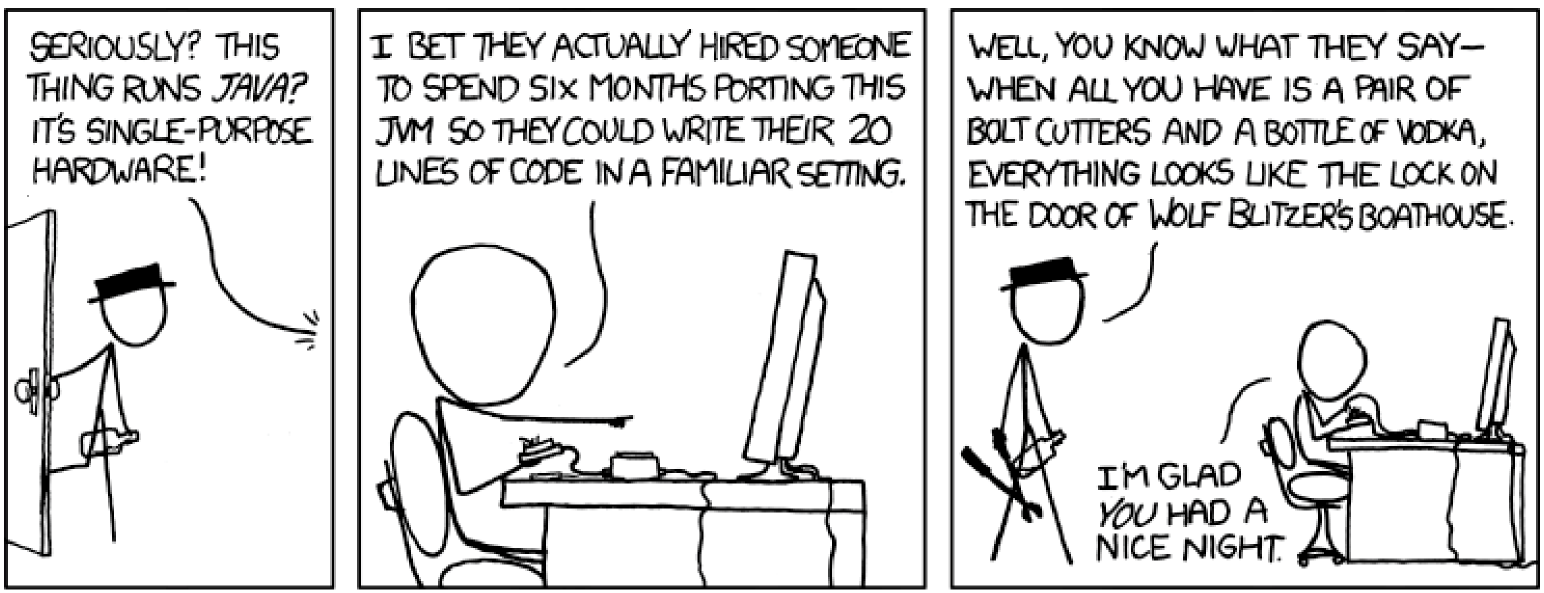
Java and C (part I)

CSE 351 Spring 2022

Instructor:
Ruth Anderson

Teaching Assistants:
Melissa Birchfield, Jacob Christy, Alena Dickmann
Kyrie Dowling, Ellis Haker, Maggie Jiang
Diya Joy, Anirudh Kumar, Jim Limprasert
Armin Magness, Hamsa Shankar, Dara Stotland
Jeffery Tian, Assaf Vayner, Tom Wu
Angela Xu, Effie Zheng



https://xkcd.com/801/

Relevant Course Information

- Lab 5 (on Mem Alloc) due Friday 6/03
  - Can be submitted at most ONE day late. (Sun 6/05)
  - The most significant amount of C programming you will do in this class – combines lots of topics from this class: pointers, bit manipulation, structs, examining memory
  - Understanding the concepts *first* and efficient *debugging* will save you lots of time
  - Light style grading
- hw25 – Do EARLY, will help with Lab 5 (due Mon 5/30)

