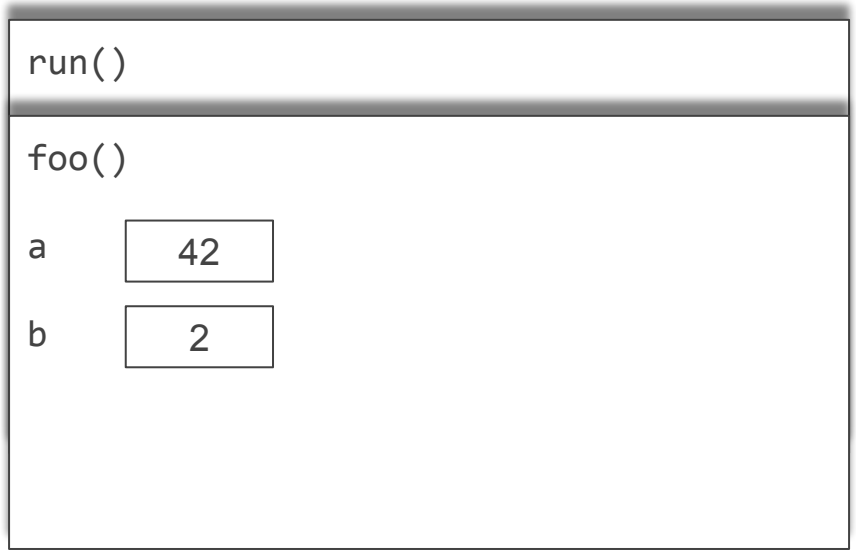

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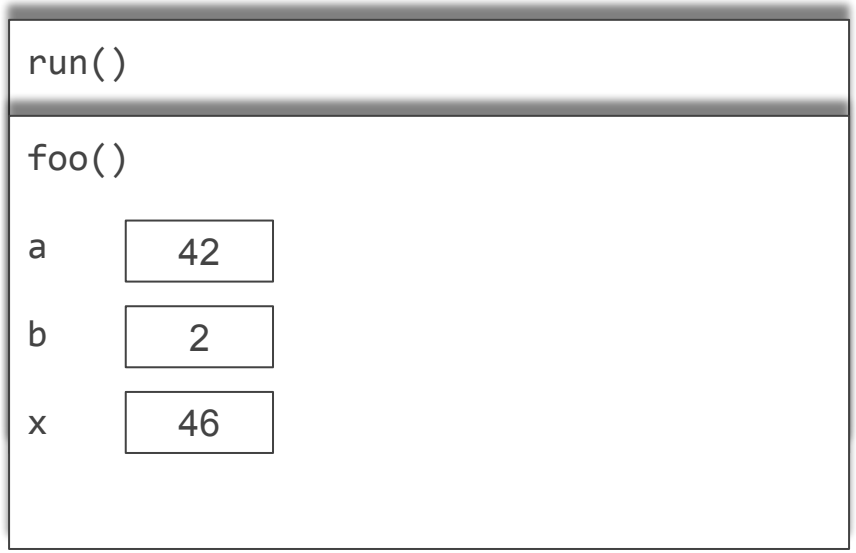

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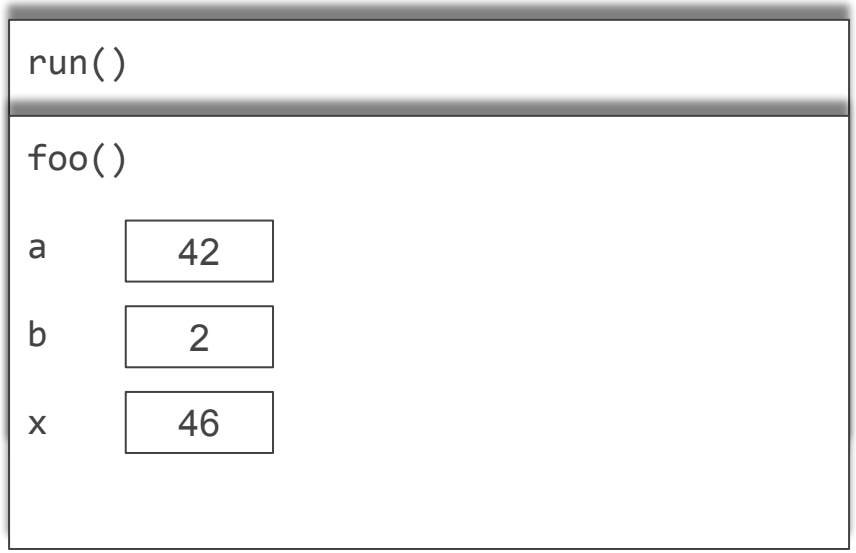

Returning allows a method to pass information back to its caller

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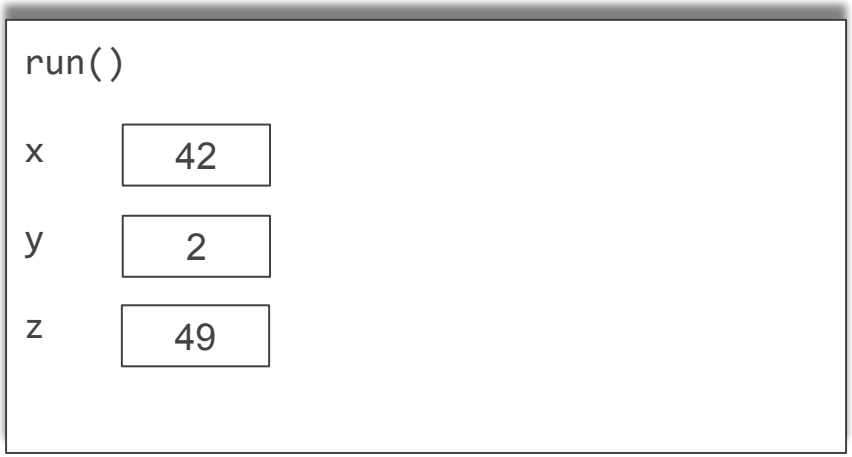
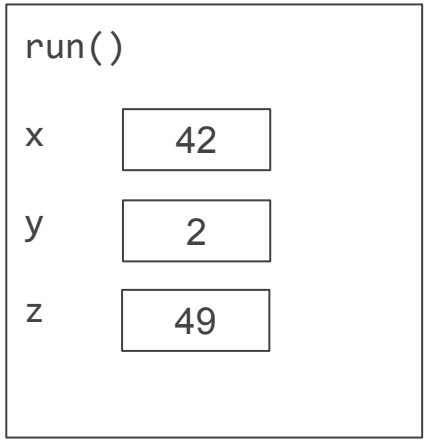


When a method returns, its stack frame gets erased

Let’s talk about the boxes



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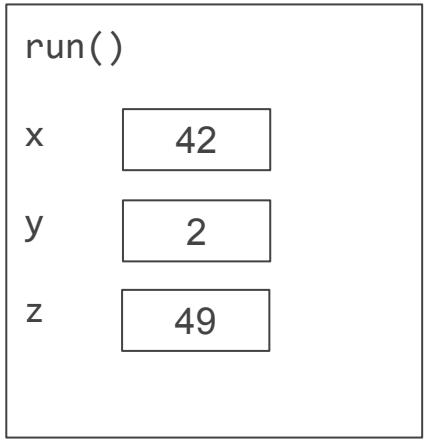

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These boxes are a fixed size, and just large enough to store an `int` and other primitive variables

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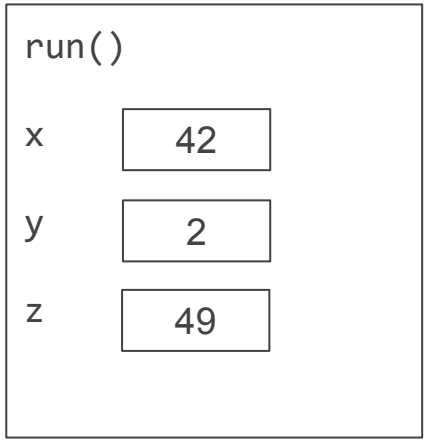

The boxes for variables are stored in our computer's memory

These boxes are a fixed size, and just large enough to store an `int` and other primitive variables

All of these boxes are in a part of memory called the Stack

What happens when we make an object?

```
GRect rect = new GRect(40, 50);
```

What happens when we make an object?

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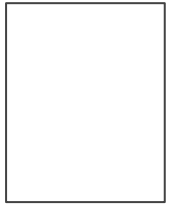
GRect rect = new GRect(40, 50);
```

Ask the `GRect` factory for a new `GRect`

What happens when we make an object?

