TODO: record lecture

Week03

Today is...
✨ No-Laptop Monday! ✨

- HW03 preview
- functions
- classes
- HW03 behind the scenes
- references

WARMUP
What is a bullet hell?

BONUS
Who wrote the game Everyday Shooter? What is she working on now?

BONUS
What does Touhou 7: Perfect Cherry Blossom's Extra Stage look like? Who wrote this?

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HW03 preview

239

functions

240

anatomy of a function

241

anatomy of a function (1/2)

```
ReturnType functionName(ArgumentOneType argumentOne, ...) {
    ...
}
```

- a **function** is a lil chunk of code you can call from elsewhere
  - a function takes any number of **arguments**
    - `... foo(int arg) { ... } // function foo takes an int`
  - a function with a non-void **return type** must **return** a value of that type
    - `int bar(...) { ... } // bar returns an int`
    - `void baz(...) { ... } // baz doesn't return anything`

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anatomy of a function (2/2)

```
void drawLine(
        double a_x,
        double a_y,
        double b_x,
        double b_y,
        Color color) {
    ...
}
```

243

return

244

return (1/2)

- a **return** statement stops execution of a function and returns the program to where the function was called
  - some return statements return a value
    - `return 123;`
  - others do not
    - `return;`
      - ✨ this can be used to stop running a void-returning function in the middle

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return (2/2)

- a function with a non-void **return type** must **return** a value of that type, regardless of the path taken through the function

```
Error: missing return statement

static boolean isEven(int n) {
    if (n % 2  == 0) {
        return true;
    }
}
```

246

return (2/2)

- a function with a non-void **return type** must **return** a value of that type, regardless of the path taken through the function

```
static boolean isEven(int n) {
    if (n % 2  == 0) {
        return true;
    }
    return false;
}
```

247

return (3/2)

- a function with a non-void **return type** must **return** a value of that type, regardless of the path taken through the function

```
static boolean isEven(int n) {
    return (n % 2  == 0);
}
```

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return (3/2)

- a function with a non-void **return type** must **return** a value of that type, regardless of the path taken through the function

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void

void

- **void** is a special return type meaning a function does not return a value
  - void functions often modify (the objects referenced by) their arguments
    - `static void inPlaceReverse(int[] array) { ... }`
      - `// no need to return a reference to array`
        `// (user of the function already has one)`
  - in Java, the **main method** is a void function (it doesn't return anything)
    - `public static void main(String[] arguments) { ... }`

the call stack

the call stack

- functions can call other functions
  - the resulting "stack" of function calls is called the **call stack**

```
class Main {

    static void snap() {
        crackle();
    }

    static void crackle() {
        pop();
    }

    static void pop() {
        return;
    }

    public static void main(String[] arguments) {
        snap();
    }
}
```

Stack | Threads

Method	Line
Main.pop	12
Main.crackle	8
Main.snap	4
Main.main	16
sun.reflect.NativeMethodAccessorImpl.invoke0	-1
sun.reflect.NativeMethodAccessorImpl.invoke	62
sun.reflect.DelegatingMethodAccessorImpl.invoke	43
java.lang.reflect.Method.invoke	498
edu.rice.cs.drjava.model.compiler.JavacCompiler.runCommand	259
sun.reflect.NativeMethodAccessorImpl.invoke0	-1
sun.reflect.NativeMethodAccessorImpl.invoke	62
sun.reflect.DelegatingMethodAccessorImpl.invoke	43
java.lang.reflect.Method.invoke	498
edu.rice.cs.dynamicjava.symbol.JavaClass$JavaMethod.evalu...	362
edu.rice.cs.dynamicjava.interpreter.ExpressionEvaluator.han...	92
edu.rice.cs.dynamicjava.interpreter.ExpressionEvaluator.visit	84
koala.dynamicjava.tree.StaticMethodCall.acceptVisitor	121
edu.rice.cs.dynamicjava.interpreter.ExpressionEvaluator.value	38
edu.rice.cs.dynamicjava.interpreter.ExpressionEvaluator.value	37
edu.rice.cs.dynamicjava.interpreter.StatementEvaluator.visit	106
edu.rice.cs.dynamicjava.interpreter.StatementEvaluator.visit	29
koala.dynamicjava.tree.ExpressionStatement.acceptVisitor	101

```
sun.reflect.NativeMethodAccessorImpl.invoke0
sun.reflect.NativeMethodAccessorImpl.invoke
sun.reflect.DelegatingMethodAccessorImpl.invoke
java.lang.reflect.Method.invoke
edu.rice.cs.drjava.model.compiler.JavacCompiler.runCommand
sun.reflect.NativeMethodAccessorImpl.invoke0
sun.reflect.NativeMethodAccessorImpl.invoke
sun.reflect.DelegatingMethodAccessorImpl.invoke
java.lang.reflect.Method.invoke
edu.rice.cs.dynamicjava.symbol.JavaClass$JavaMethod.evalu...
edu.rice.cs.dynamicjava.interpreter.ExpressionEvaluator.han...
edu.rice.cs.dynamicjava.interpreter.ExpressionEvaluator.visit
koala.dynamicjava.tree.StaticMethodCall.acceptVisitor
edu.rice.cs.dynamicjava.interpreter.ExpressionEvaluator.value
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edu.rice.cs.dynamicjava.interpreter.StatementEvaluator.visit
edu.rice.cs.dynamicjava.interpreter.StatementEvaluator.visit
koala.dynamicjava.tree.ExpressionStatement.acceptVisitor
```


[let's see what Eclipse does]

recursion

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recursion (1/2)

- a **recursive function** is a function that calls itself
  - each call must make progress towards a **base case**
    (when the function finally returns without calling itself)
    - ✨ when in doubt, try something like zero for your base case

```
class Main extends Cow {
    static int digitSum(int n) {
        if (n == 0) {
            return 0;
        }
        return digitSum(n / 10) + (n % 10);
    }

    public static void main(String[] arguments) {
        PRINT(digitSum(256)); // 13
    }
}
```

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```
static int digitSum(int n) {
    if (n == 0) {
        return 0;
    }
    return digitSum(n / 10) + (n % 10);
}
```

return 0;
return digitSum(0) + 2;
return digitSum(2) + 5;
return digitSum(25) + 6;
int a = digitSum(256);

260

```
static int digitSum(int n) {
    if (n == 0) {
        return 0;
    }
    return digitSum(n / 10) + (n % 10);
}
```

return 0;
return digitSum(0) + 2;
return digitSum(2) + 5;
return digitSum(25) + 6;
int a = digitSum(256);

261

```
static int digitSum(int n) {
    if (n == 0) {
        return 0;
    }
    return digitSum(n / 10) + (n % 10);
}
```

return 0 + 2;
return digitSum(2) + 5;
return digitSum(25) + 6;
int a = digitSum(256);

262