Lab 5 Hints

- Struct pointers can be used to access field values, even if no struct instances have been created – just reinterpreting the data in memory
- Pay attention to boundary tag data
  - Size value + 2 tag bits – when do these need to be updated and do they have the correct values?
  - The `examine_heap` function follows the implicit free list searching algorithm – don't take its output as "truth"
- Learn to use and interpret the trace files for testing!!!
- A special heap block marks the end of the heap

Roadmap

1970's 1990's

C:

```
car *c = malloc(sizeof(car));
c->miles = 100;
c->gals = 17;
float mpg = get_mpg(c);
free(c);
```

Java:

```
Car c = new Car();
c.setMiles(100);
c.setGals(17);
float mpg =
    c.getMPG();
```

Assembly language:

```
get_mpg:
    pushq   %rbp
    movq    %rsp, %rbp
    ...
    popq    %rbp
    ret
```

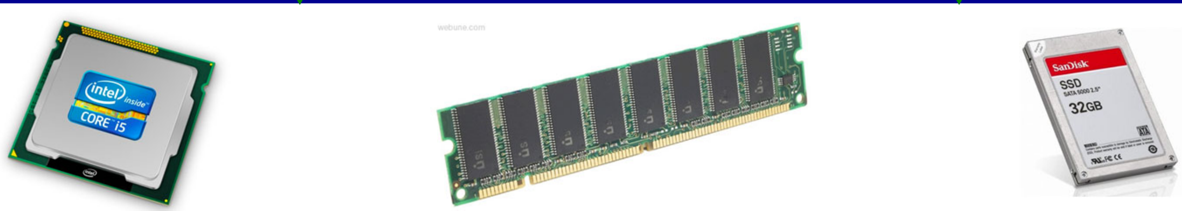
Machine code:

```
0111010000011000
100011010000010000000010
1000100111000010
110000011111101000011111
```

OS:

Windows 10 OS X Yosemite

Computer system:



- Memory & data
- Integers & floats
- x86 assembly
- Procedures & stacks
- Executables
- Arrays & structs
- Memory & caches
- Processes
- Virtual memory
- Memory allocation
- Java vs. C

Java vs. C

- Reconnecting to Java (hello CSE143!)
  - But now you know a lot more about what really happens when we execute programs

- We've learned about the following items in C; now we'll see what they look like for Java:
  - Representation of data
  - Pointers / references
  - Casting
  - Function / method calls including dynamic dispatch

Worlds Colliding

- CSE351 has given you a “really different feeling” about what computers do and how programs execute

- We have occasionally contrasted to Java, but CSE143 may still feel like “a different world”
  - It’s not – it’s just a higher-level of abstraction
  - Connect these levels via how-one-could-implement-Java in 351 terms

Meta-point to this lecture

- None of the data representations we are going to talk about are *guaranteed* by Java
- In fact, the language simply provides an *abstraction* (Java language specification)
  - Tells us how code should behave for different language constructs, but we can't easily tell how things are really represented
  - But it is important to understand an *implementation* of the lower levels – useful in thinking about your program

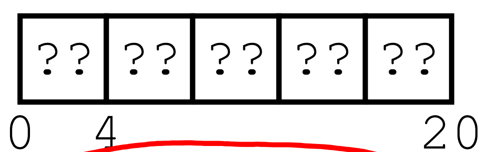
Data in Java

- Integers, floats, doubles, pointers – same as C
  - "Pointers" are called "references" in Java, but are much more constrained than C's general pointers
  - Java's portability-guarantee fixes the sizes of all types
    - Example: `int` is 4 bytes in Java regardless of machine
  - No unsigned types to avoid conversion pitfalls
    - Added some useful methods in Java 8 (also use bigger signed types)
- `null` is typically represented as `0` but "you can't tell"
- Much more interesting:
  - **Arrays**
  - **Characters and strings**
  - **Objects**

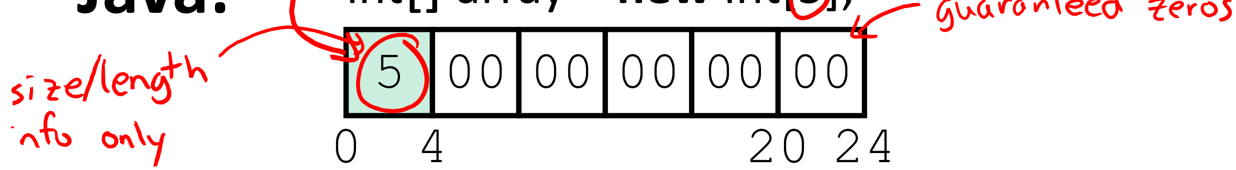
Data in Java: Arrays

- Every element initialized to `0` or `null`
- Length specified in immutable field at start of array (`int`: 4B)
  - `array.length` returns value of this field
- *Since it has this info, what can it do?*