```
GRect rect = new GRect(40, 50);
```

Now where should we put it?



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The place in memory to store larger pieces of information like this is the Heap

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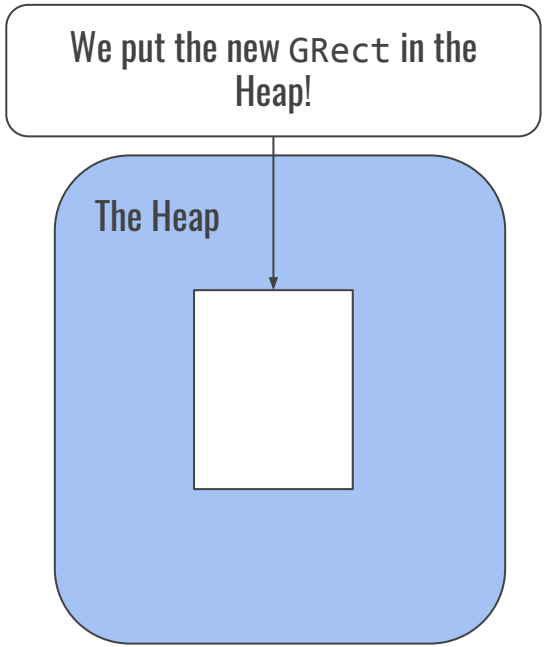

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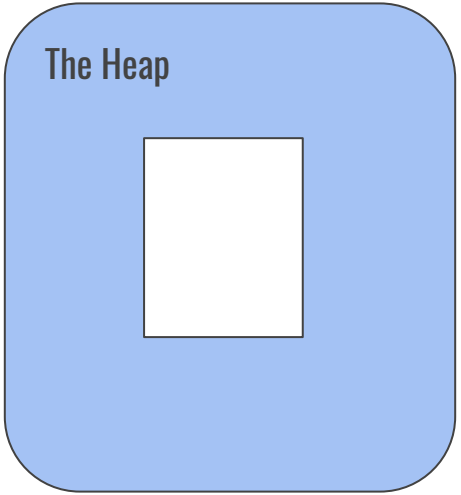
Now, we need to know where to find this `GRect` in the Heap



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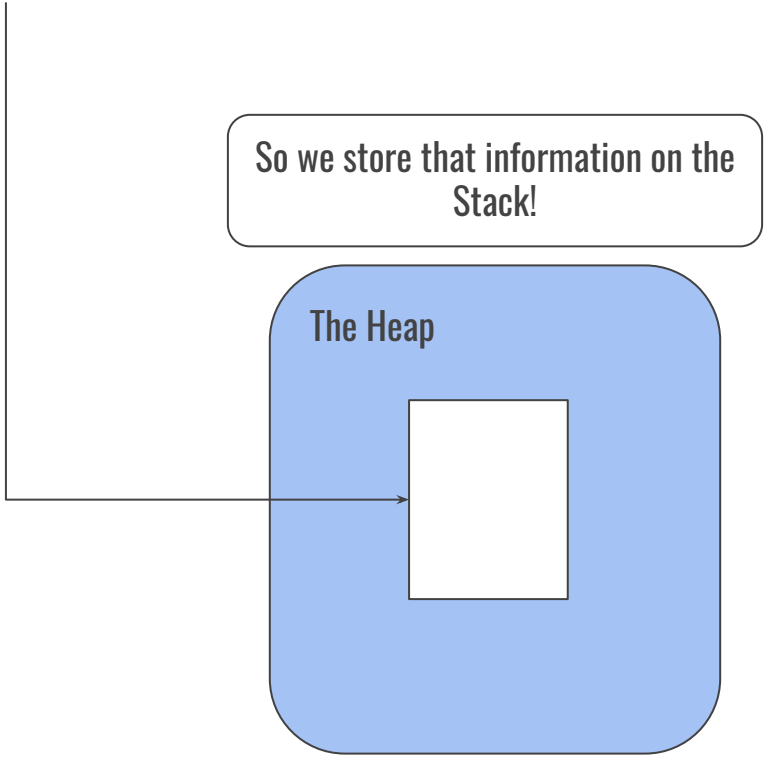

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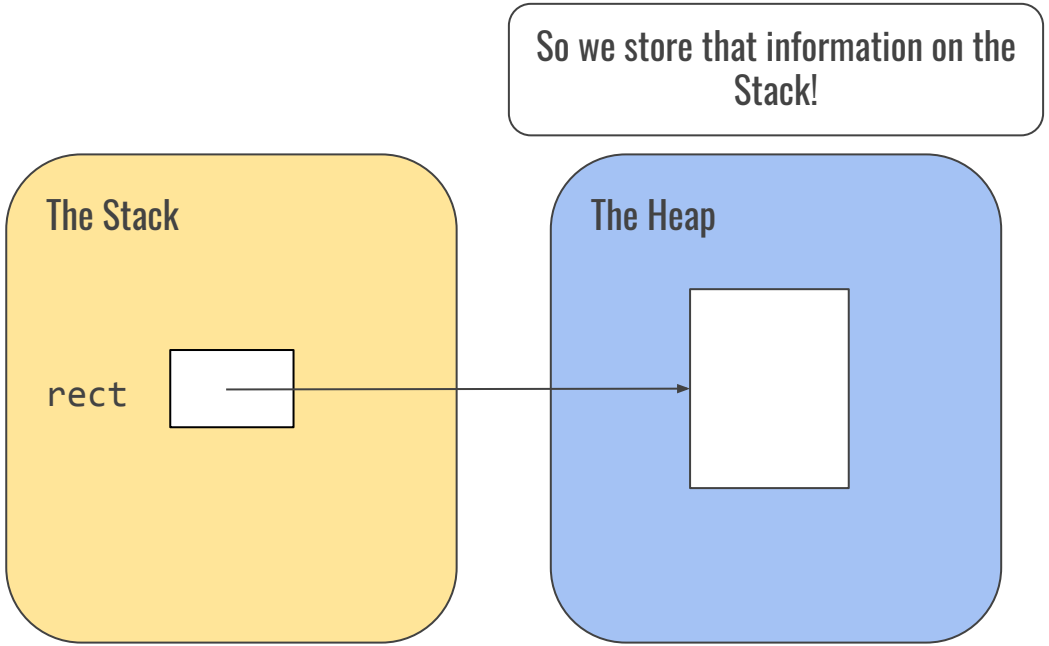

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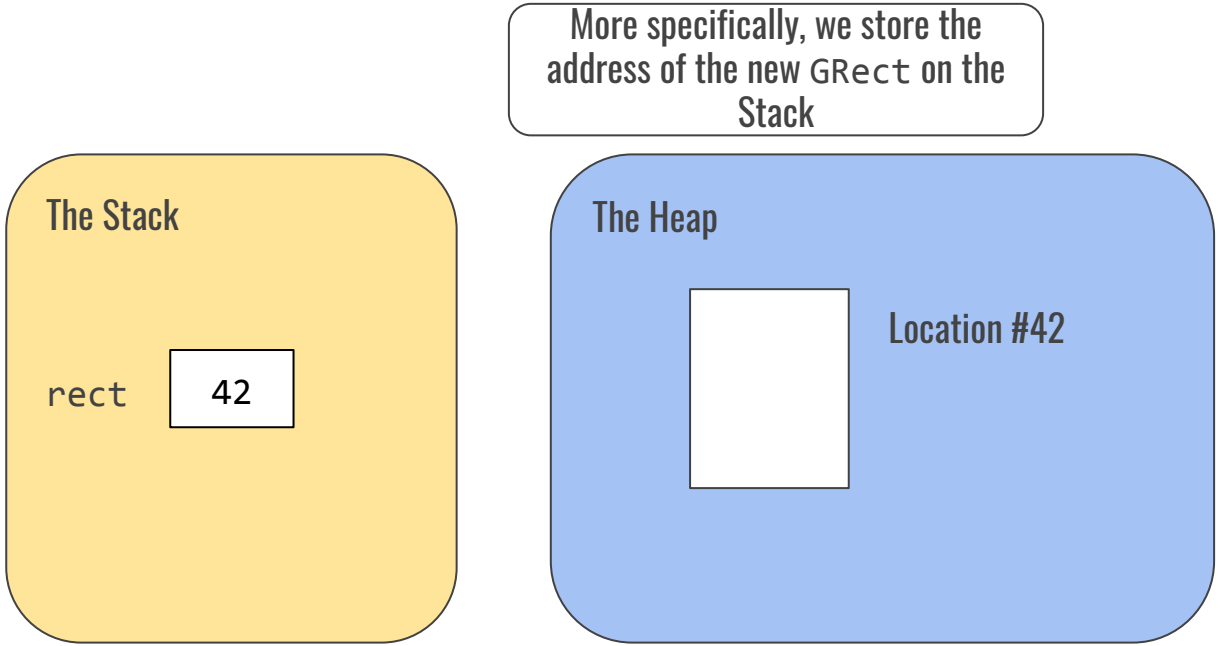

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```
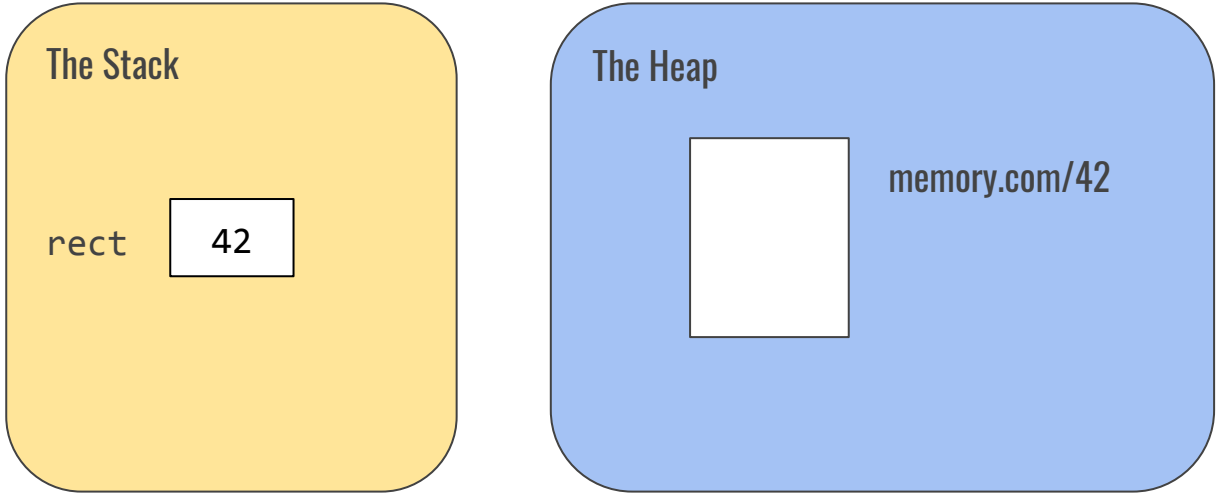

You can think of the stack variable as a URL...

...and the object on the heap as a website



Our takeaways

Primitive variables are stored on the Stack

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This value is on the Stack

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Objects are stored on the Heap and referred to from the Stack

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This reference to an object is on the Stack

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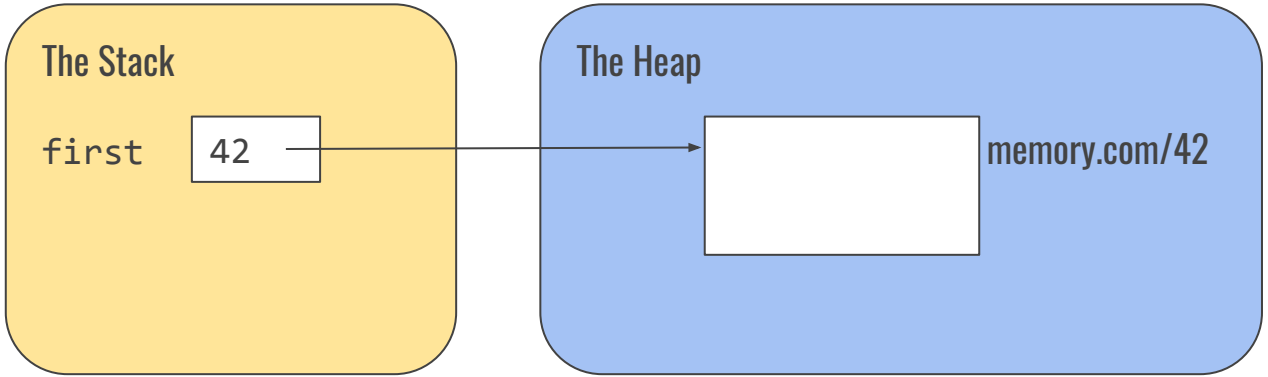
This reference to an object is on the Stack

This object is on the Heap

An example