```
static int digitSum(int n) {
    if (n == 0) {
        return 0;
    }
    return digitSum(n / 10) + (n % 10);
}
```

return 2;
return digitSum(2) + 5;
return digitSum(25) + 6;
int a = digitSum(256);

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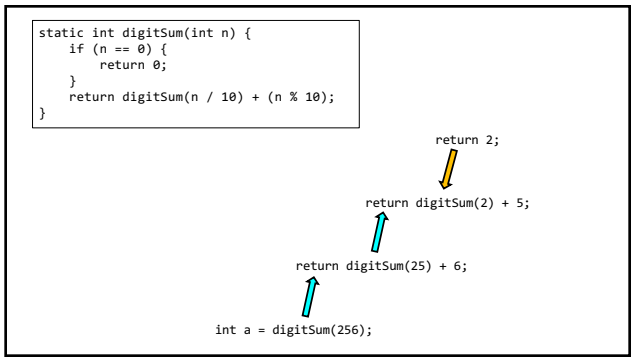
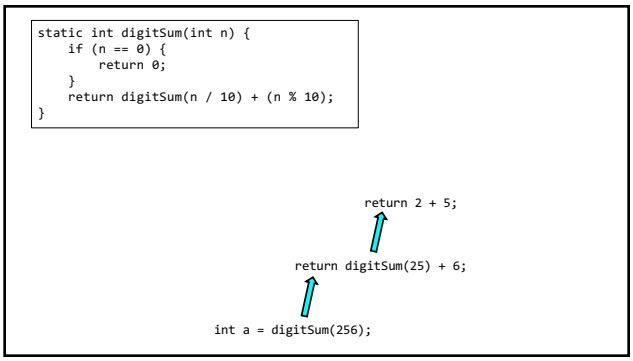
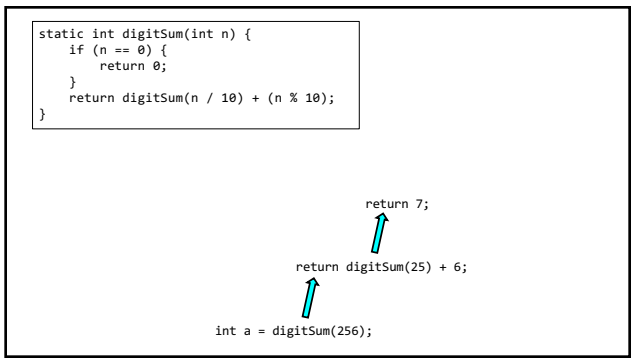


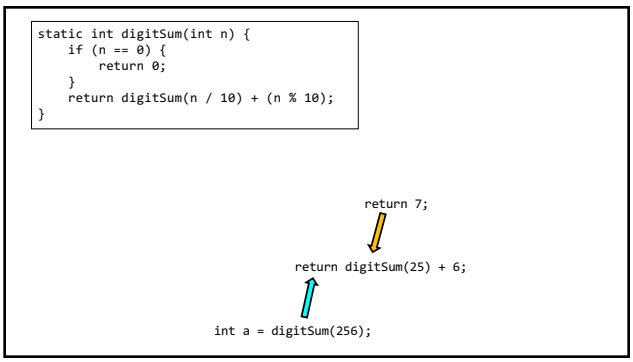
264



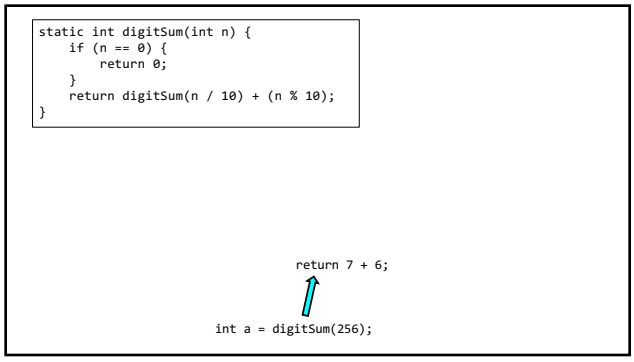
265



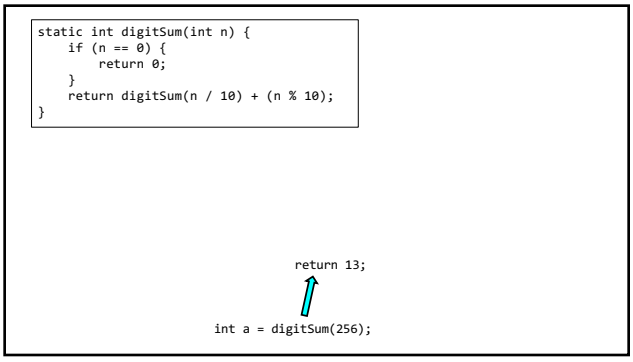
266



267



268



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```
static int digitSum(int n) {
    if (n == 0) {
        return 0;
    }
    return digitSum(n / 10) + (n % 10);
}
```

return 13;

int a = digitSum(256);

270

```
static int digitSum(int n) {
    if (n == 0) {
        return 0;
    }
    return digitSum(n / 10) + (n % 10);
}
```

int a = 13;

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fin.

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recursion (2/2)

- a **stack overflow** error happens when functions call too many functions without returning; these errors are usually caused by broken recursive code

```
class Main {
    static void stackOverflow() {
        stackOverflow();
    }

    public static void main(String[] arguments) {
        stackOverflow();
    }
}
```

```
java.lang.StackOverflowError
        at Main.stackOverflow(Tmp.java:3)
        at Main.stackOverflow(Tmp.java:3)
        at Main.stackOverflow(Tmp.java:3)
        at Main.stackOverflow(Tmp.java:3)
        at Main.stackOverflow(Tmp.java:3)
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        at Main.stackOverflow(Tmp.java:3)
```

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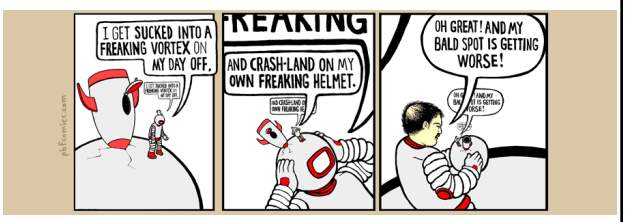

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classes

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anatomy of a class

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anatomy of a class (1/2)

```
class ClassName {
    VariableOneType variableOne;
    ...

    FunctionOneReturnType functionOneName(...) { ... }
    ...
}
```

- a **class** lets you bundle together data and functions
  - a class may have any number of **variables** (fields)
    - `int foo; // objects of this class have an int called foo`
  - a class may have any number of **functions** (methods)
    - `int bar() { ... } // objects of class have function bar`

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anatomy of a class (2/2)

```
class Thing {
    // instance variables
    double x;
    double y;
    Color color;
    double radius;

    // instance methods
    void draw() { ... }
    ...
}
```

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dot

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dot

- the **dot** operator is used to access an object's variables and functions

```
Thing thing = new Thing();
thing.x = 3.0;
thing.y = 4.0;
thing.draw();
```

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terminology

281

class vs. object (instance of a class)

- a **class** is NOT the same thing as an **object**
  - a class is "a blueprint for making objects"
  - we can make an **instance of a class** (an **object**) using the **new** keyword
    - this is called "instantiating the class"
    - `Thing thing = new Thing();`

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[off the record note on OOP (Object Oriented Programming) terminology]

283

new and constructors

284

new

- the **new** keyword create a new instance of a class and calls its appropriate **constructor**
  - `int[] array = new int[5]; // { 0, 0, 0, 0, 0 }`
  - `Color color = new Color(1.0, 0.0, 0.0); // (1.0, 0.0, 0.0)`
  - 🤓 **you don't need `new` to create a new string**
    - `String string = "strings are their own thing";`
  - 🤓 **you don't need `new` to create a new array when using {} syntax**
    - `int[] array = { 1, 2, 3 };`
  - 🤓 **`new` doesn't actually return the *object* it created; it returns *a reference to the object***

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constructors (1/2)

- a **constructor** is called when an object is created
  - if the class does not have a constructor, then the **default constructor** must be called, which takes no arguments and sets all variables to zero
    - `Color color = new Color(); // (0.0, 0.0, 0.0)`

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constructors (2/2)

- a (non-default) **constructor** is never necessary, but is often convenient

```
Color color = new Color(1.0, 1.0, 1.0); // (r=1.0, g=1.0, b=1.0)
```

```
Color color = new Color(); // (0.0, 0.0, 0.0)
color.r = 1.0;             // (1.0, 0.0, 0.0)
color.g = 1.0;             // (1.0, 1.0, 0.0)
color.b = 1.0;             // (1.0, 1.0, 1.0)
```

287

this

in Python, `this` is `self`

288

this

- **this** is a reference to the instance of the class whose function we're inside of
  - ✨ especially useful inside a constructor

```
class Color {
    ...

    void shade() {
        this.r /= 2;
        this.g /= 2;
        this.b /= 2;
    }

    Color(double r, double g, double b) { // constructor
        this.r = r;
        this.g = g;
        this.b = b;
    }
```

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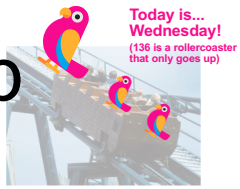
TODO: record lecture

Week03b



- ~~HW03 preview~~
- ~~functions~~
- ~~class~~es (not quite done)
- memory FUNdaMENTALs
- the stack and the heap
- passing arguments to functions

WARMUP
what is 42 in hex?

290

static

(wrapping up last lecture)

291

static variables and static methods

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instance variables vs static variables

- an **instance variable** is part of an instance of a class
- a **static variable** (class variable) is part of the class itself
  - there is only one, period. (it's a global variable that lives "on the class")

```
class Thing {
    int type;
    static int TYPE_BULLET = 1;
    ...
}

// Thing thing = new Thing();
// thing.type = Thing.TYPE_BULLET;
```

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instance methods vs static methods

- an **instance method** must be called on an instance (object) of a class
- a **static method** (class method) can be called on the class itself
  - ✅ there is no `this` in a static method

```
class Thing {
    void draw() { ... }; // (non-static method)
    static boolean collisionCheck(Thing a, Thing b) { ... }
    ...
}
// Thing a, b;
// a.draw();
// if (Thing.collisionCheck(...)) { ... }
```

294

and now... today's lecture!