C: **int** array[5];



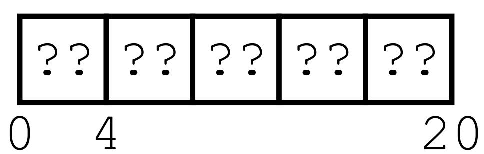
Java: int[] array = **new** int[5];



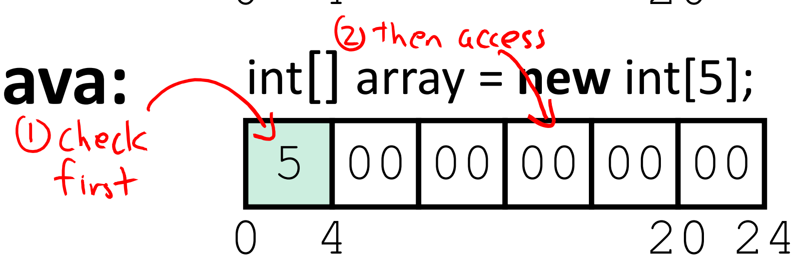
Data in Java: Arrays

- Every element initialized to `0` or `null`
- Length specified in immutable field at start of array (`int`: 4B)
  - `array.length` returns value of this field
- Every access triggers a <u>bounds-check</u>
  - Code is added to ensure the index is within bounds
  - Exception if out-of-bounds

C: **int** array[5];



Java: int[] array = **new** int[5];



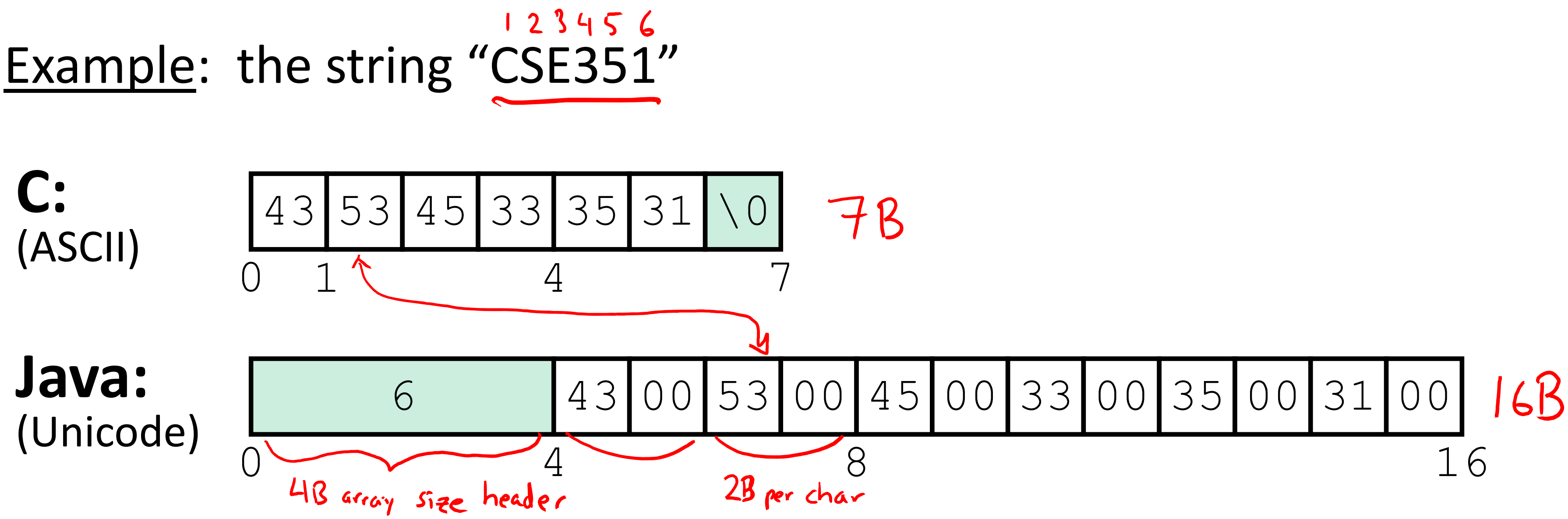
To speed up bounds-checking:

- Length field is likely in cache
- Compiler may store length field in register for loops
- Compiler may prove that some checks are redundant

Data in Java: Characters & Strings

- Two-byte Unicode instead of ASCII
  - Represents most of the world's alphabets
- String not bounded by a `'\0'` (null character)
  - Bounded by hidden length field at beginning of string
- All String objects read-only (vs. StringBuffer)

<u>Example</u>: the string "CSE351"



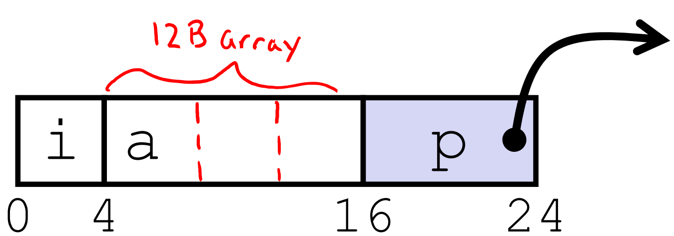
Data in Java: Objects

- Data structures (objects) are always stored by reference, never stored "inline"
  - Include complex data types (arrays, other objects, etc.) using references

C:

```
struct rec {
  int i;
  int a[3];
  struct rec *p;
};
```

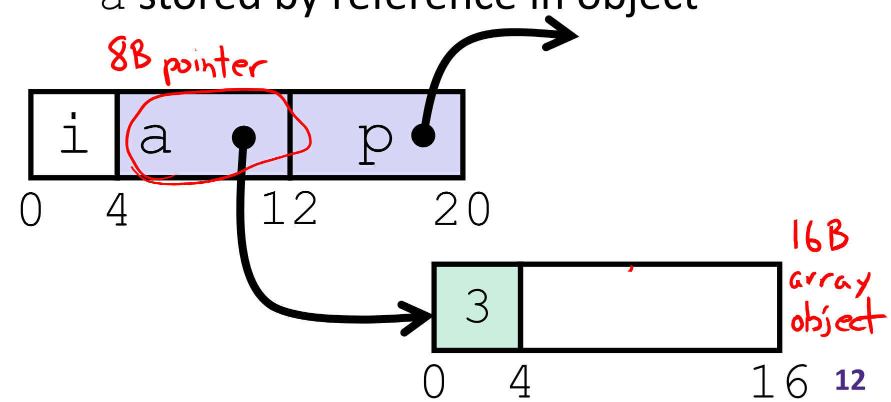
- `a[]` stored "inline" as part of struct



Java:

```
class Rec {
  int i;
  int[] a = new int[3];
  Rec p;
  ...
}
```

- `a` stored by reference in object



Pointer/reference fields and variables

- In C, we have "`->`" and "`.`" for field selection depending on whether we have a pointer to a struct or a struct
  - `(*r).a` is so common it becomes `r->a`
- In Java, *all non-primitive variables are references to objects*
  - We always use `r.a` notation
  - But really follow reference to `r` with offset to `a`, just like `r->a` in C
  - So no Java field needs more than 8 bytes

C:

```
struct rec *r = malloc(...);
struct rec r2;
r->i = val;
r->a[2] = val;
r->p = &r2;
```

Java:

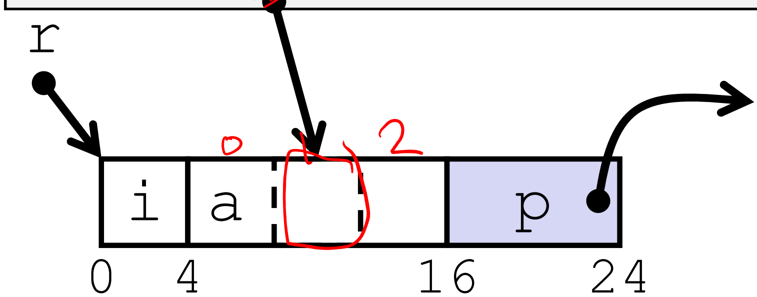
```
r = new Rec();
r2 = new Rec();
r.i = val;
r.a[2] = val;
r.p = r2;
```