```
public void run() {
    GRect first = new GRect(20, 10);
    GRect second = first;
    second.setColor(Color.GREEN);
    add(first, 0, 0);
}
```

First, we make a new GRect on the Heap and store a reference to it on the Stack



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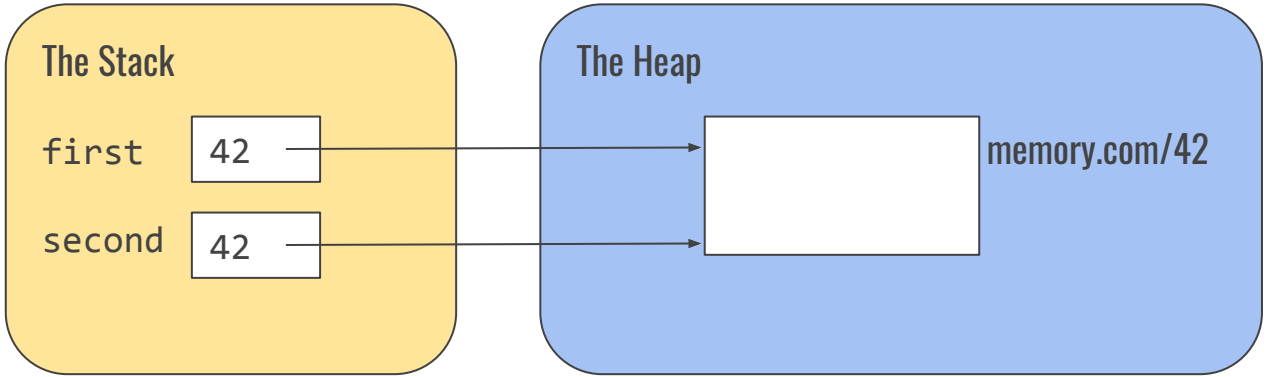
Next, we copy that reference to another spot on the stack



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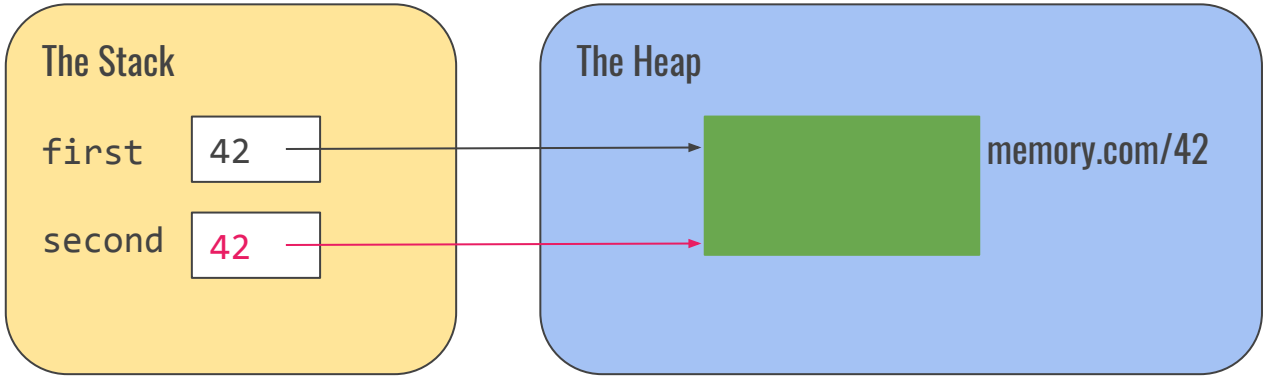
Then, we call a method on the object that we're referencing



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    add(first, 0, 0);
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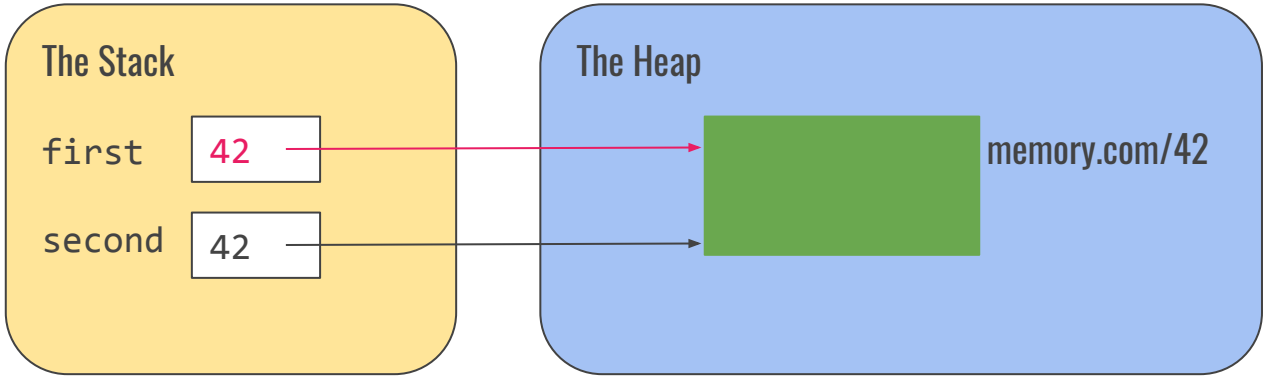
Finally, we pass that object into the `add()` method



Now for a quick detour

What’s in a box?

We saw earlier that each ‘box’ on the stack has a fixed size

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That fixed size is called a word

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On most computers today, a word is 64 bits (1s and 0s)

8 bits are called a byte

What’s in a name?

Bit is short for Binary Digit (a 1 or a 0)

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… but Bytes were given that name because of the ~wordplay~

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Me, saying this fact, 2019 (Colorized)

// end of detour

Modifying primitive parameters

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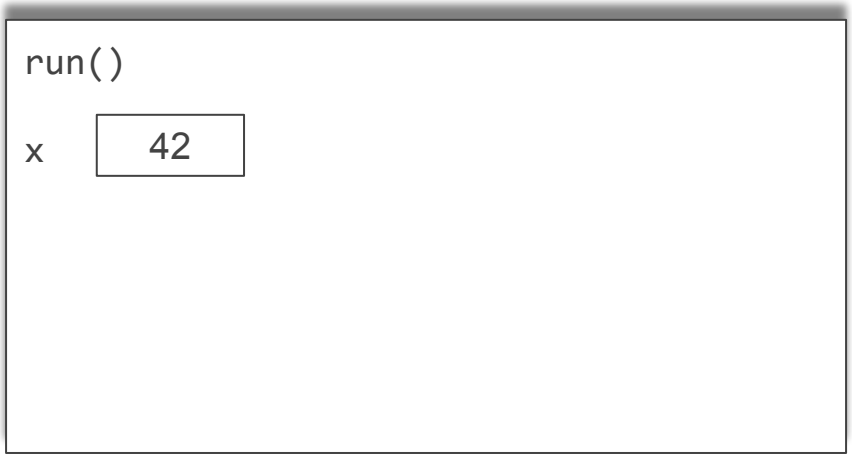
public void run() {
    int x = 42;
    foo(x);
    println(x);
}

public void foo(int x) {
    x = 7;
}
```