295

☠️

this is the hardest lecture in 136

296

but learning this stuff is very worth

🥲 👍

297

but learning this stuff is very worth

🥲 👍

note: you will likely need to review this lecture a few times

298

but learning this stuff is very worth

🥲 👍

note: you will likely need to review this lecture a few times

(i am sure you will all do this)

299

but learning this stuff is very worth
🥹 👍

note: you will likely need to review this lecture a few times

(i am sure you will all do this 🤯)

300

memory FUNdaMENTALs

302

the two kinds of variables in Java

303

a variable in Java is either...

a primitive
or
a reference to an Object

304

primitives (review)

305

primitive types

- in this class, "a variable being a **primitive**" means that the variable is a `boolean`, `char`, `double`, or `int`

- primitive types are simple
- primitive types are small
- primitive types are NOT Objects
  - we will talk about Objects later
  - **examples of Objects:** `String`, `MyCoolClass`, `int[]` (array of ints)

306

`boolean`, `char`, `double`, `int`

- a **`boolean`** stores a truth value
  - `true`, `false`
- a **`char`** stores a character
  - `'\0'`, `'a'`, `'Z'`, `'!'`, `'\n'`
- a **`double`** stores a real number
  - `0.0`, `-0.5`, `3.1415926`, `Double.NEGATIVE_INFINITY`
- an **`int`** stores an integer
  - `0`, `-1`, `4`

307

primitives

- some examples of primitives
  - `int a;     // a is an int`
  - `boolean b; // b is a boolean`
  - `char c;    // c is a char`

308

references to Objects

309

references (1/2)

- we interact with Object's through **references**
  - `String string; // string is a reference to a String object`
  - `Color color;   // color is a reference to a Color object`
  - `int[] array;   // array is a reference to an int array`

310

references (2/2)

- a **reference** is a memory address ("where the object lives in memory")
  - a **memory address** is an **integer**
  - a memory address is often written in **hexadecimal** (**hex, base-16**, 0...9A...F)
- `Thing a = new Thing();`
- `//    ^ refers to a Thing object at memory address 0x70f806418`

311

null

312

null (1/2)

- a **null** reference refers to nothing
- the actual memory address referred to by null is zero (0x00... in hex)

```
Thing b = null;
//    ^ refers to nothing (memory address 0x000000000)
```

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null (2/2)

```
Thing[] pool = new Thing[7];
//    ^ refers to a Thing[] object at memory address 0x70f805b68
//
// NOTE: the Thing array referred to by pool has 7 entries,
// all zero-initialized (null; memory address 0x000000000)

pool[0] = new Thing();
// pool[0] now refers to a Thing object at memory address
//                                          0x70f8079c0
```

314

the stack and the heap

(where stuff lives)

315

overview

316

let's get more specific than saying "variables live in memory"

we divide memory into two parts: **the stack** and **the heap**

317

"the stack"

local variable primitives & **references** to Objects live here
variables ***undefined*** (?) by default (will NOT compile if used)

"the heap"

the actual **Objects** (including arrays and Strings) live here
Objects are *cleared to 0* by default

318

primitives live on the stack

319

"the stack"

local variable primitives & **references** to Objects live here
variables ***undefined*** (?) by default (will NOT compile if used)

"the heap"

the actual **Objects** (including arrays and Strings) live here
Objects are *cleared to 0* by default

320

```
int a;
int b;
a = 3;
b = a;
a = 7;
```

321

a
?

```
int a;
int b;
a = 3;
b = a;
a = 7;
```

322

a
?
b
?

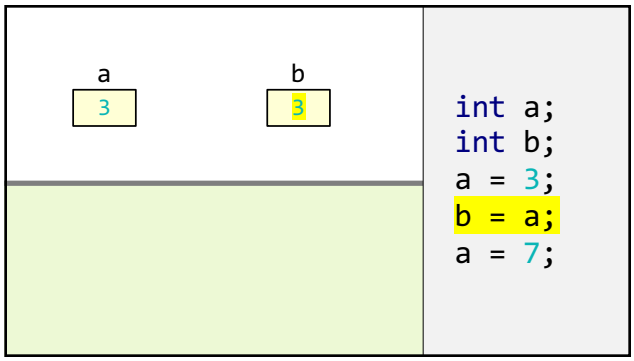
```
int a;
int b;
a = 3;
b = a;
a = 7;
```

323

a
3
b
?

```
int a;
int b;
a = 3;
b = a;
a = 7;
```

324



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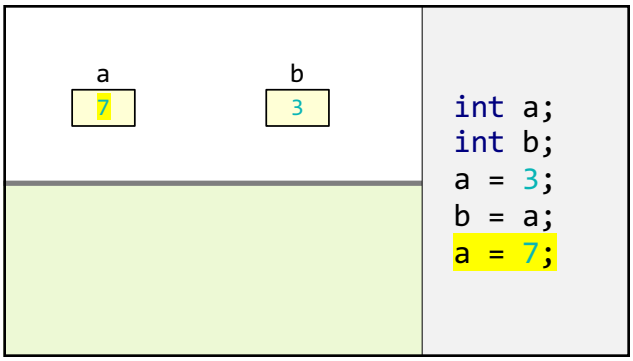

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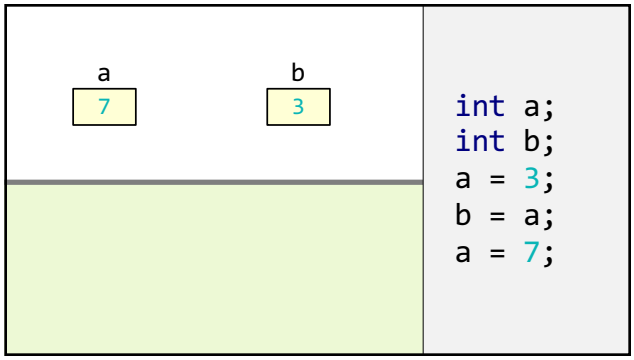


327

Objects live on the heap

(but *references to objects* live on the stack)

328

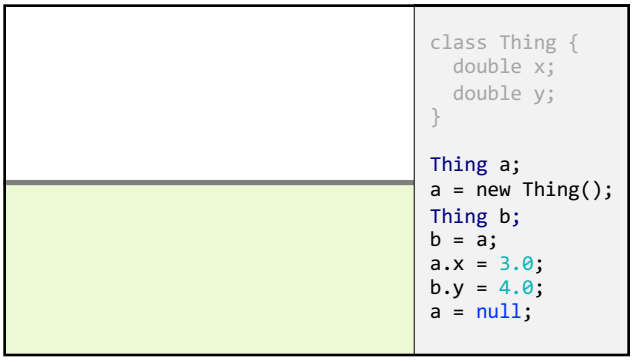
"the stack"

local variable primitives & **references** to Objects live here
variables ***undefined*** (?) by default (will NOT compile if used)

"the heap"

the actual **Objects** (including arrays and Strings) live here
Objects are *cleared to 0* by default

329



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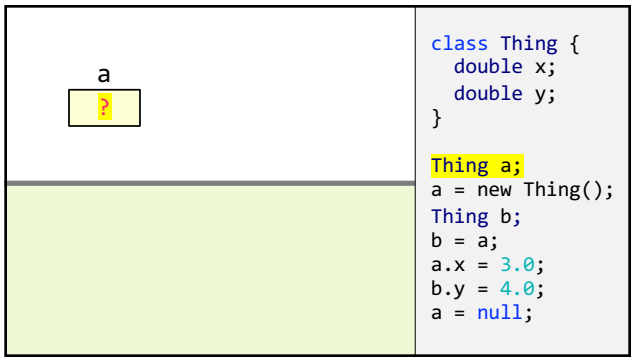

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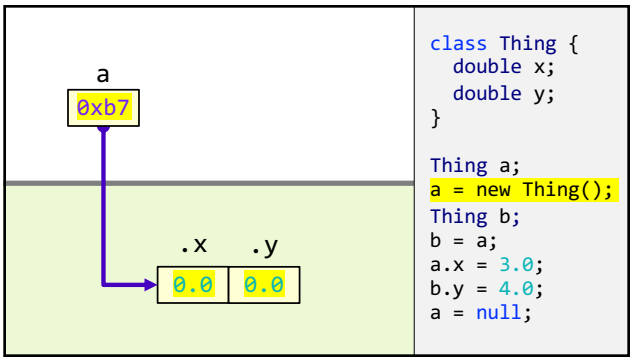
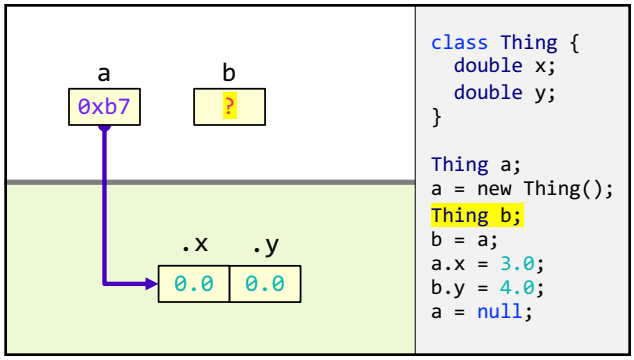