Pointers/References

- *Pointers* in C can point to any memory address
- *References* in Java can only point to [the starts of] objects
  - Can only be dereferenced to access a field or element of that object

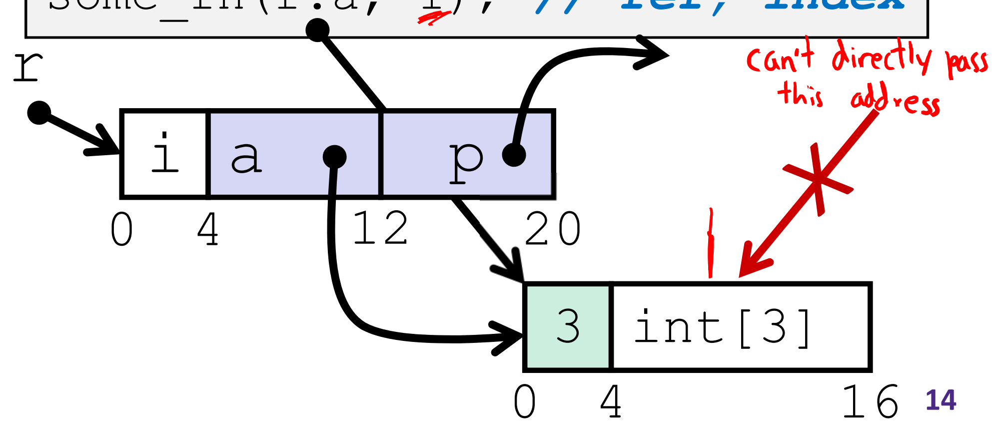
C:

```
struct rec {
  int i;
  int a[3];
  struct rec *p;
};
struct rec* r = malloc(…);
some_fn(&(r->a[1])); // ptr
```



Java:

```
class Rec {
  int i;
  int[] a = new int[3];
  Rec p;
}
Rec r = new Rec();
some_fn(r.a, 1); // ref, index
```



Casting in C (example from Lab 5)

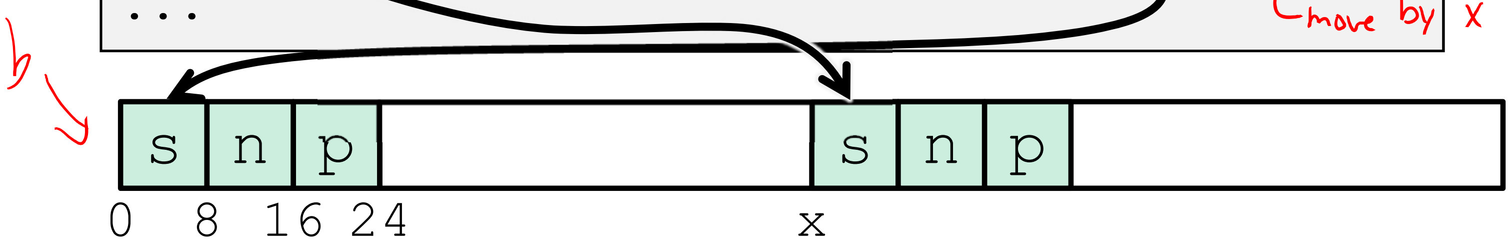
- Can cast any pointer into any other pointer
  - Changes dereference and arithmetic behavior

```
struct block_info {
        size_t size_and_tags;
        struct block_info* next;
        struct block_info* prev;
};
typedef struct block_info block_info;
...
int x;
block_info* b;
block_info* new_block;
...
new_block = (block_info*) ( (char*) b + x );
...
```