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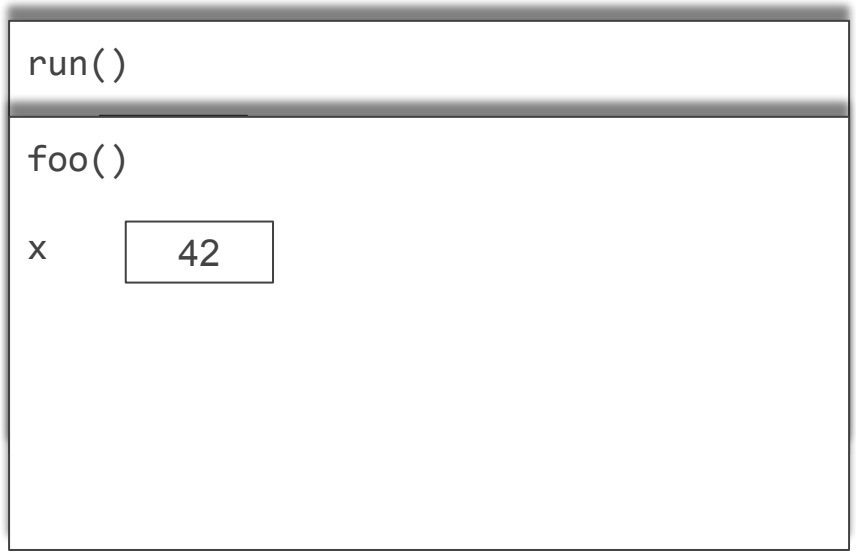

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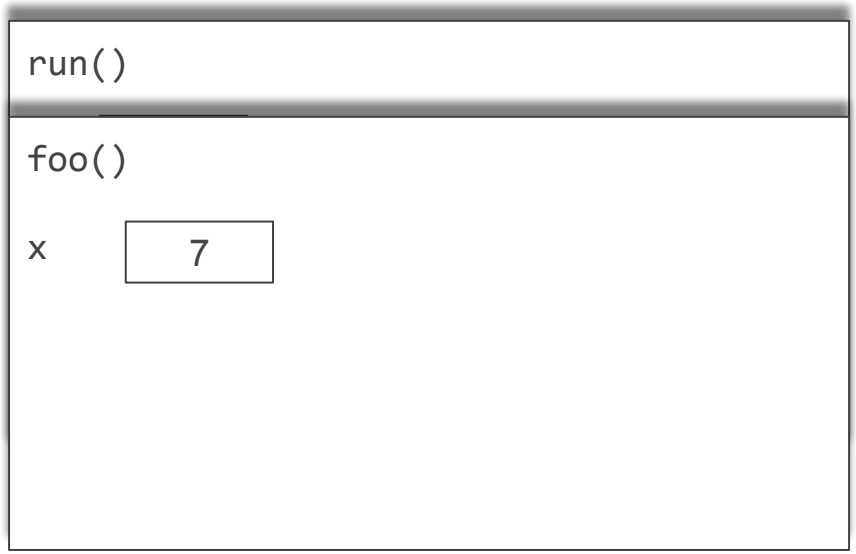

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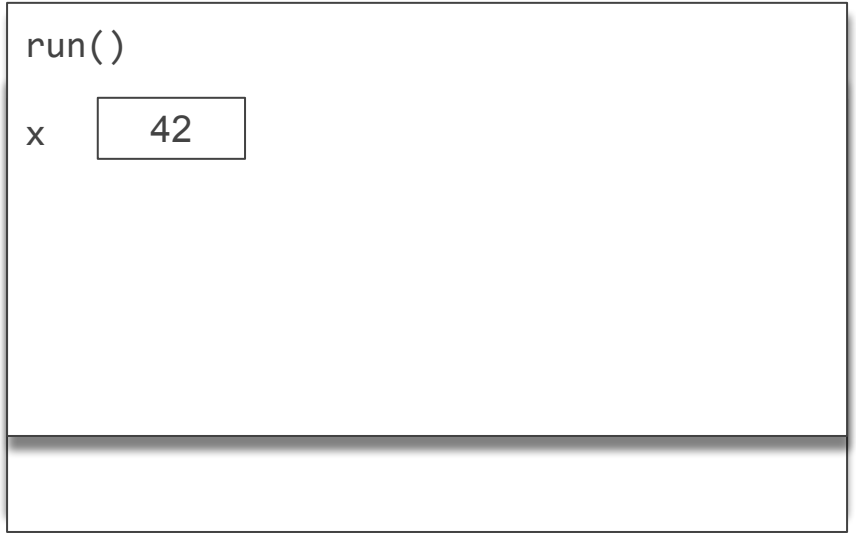

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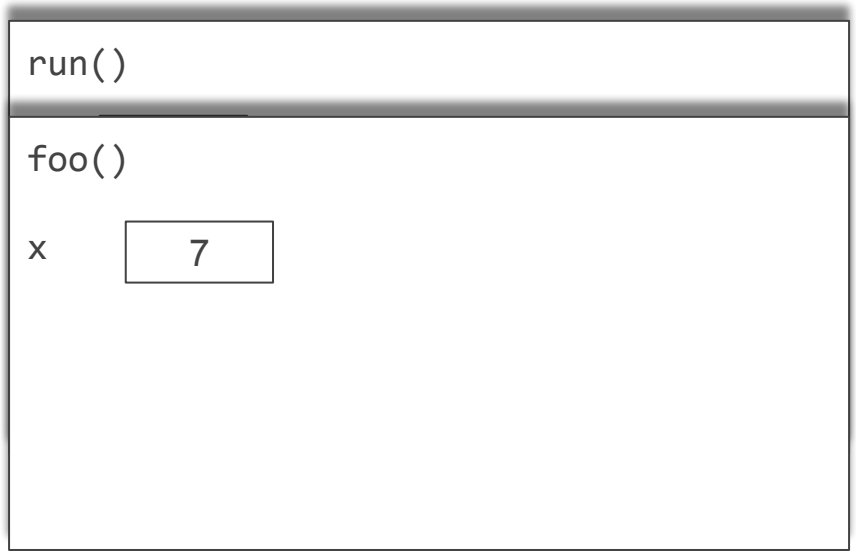

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Modifying primitive parameters

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    int x = 42;
    foo(x);
    println(x); // prints 42
}

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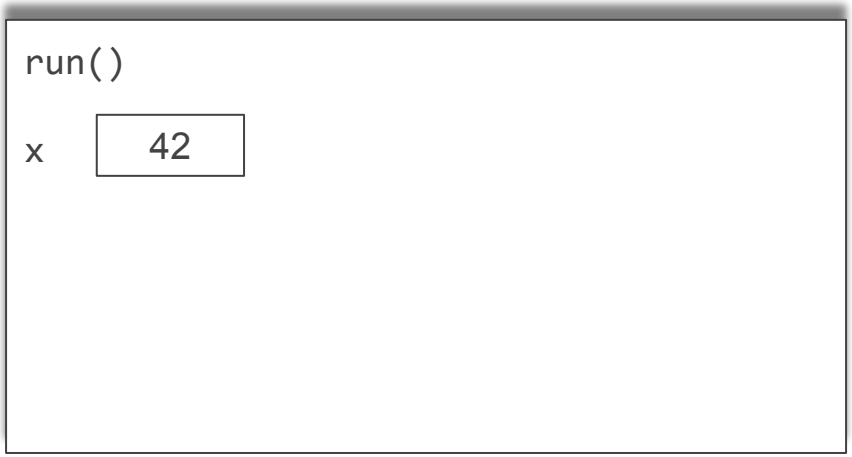