332



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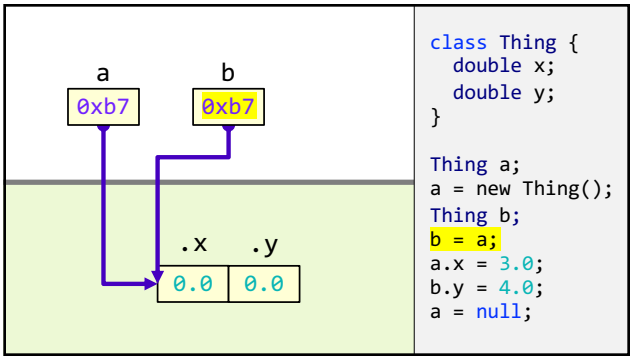

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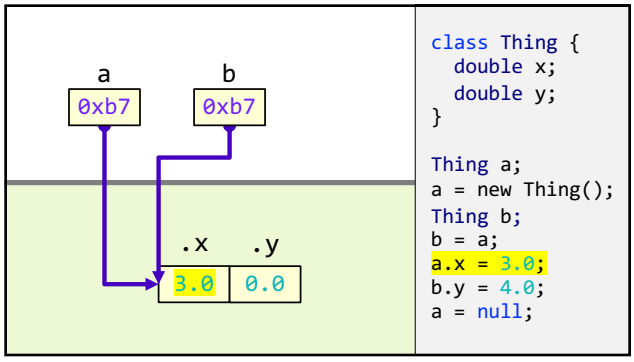

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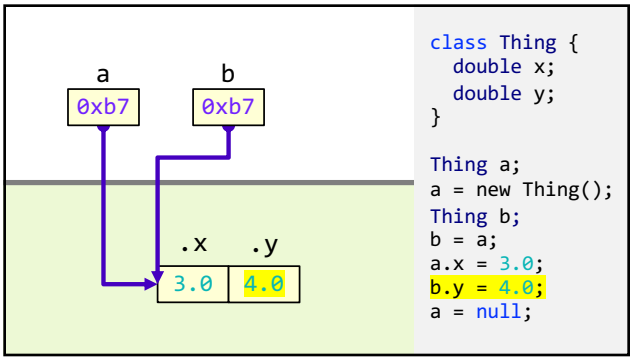

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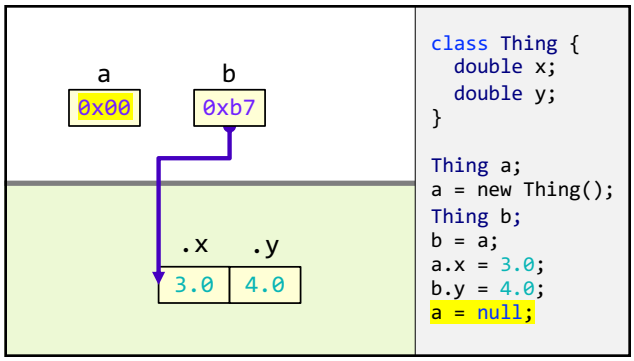

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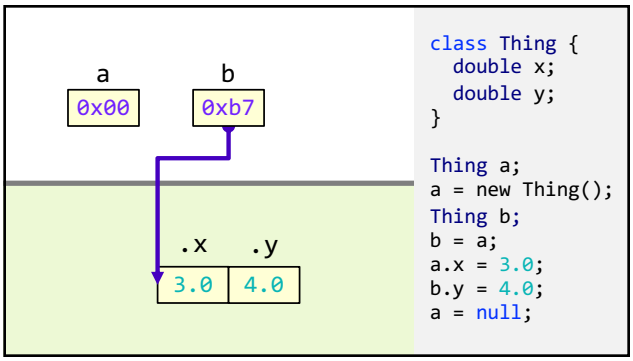


338

stack variables disappear when they leave scope

Objects are **garbage collected** when nothing refers to them anymore

339

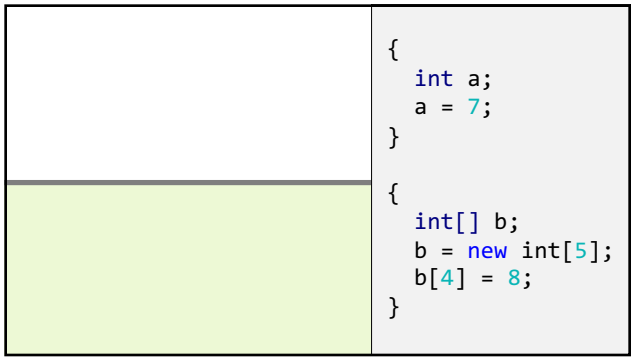
"the stack"

local variable primitives & **references** to Objects live here
variables ***undefined*** (?) by default (will NOT compile if used)

"the heap"

the actual **Objects** (including arrays and Strings) live here
Objects are *cleared to 0* by default

340



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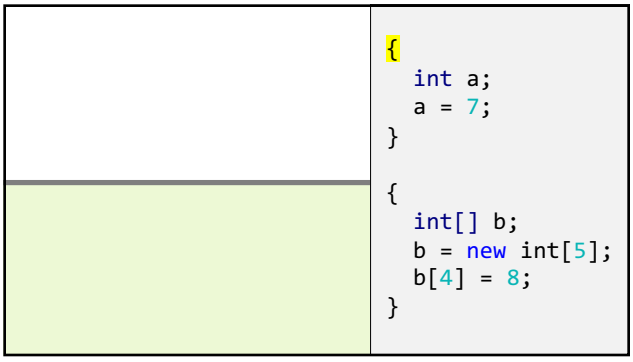

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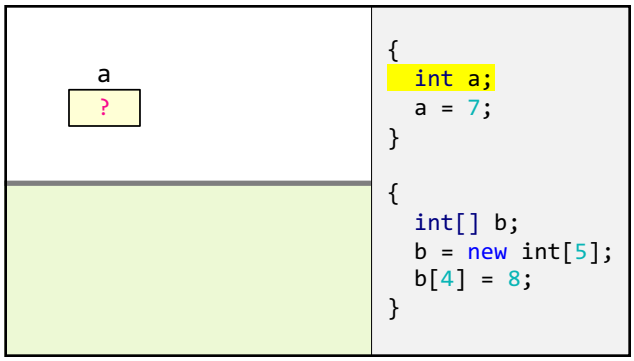

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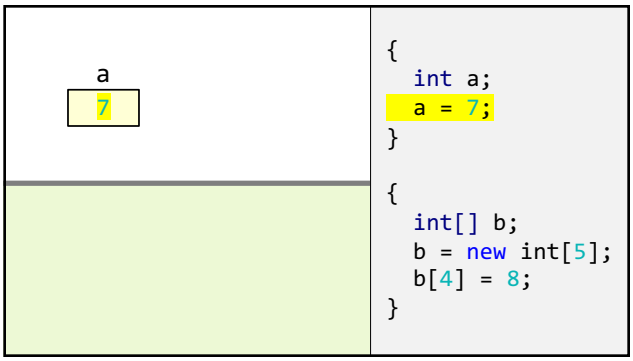

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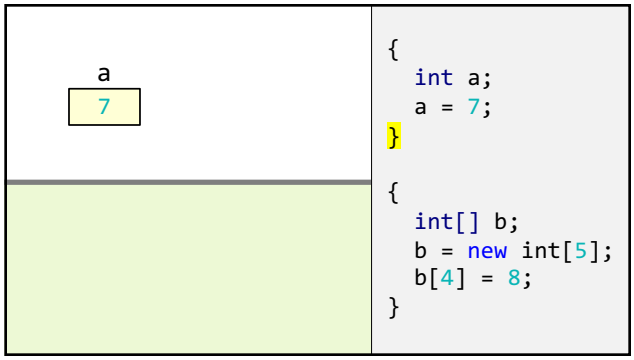