Cast b into char* to do unscaled addition

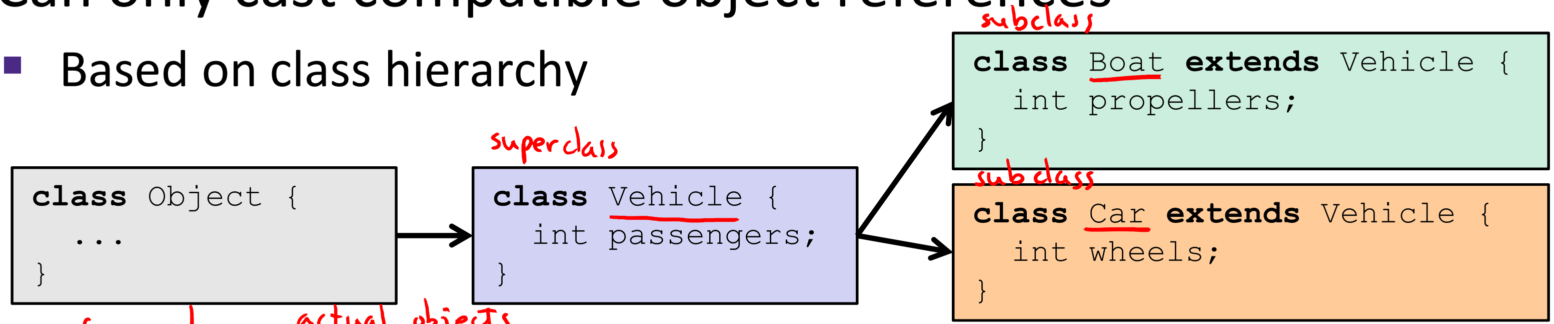
Cast back into block_info* to use as block_info struct

move by x bytes



Type-safe casting in Java

- Can only cast compatible object references
  - Based on class hierarchy




```
Vehicle  v  = new Vehicle(); // super class of Boat and Car
Boat     b1 = new Boat();    // |--> sibling
Car      c1 = new Car();     // |--> sibling

Vehicle  v1 = new Car();
Vehicle  v2 = v1;
Car      c2 = new Boat();

Car      c3 = new Vehicle();

Boat     b2 = (Boat) v;

Car      c4 = (Car) v2;
Car      c5 = (Car) b1;
```

Type-safe casting in Java

- Can only cast compatible object references
  - Based on class hierarchy

```
class Object {
  ...
}
```

```
class Vehicle {
  int passengers;
}
```

```
class Boat extends Vehicle {
  int propellers;
}
```

```
class Car extends Vehicle {
  int wheels;
}
```

```
Vehicle  v = new Vehicle(); // super class of Boat and Car
Boat     b1 = new Boat();   // |--> sibling
Car      c1 = new Car();    // |--> sibling

Vehicle v1 = new Car();
Vehicle v2 = v1;
Car     c2 = new Boat();

Car     c3 = new Vehicle();

Boat    b2 = (Boat) v;

Car     c4 = (Car) v2;
Car     c5 = (Car) b1;
```

- `Vehicle v1 = new Car();` ← ✓ Everything needed for `Vehicle` also in `Car`
- `Vehicle v2 = v1;` ← ✓ `v1` is declared as type `Vehicle`
- `Car c2 = new Boat();` ← ✗ Compiler error: Incompatible type – elements in `Car` that are not in `Boat` (siblings)

Type-safe casting in Java

- Can only cast compatible object references
  - Based on class hierarchy

```
class Object {
  ...
}
```

→

```
class Vehicle {
  int passengers;
}
```

→

```
class Boat extends Vehicle {
  int propellers;
}
```

```
class Car extends Vehicle {
  int wheels;
}
```

defines the user's interface with object

actual object that you interact with

```
Vehicle  v  = new Vehicle(); // super class of Boat and Car
Boat     b1 = new Boat();    // |--> sibling
Car      c1 = new Car();     // |--> sibling
```

- `Vehicle v1 = new Car();` ← ✓ Everything needed for `Vehicle` also in `Car`
- `Vehicle v2 = v1;` ← ✓ `v1` is declared as type `Vehicle`
- `Car c2 = new Boat();` ← ✗ Compiler error: Incompatible type – elements in `Car` that are not in `Boat` (siblings)
- `Car c3 = new Vehicle();` ← ✗ Compiler error: Wrong direction – elements `Car` not in `Vehicle` (`wheels`)
- `Boat b2 = (Boat) v;` ← ✗ Runtime error: `Vehicle` does not contain all elements in `Boat` (`propellers`)
- `Car c4 = (Car) v2;` ← ✓ `v2` refers to a `Car` at *runtime*
- `Car c5 = (Car) b1;` ← ✗ Compiler error: Unconvertable types – `b1` is declared as type `Boat`