When a method returns, its stack frame gets erased

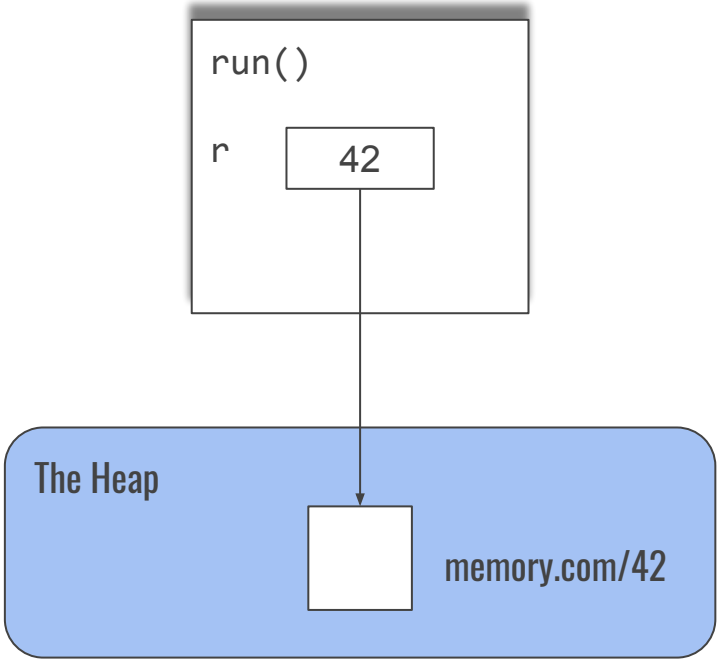
Pass by copy

When we pass primitives as parameters, we pass **copies of their values**

Modifying object parameters

```
public void run() {
    GRect r = new GRect(5, 5);
    foo(r);
    add(r);
}

public void foo(GRect r) {
    r.setColor(Color.GREEN);
}
```



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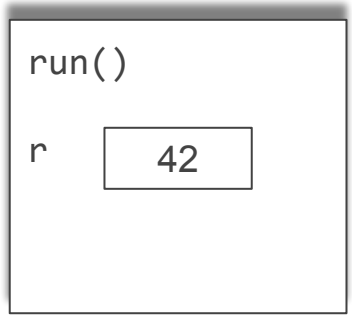

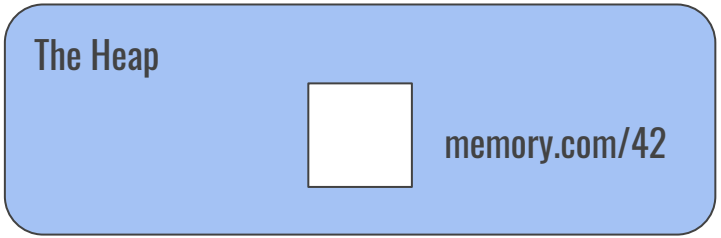

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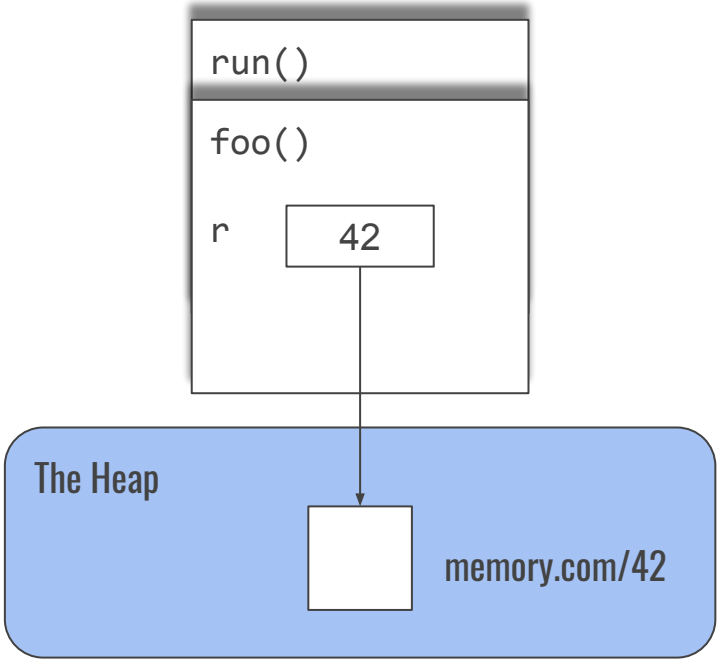

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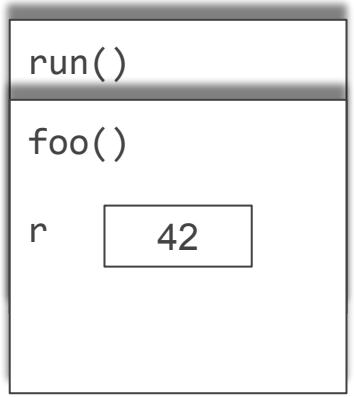

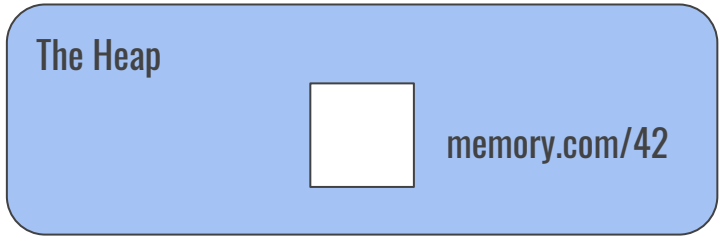

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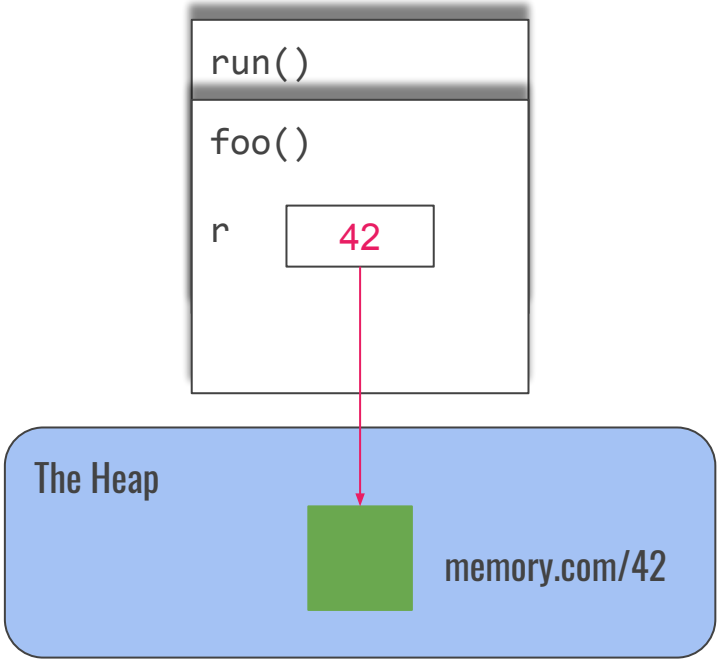
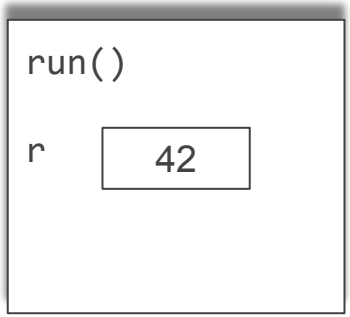


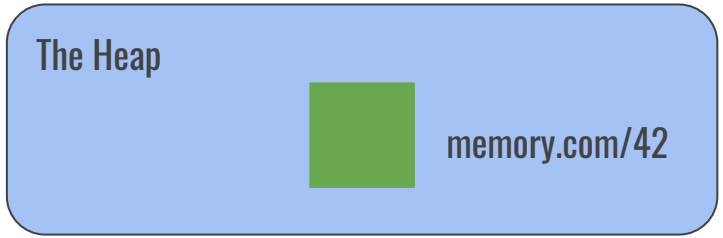
Every time a method is called, we make a new stack frame for it and copy the parameter values in the Stack

Modifying object parameters

```
public void run() {
    GRect r = new GRect(5, 5);
    foo(r);
    add(r);
}

public void foo(GRect r) {
    r.setColor(Color.GREEN);
}
```



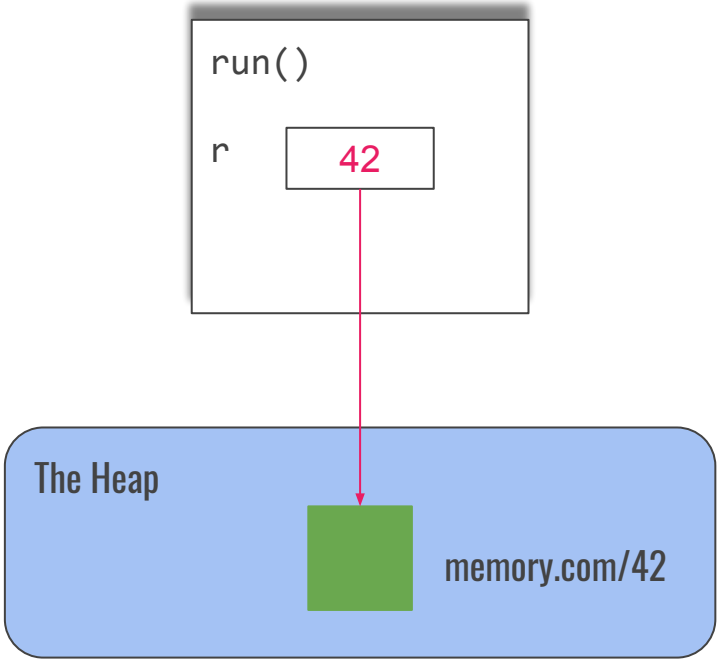


When a method returns, its stack frame gets erased

Modifying object parameters

```
public void run() {
    GRect r = new GRect(5, 5);
    foo(r);
    add(r); // green rectangle
}

public void foo(GRect r) {
    r.setColor(Color.GREEN);
}
```



The changes persisted!