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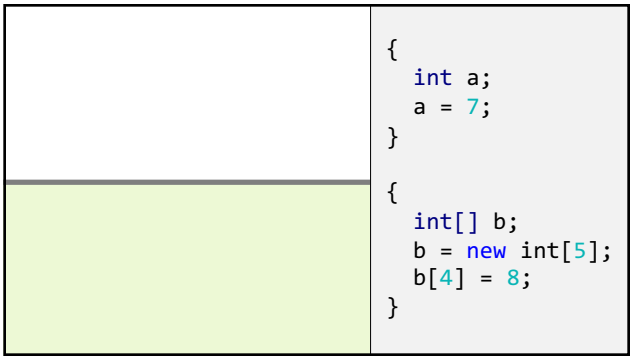

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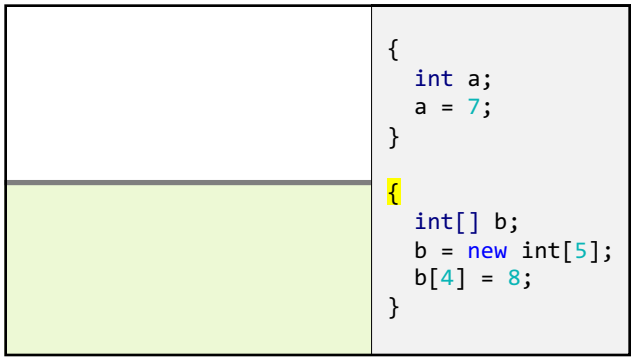

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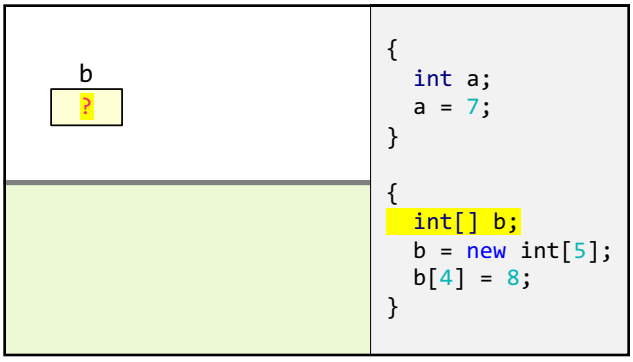

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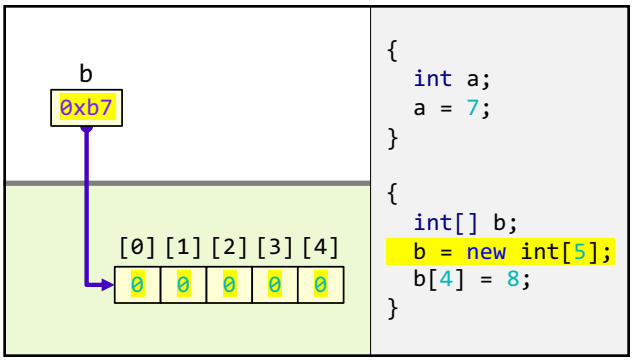

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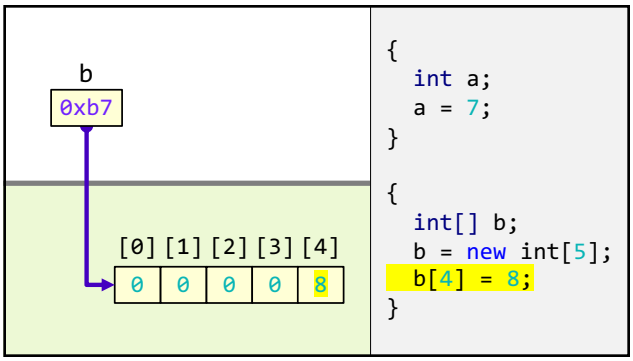

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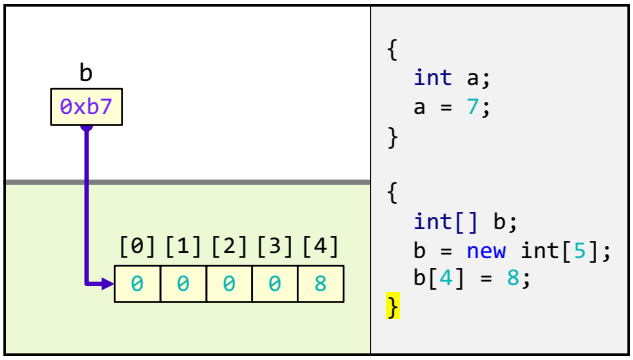

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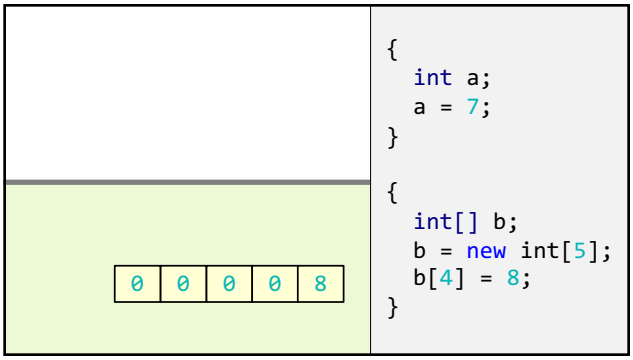

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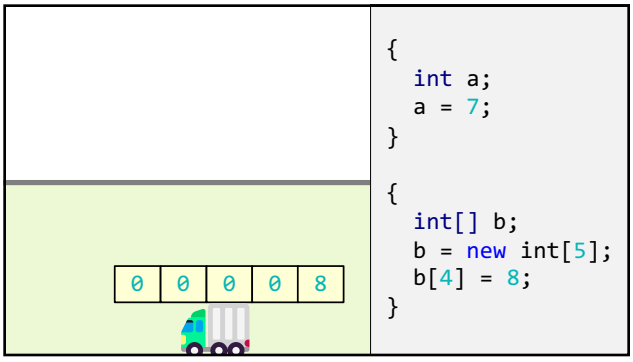


353

354

garbage collector

- the **garbage collector** is like a trash truck that drives around in the heap; when it notices an object that your program no longer has any references to, it frees up that memory for future use
  - C does NOT have a garbage collector; in C you free heap-allocated memory yourself by calling `free(...)`

355

[review all examples at least one more time]

356

passing arguments to functions

357

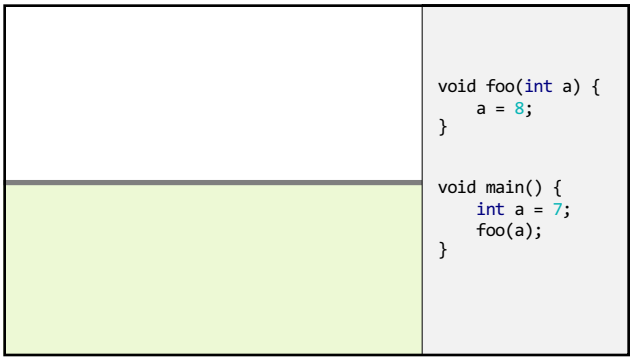
arguments to functions
are **passed by value**

(a copy of the) value of the primitive
or
(a copy of the) value of the reference

358

primitives are passed by value

359



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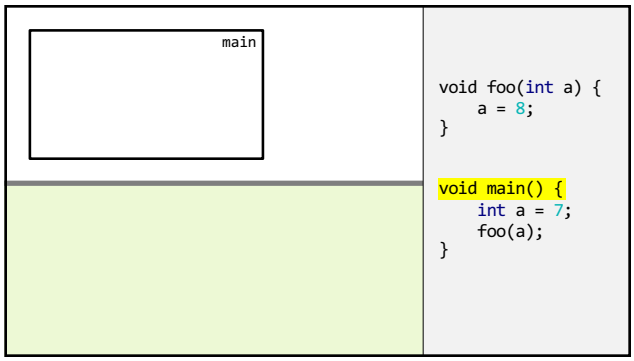

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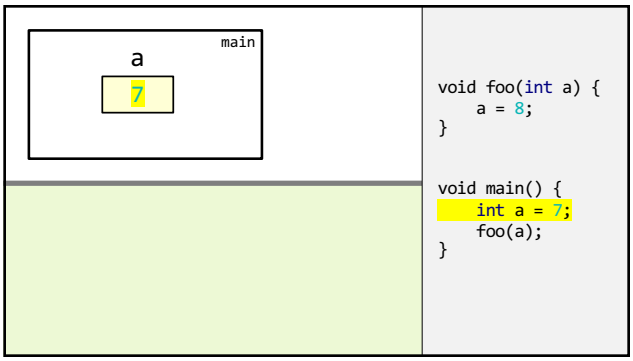