Java Object Definitions

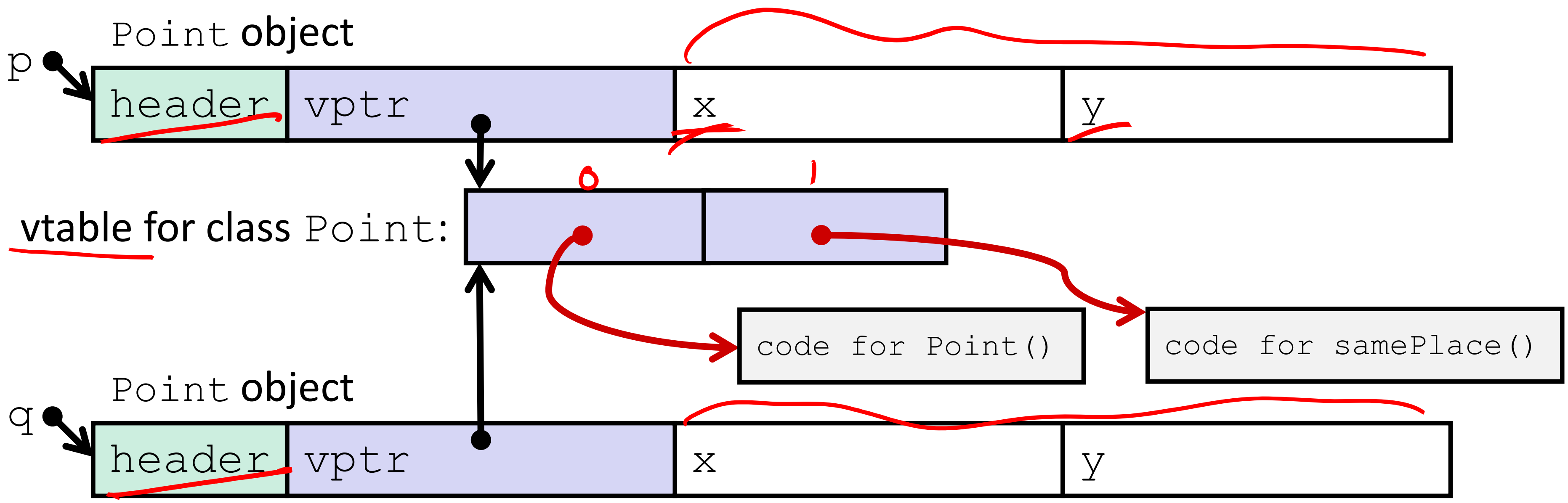
```
class Point {
  double x;
  double y;

  Point() {
    x = 0;
    y = 0;
  }

  boolean samePlace(Point p) {
    return (x == p.x) && (y == p.y);
  }
}
...
Point p = new Point();
...
```

- fields
- constructor
- method(s)
- creation

Point q = new Point();

p.samePlace(q);

Java Objects and Method Dispatch



- *Virtual method table* (*vtable*)
  - Like a jump table for instance ("virtual") methods plus other class info
  - One table per class
  - Each object instance contains a *vtable pointer (vptr)*
- *Object header* : GC info, hashing info, lock info, etc.

Java Constructors

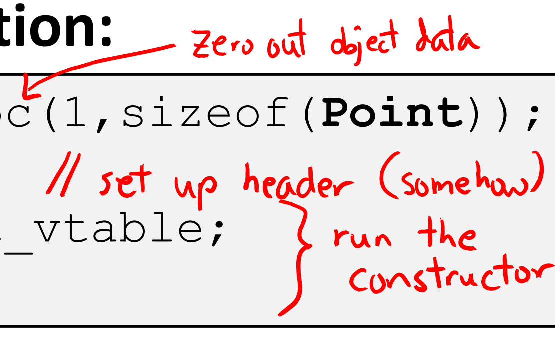
- **When we call `new`:** allocate space for object (data fields and references), initialize to zero/null, and run constructor method