Pass by reference

When we pass objects as parameters, we pass copies of references to the same object

A general heuristic

There are two kinds of variables on the Stack: Primitive values and Object references

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When we pass, copy or return something, we're modifying the Stack

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We can have multiple references to the same object

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We can have multiple references to the same object

- Modifying the object changes it for all of its references

A general heuristic

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We can have multiple references to the same object

- Modifying the object changes it for all of its references
- Modifying a reference changes only what it's pointing at

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We can have multiple references to the same object

- Modifying the object changes it for all of its references
- Modifying a reference changes only what it's pointing at

A hot take: identity and equality are different

The same thing

The same properties

identity equality

```
int x = 42;
int y = 42;
if (x == y) {
    println("Equal");
} else {
    println("Different");
}


GRect r1 = new GRect(20, 50);
GRect r2 = new GRect(20, 50);

if (r1 == r2) {
    println("Equal");
} else {
    println("Different");
}
```

identity equality

```
int x = 42;
int y = 42;
if (x == y) {
    println("Equal");
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}
```

```
GRect r1 = new GRect(20, 50);
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if (r1 == r2) {
    println("Equal");
} else {
    println("Different");
}
```

identity equality

```
int x = 42;
int y = 42;
if (x == y) {
    println("Equ
} else {
    println("Dif
}
```

The values of these primitives on the Stack are equal

```
GRect r1 = new GRect(20, 50);
GRect r2 = new GRect(20, 50);

if (r1 == r2) {
    println("Equal");
} else {
    println("Different");
}
```

identity equality

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int x = 42;
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GRect r1 = new GRect(20, 50);
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if (r1 == r2) {
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} else {
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}
```

r1 and r2 reference different objects on the Heap

identity equality

```
int x = 42;
int y = 42;
if (x == y) {
    println("Equ
} else {
    println("Dif
}
```

The values of these primitives on the Stack are equal

```
GRect r1 = new GRect(20, 50);
GRect r2 = new GRect(20, 50);

if (r1 == r2) {
    println("Equ
} else {
    println("Dif
}
```

The value of these references on the Stack are different

identity equality

```
int x = 42;
int y = 42;
if (x == y) {
    println("Equ
} else {
    println("Dif
}
```

The values of these primitives on the Stack are equal

```
GRect r1 = new GRect(20, 50);
GRect r2 = new GRect(20, 50);

if (r1 == r2) {
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} else {
    println("Dif
}
```

The value of these references on the Stack are different

identity equality

The == operator compares whatever values are on the Stack

```
int x = 42;
int y = 42;
if (x == y) {
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} else {
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```

The values of these primitives on the Stack are equal

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```

We want to compare what r1 and r2 are referencing on the heap

identity

equality

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```

The value of these references on the Stack are different

```
GRect r1 = new GRect(20, 50);
GRect r2 = new GRect(20, 50);

if (r1.equals(r2)) {
    pri tln("Equ
} else {
    println("Dif
}
```

We want to compare what r1 and r2 are referencing on the heap

identity

The == operator compares whatever values are on the Stack

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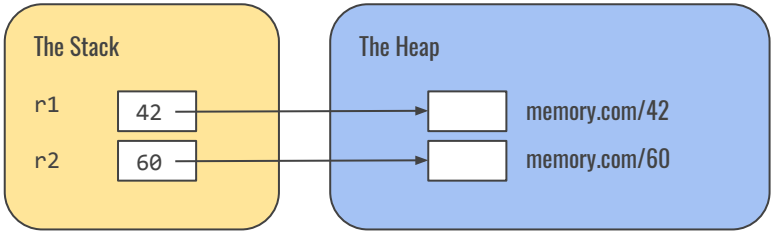

identity

equality

The == operator compares whatever values are on the Stack

```
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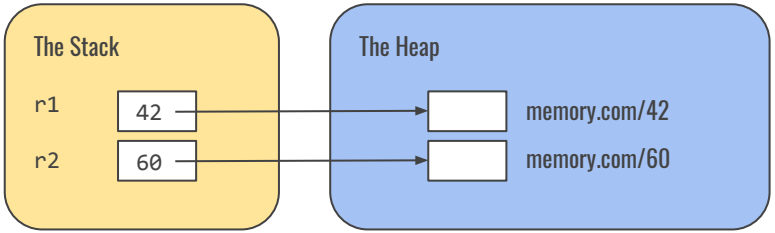

== compares the values in the Stack

identity

equality

The == operator compares whatever values are on the Stack

```
int x = 42;
int y = 42;
if (x == y) {
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} else {
    println("Dif
}
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The values of these primitives on the Stack are equal

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The value of these references on the Stack are different

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if (r1.equals(r2)) {
    pri tln("Equ
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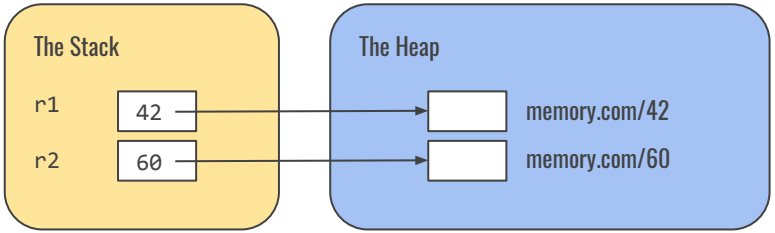
We want to compare what r1 and r2 are referencing on the heap