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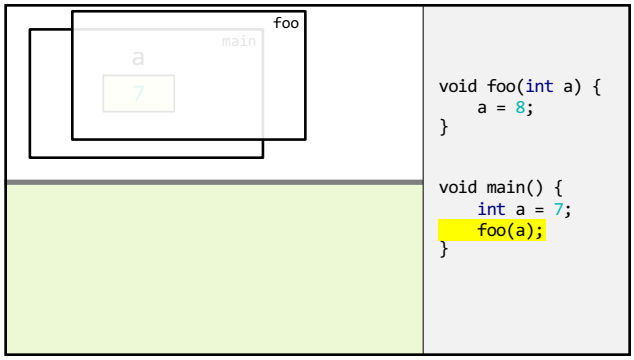

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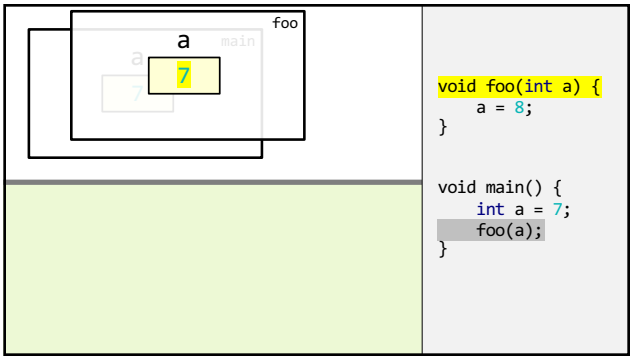

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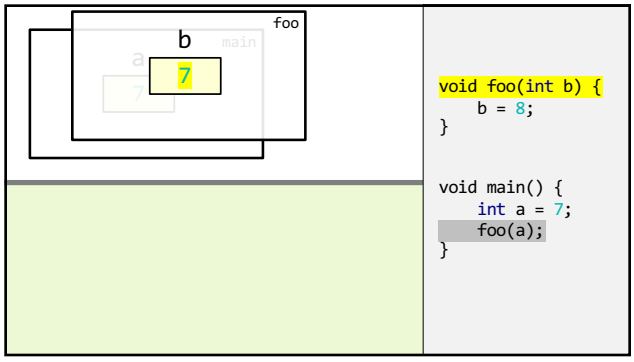

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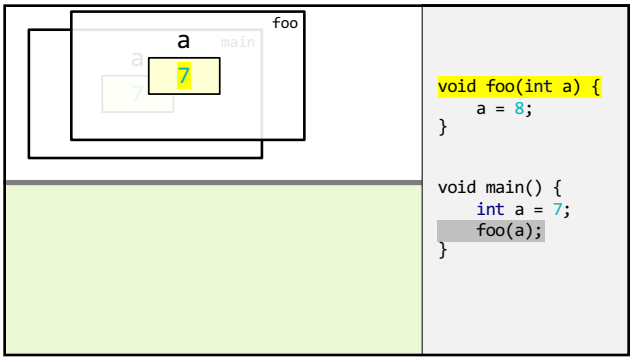

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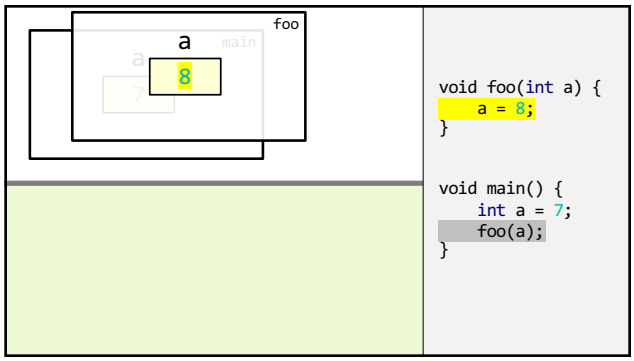

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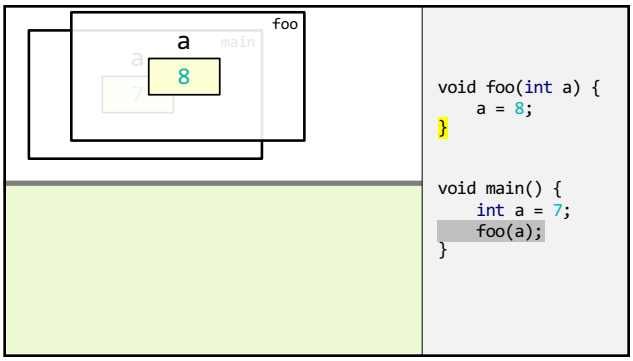

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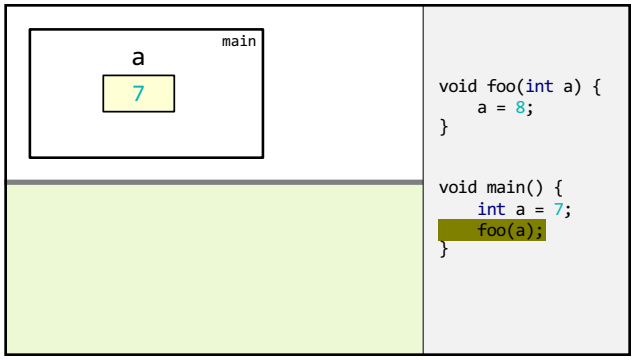

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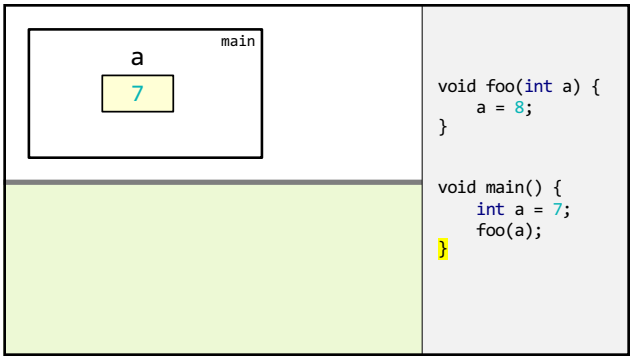

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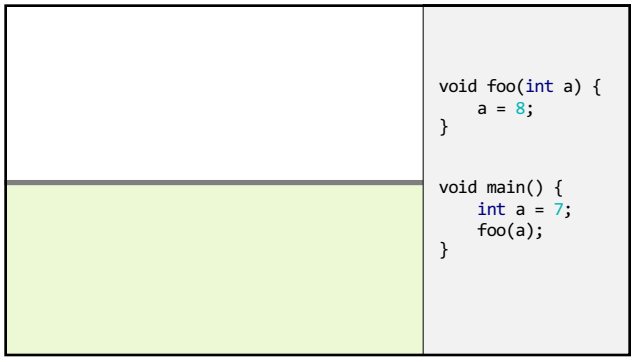
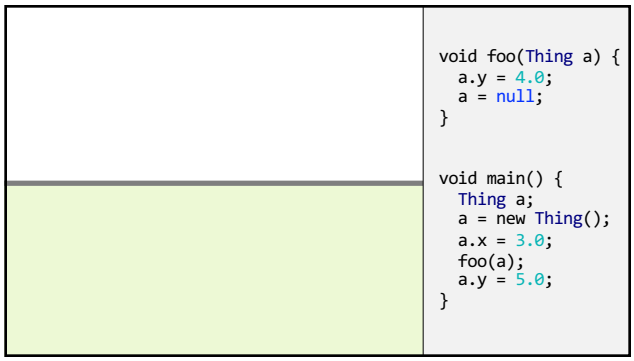


371

references are also passed by value

372



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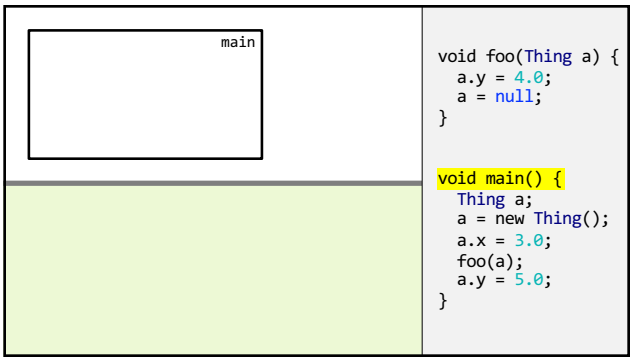

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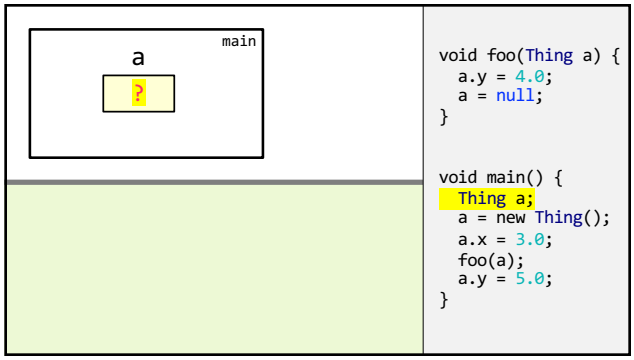

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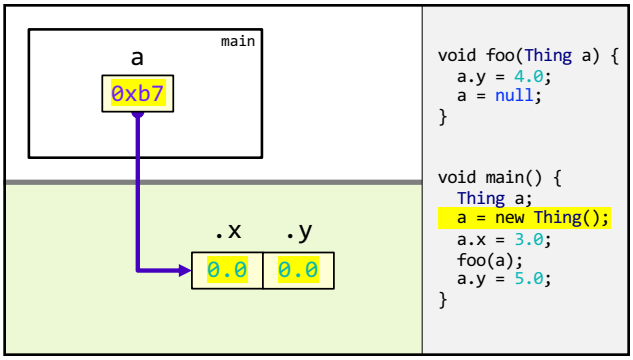

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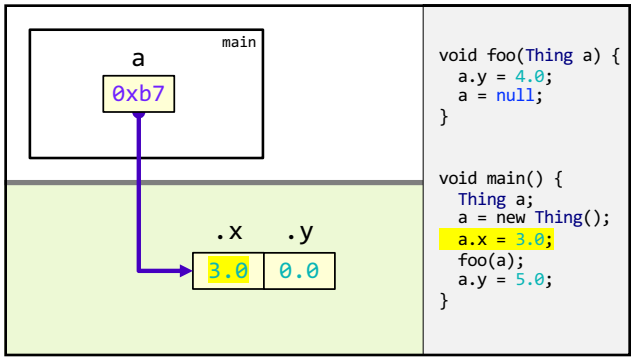

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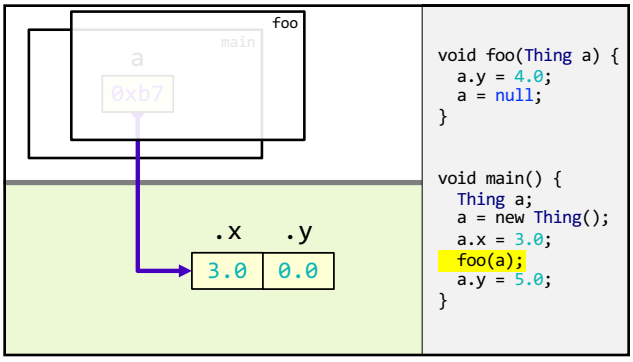

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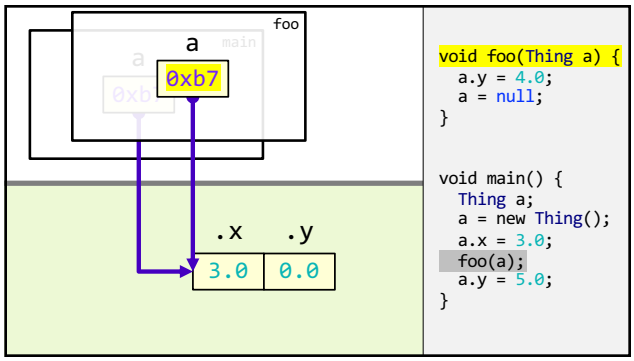

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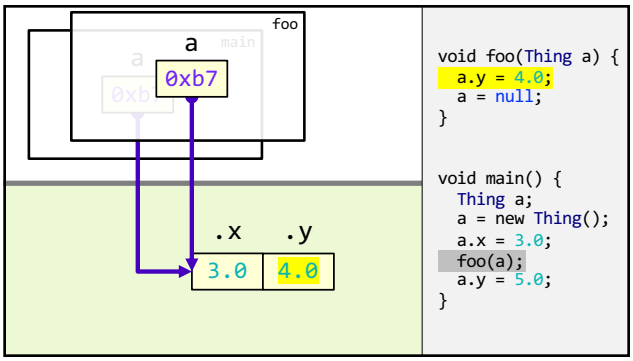

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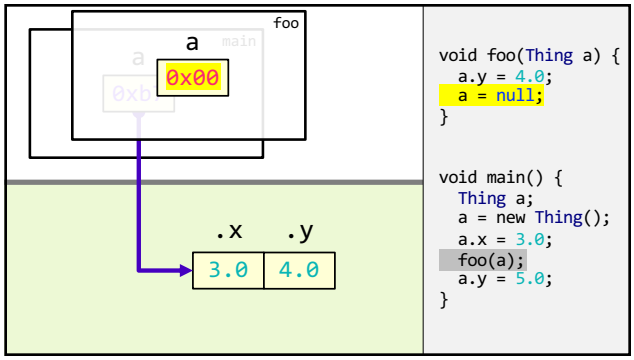

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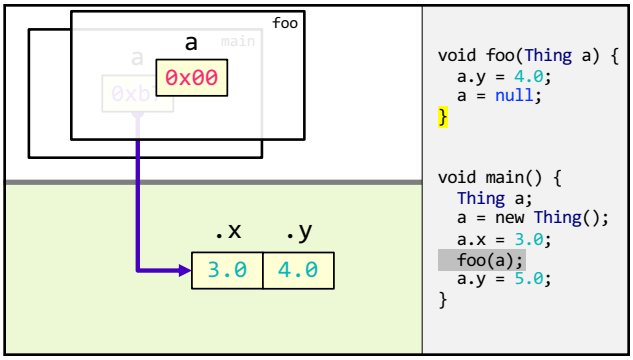

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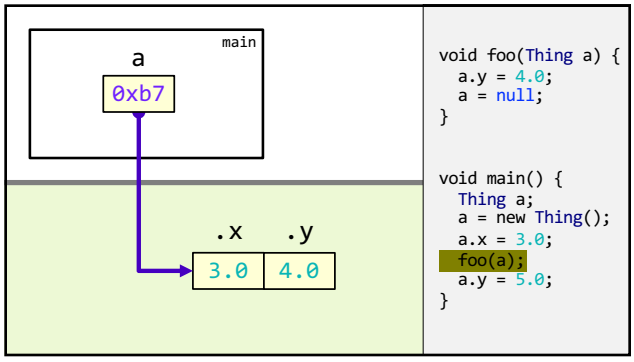

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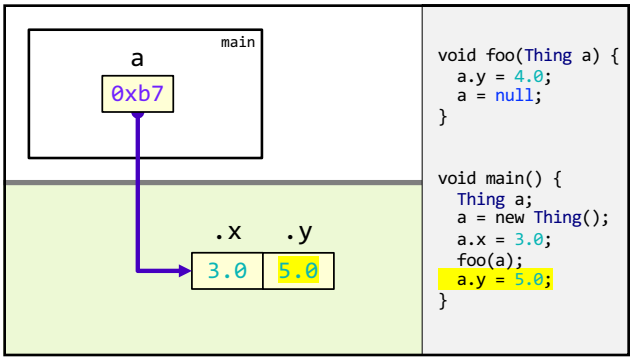

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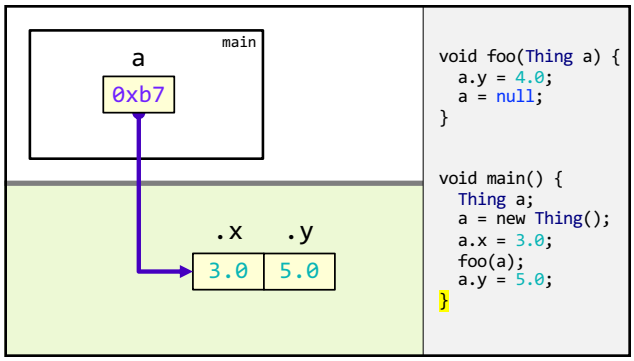

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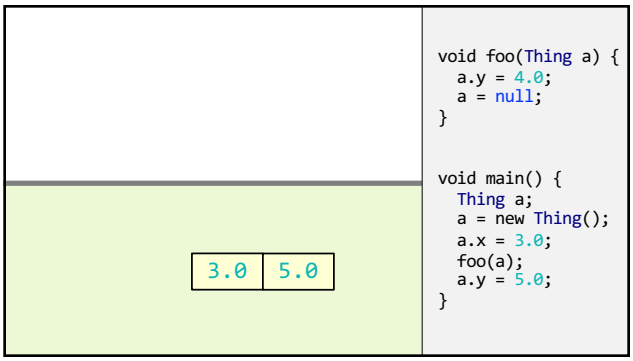

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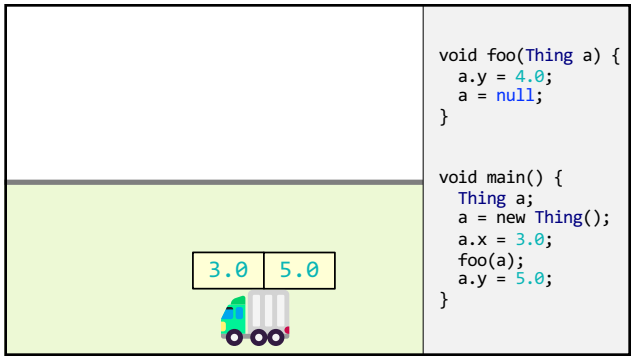

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Week03c

no Jim office hours today
(i have to catch a train)

- String
- HW03 questions
- review

Today is Fun Friday!