== compares the values in the Stack

.equals() compares objects on the Heap

identity

Compared using the == operator

equality

Compared using the `.equals()` method

identity

Compared using the == operator

Compares values and references on the Stack

equality

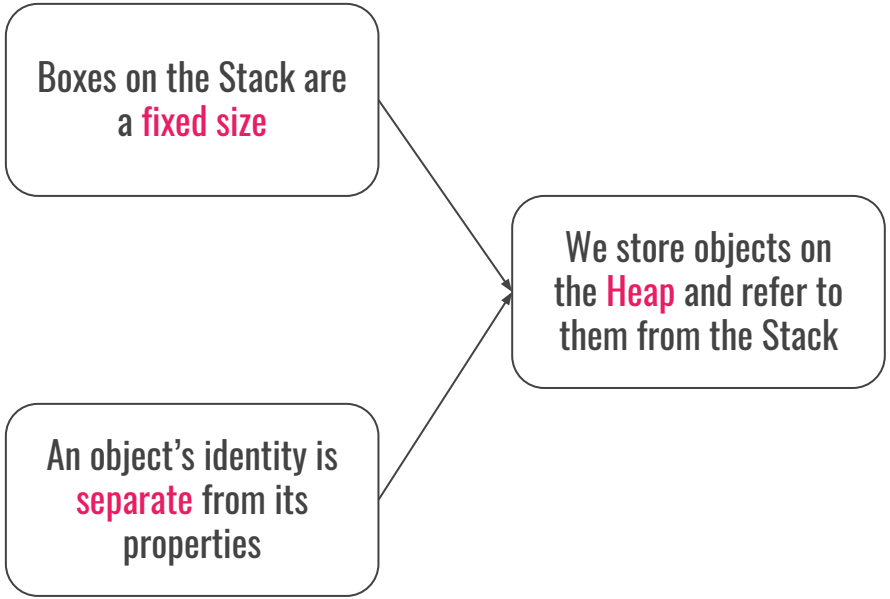
Compared using the `.equals()` method

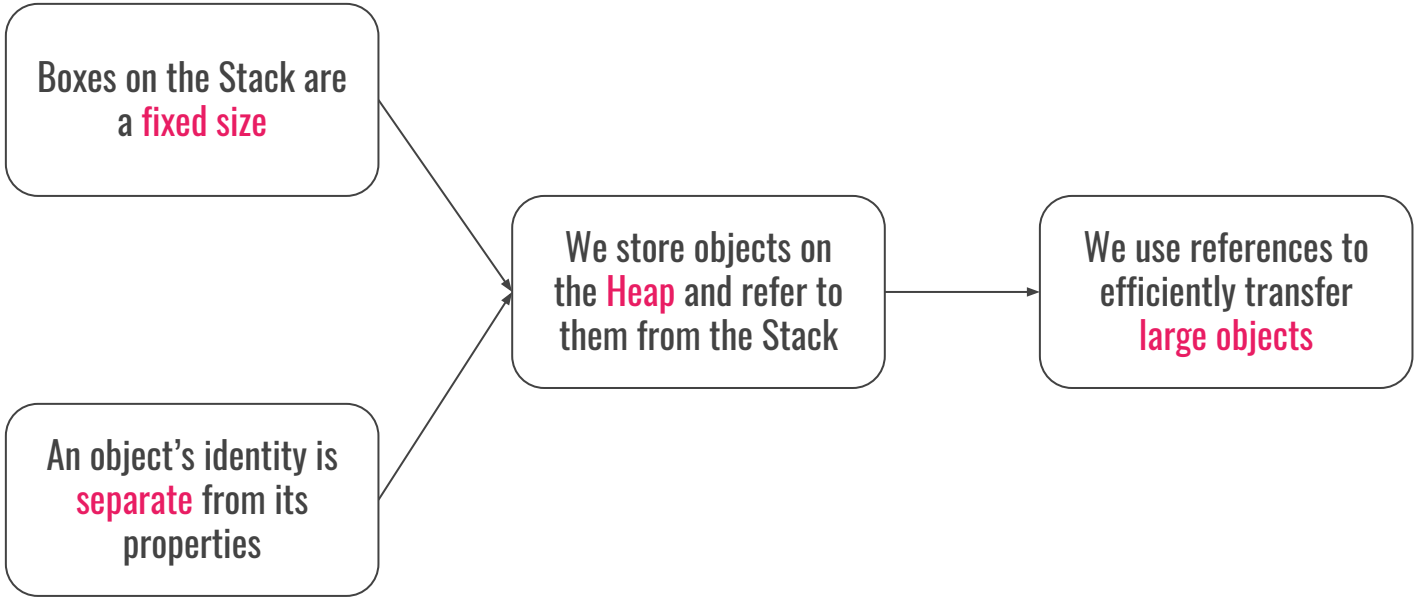
Follows references to compare objects on the Heap

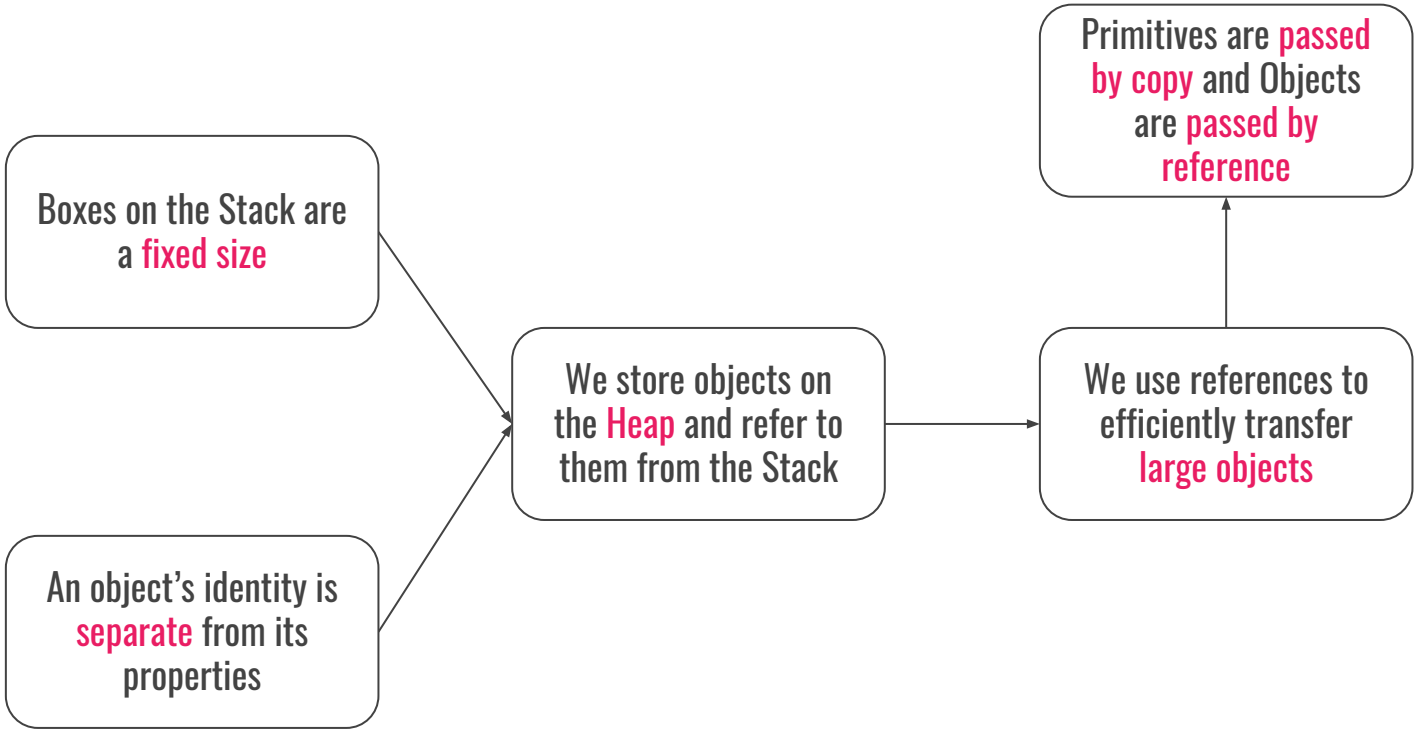
identity	equality
Compared using the == operator	Compared using the `.equals()` method
Compares values and references on the Stack	Follows references to compare objects on the Heap
Applies to objects and primitives	Applies only to objects

Boxes on the Stack are a fixed size

An object's identity is separate from its properties


Boxes on the Stack are a fixed size
An object's identity is separate from its properties
We store objects on the Heap and refer to them from the Stack


Boxes on the Stack are a fixed size
An object's identity is separate from its properties
We store objects on the Heap and refer to them from the Stack
We use references to efficiently transfer large objects