WARMUP
what is a string?

TODO: record lecture

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String (structure)

8 languages

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String is a long flexible structure made from fibers twisted together into a single strand, or from multiple such strands which are in turn twisted together. String is used to tie, bind, or hang other objects. It is also used as a material to make things, such as textiles, and in arts and crafts. String is a simple tool, and its use by humans is known to have been developed tens of thousands of years ago.[1] In Mesoamerica, for example, string was invented some 20,000 to 30,000 years ago, and was made by twisting plant fibers together.[1] String may also be a component in other tools, and in devices as diverse as weapons, musical instruments, and toys.

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Two pieces of string under a light microscope

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built-in classes

(classes that are "built in" to Java)

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built-in classes are "special"

(they break the rules of other classes in Java)

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review:
instantiating a class
(creating an object)

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constructors

```
// Option A: Use default constructor and initialize using dot
Color color = new Color(); // (r=0.0, g=0.0, b=0.0)
color.r = 1.0;             // (r=1.0, g=0.0, b=0.0)
color.g = 1.0;             // (r=1.0, g=1.0, b=0.0)
color.b = 1.0;             // (r=1.0, g=1.0, b=1.0)
```

```
// Option B: Use a custom constructor
Color color = new Color(1.0, 1.0, 1.0); // (r=1.0, g=1.0, b=1.0)
```

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review: array

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creating an array (1/2)

- you can create a new array by
  specifying its length inside of square brackets;
  if you do, the array is **zero-initialized** (all elements are initially set to zero)
  - `int[]     A = new int[8];     // { 0, 0, 0, 0, 0, 0, 0, 0 }`
  - `double[]  B = new double[1];  // { 0.0 }`
  - `boolean[] C = new boolean[2]; // { false, false }`
  - `char[]    D = new char[4];    // { '\0', '\0', '\0', '\0' }`
  - `String[]  E = new String[3];  // { null, null, null }`

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creating an array (2/2)

- you can also create a new array by
  specifying its elements inside of curly braces;
  if you do, the array's length is the number of elements you specified
  - `int[] array = { 7, 7, 9 }; // new int[3] is implied`
    - NOTE: this syntax can only be used for **creation**
      - 🙅 NOT okay to do later: `array = { 4, 5, 6 };`
      - 🙆 OKAY to do later:
        - `array[0] = 4;`
        - `array[1] = 5;`
        - `array[2] = 6;`
  - `boolean[] array = { true };`
  - `String[] array = { "hello", "world" };`

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String

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`String` (1/2)

- a **`String`** is a sequence of characters
  - `"Hello World"`, `"Foo123"`

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`String` (2/2)

- you can create a new String by
  specifying its elements inside of double quotation marks
  - `String string = "Hello";`
- `String` has some useful instance methods (see Docs)
  - `PRINT(string.length()); // 5`
  - `PRINT(string.charAt(1)); // 'e'`
  - `PRINT(string.substring(1, 3)); // "el"`

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`String` concatenation (1/2)

- **+ concatenates two `String`'s**
  - `// String foo = "Hello".concat("World");`
    `String foo = "Hello" + "World"; // "HelloWorld"`
- **it also does some conversions for you (very convenient; kind of confusing)**
  - `// String foo = "Hello".concat(Integer.toString(2));`
    `String foo = "Hello" + 2; // "Hello2"`

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`String` concatenation (2/2)

- `stringA + foo` is the ONLY example of **operator overloading** in Java
  - (the * operator just does multiplication)
  - (the / operator just does division)
  - ...but the + operator does both addition and string concatenation
- Python and C++ let you implement your *own* operator overloading
  - (very fun; very confusing)

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inside of a String (1/4)

- inside of `String`, there must be a `char[]`
  - **motivation:** as you experienced in HW02, working directly with character arrays is hard / painful
  - **idea:** `String` "wraps up" a `char[]` into an easy-to-use package

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inside of a String (2/4)

- if a `String` is really just a `char[]`...
  - ...then what does this code actually *do*? 🧠

```
String a = "Hello";
String b = "World";
String c = a + b;
PRINT(c);
```

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XStringExample

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inside of a String (3/4)

- if a `String` is really just a `char[]`...
  - ...then what does this code actually *do*? 🧠
  - .. how many `char[]`'s are created?

```
String a = "Hello";
String b = " ";
String c = "World";
String d = "!";
String e = a + b + c + d;
PRINT(e);
```

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interlude

-
  -
  - ...what is this code's big O runtime? 🧠

```
int foo = 0;
for (int i = 0; i < n; ++i) { // O(n)
    foo += 1;                 // * O(1)
}
PRINT(foo);
```


inside a String (4/4)

- if a `String` is really just a `char[]`...
  - ...then what does this code *do*?
  - ...what is its big O runtime? 🧠

```
String scream = "";
for (int i = 0; i < n; ++i) {
    scream += "A";
}
PRINT(scream);
```


questions on HW03?

`pool[i]` inside of specific updates

(don't define `enemy1` and `enemy2`)

why i gave you a `player` reference

`this` inside of `fireBullet`

the art of coding things in the right order

compile and run early, compile and run often

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well, let us imagine...

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let's imagine...

- ...you decide to develop n different things at once...
  - ...and then, finally, you compile and run...
    - ...aaaaand you have a bug! 🐛
- so...what is the cause of the bug? what code is broken? 🤔
  - well...i guess it could be any of the n things you just wrote!
- **and while $\mathcal{O}(n)$ possible sources of bugs might seem bad...**

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...the reality is

✨ **so much worse** ✨ !

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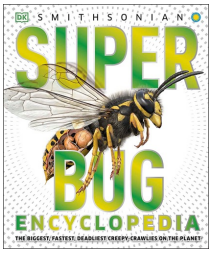
because broken code likes to interact with other broken code, to make ✨ **super bugs** ✨ !



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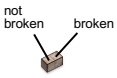

developing one
thing at a time

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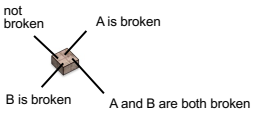

developing two
things at a time

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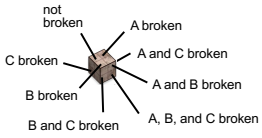

developing three
things at a time

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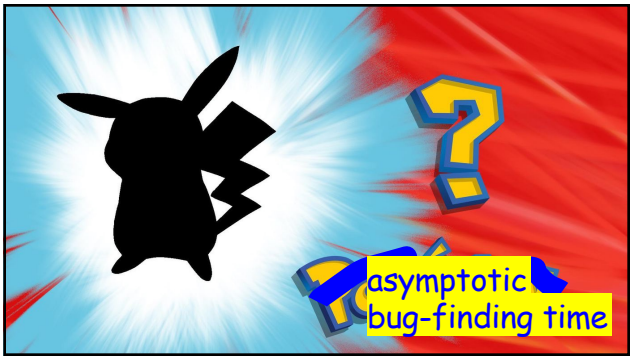

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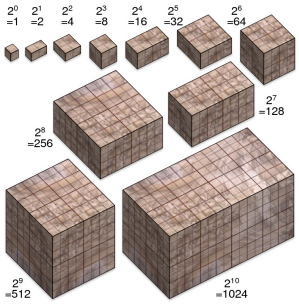

$\mathcal{O}(2^n)$

gl;hf 😊 👍

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big lesson

- implement code one thing at a time
- compile and run and test after implementing every single thing
- figuring out the order to do things in is a learned skill!
  - sometimes i choose the wrong order...
  - ...and then i usually have to start over 😊 👍

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this is a learned skill!

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in summary

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