Boxes on the Stack are a fixed size
An object's identity is separate from its properties
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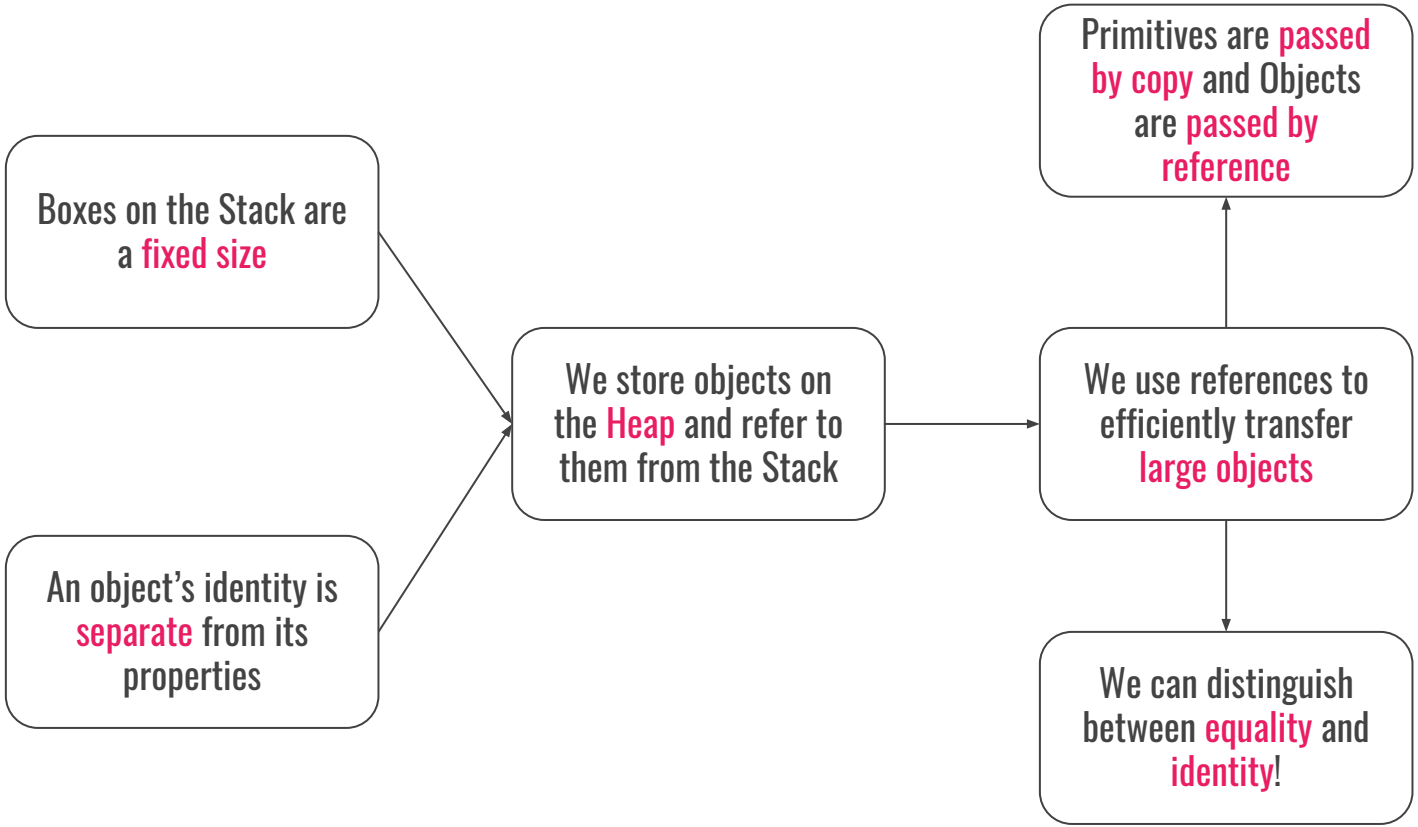
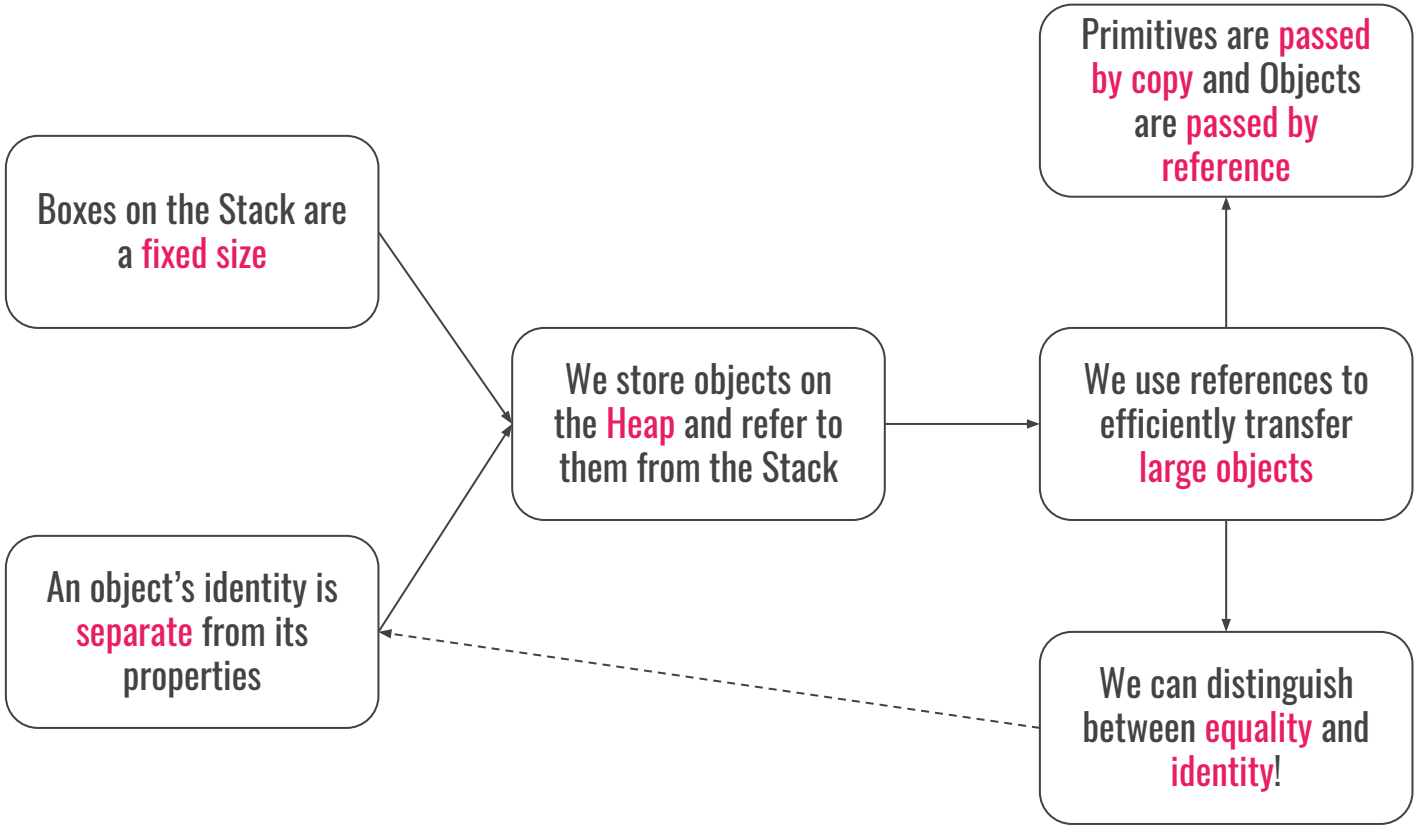
Primitives are passed by copy and Objects are passed by reference


Boxes on the Stack are a fixed size
An object's identity is separate from its properties
We store objects on the Heap and refer to them from the Stack
We use references to efficiently transfer large objects
Primitives are passed by copy and Objects are passed by reference
We can distinguish between equality and identity!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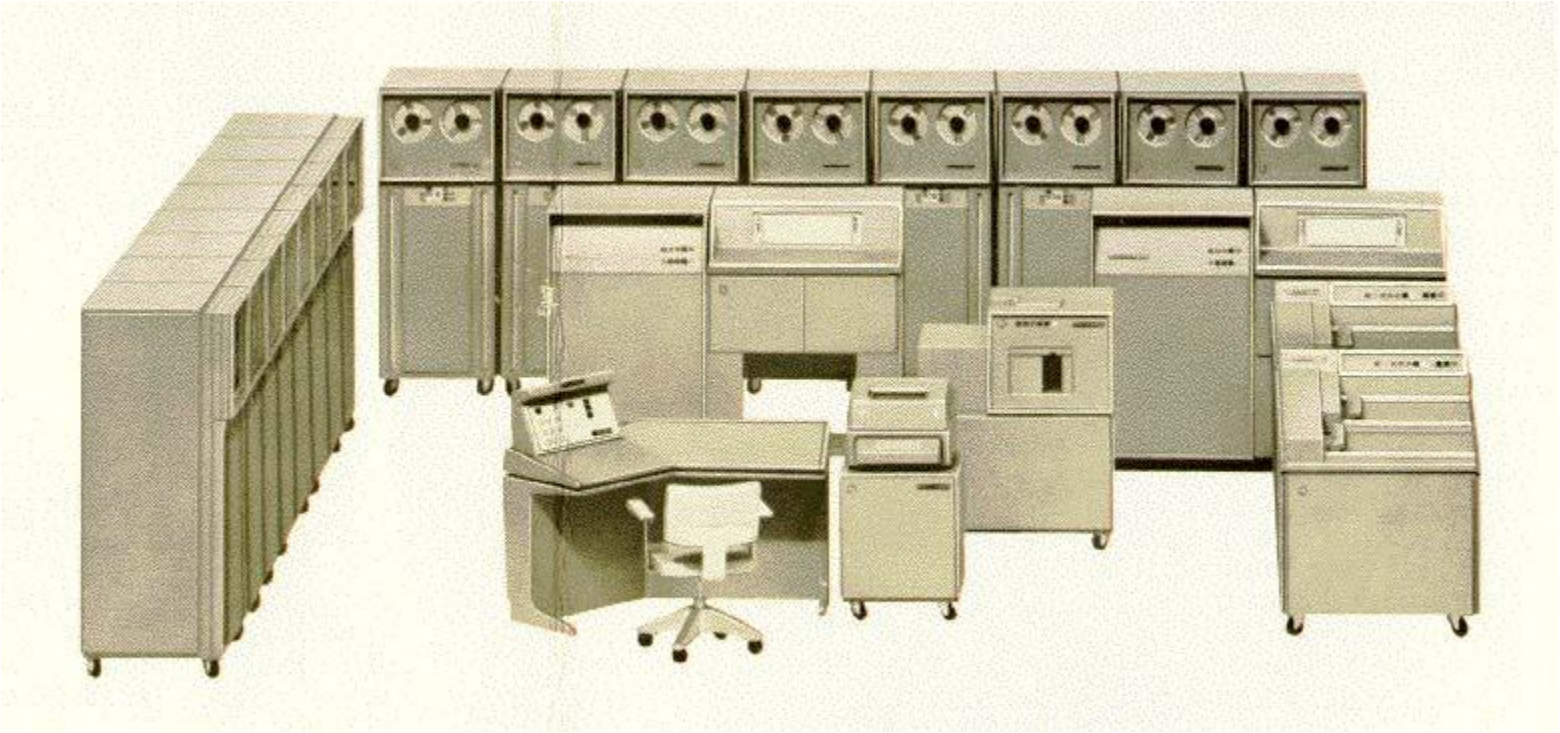

The Burroughs B5000 computer, 1961