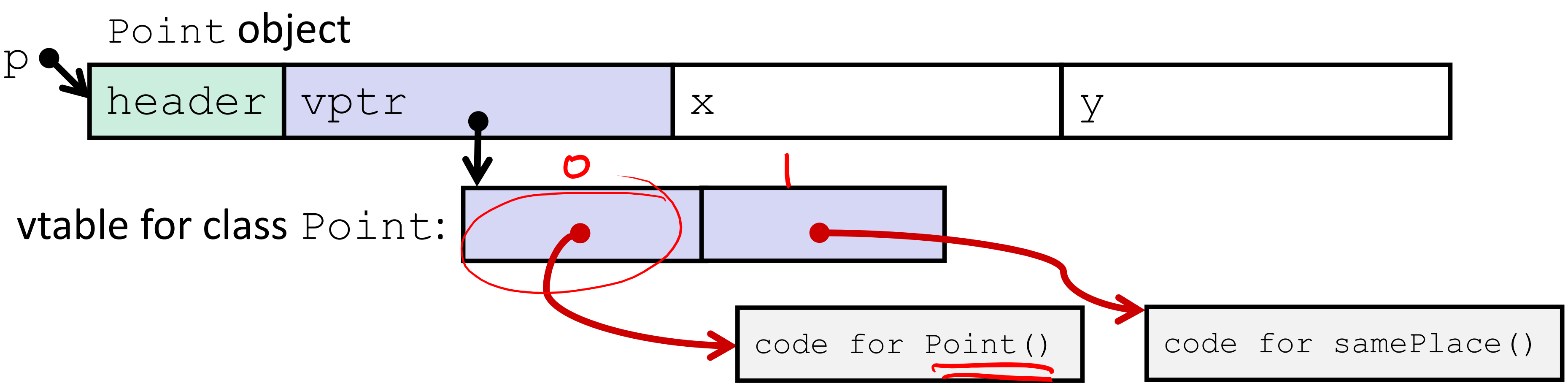
Java:

```
Point p = new Point();
```

C pseudo-translation:

```
Point* p = calloc(1,sizeof(Point));
p->header = ...;
p->vptr = &Point_vtable;
p->vptr[0](p);
```





Java Methods

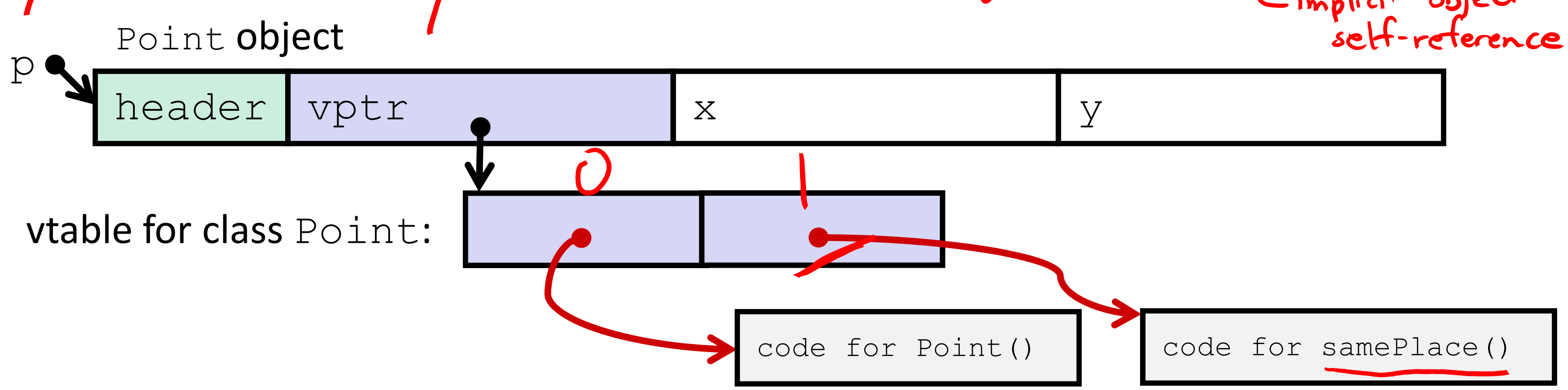
- Static methods are just like functions
- Instance methods:
  - Can refer to *this;*
  - Have an implicit first parameter for *this;* and
  - Can be overridden in subclasses
- The code to run when calling an instance method is chosen *at runtime* by lookup in the vtable

Java:

```
p.samePlace(q);
```

C pseudo-translation:

```
p->vptr[1](p, q);
```



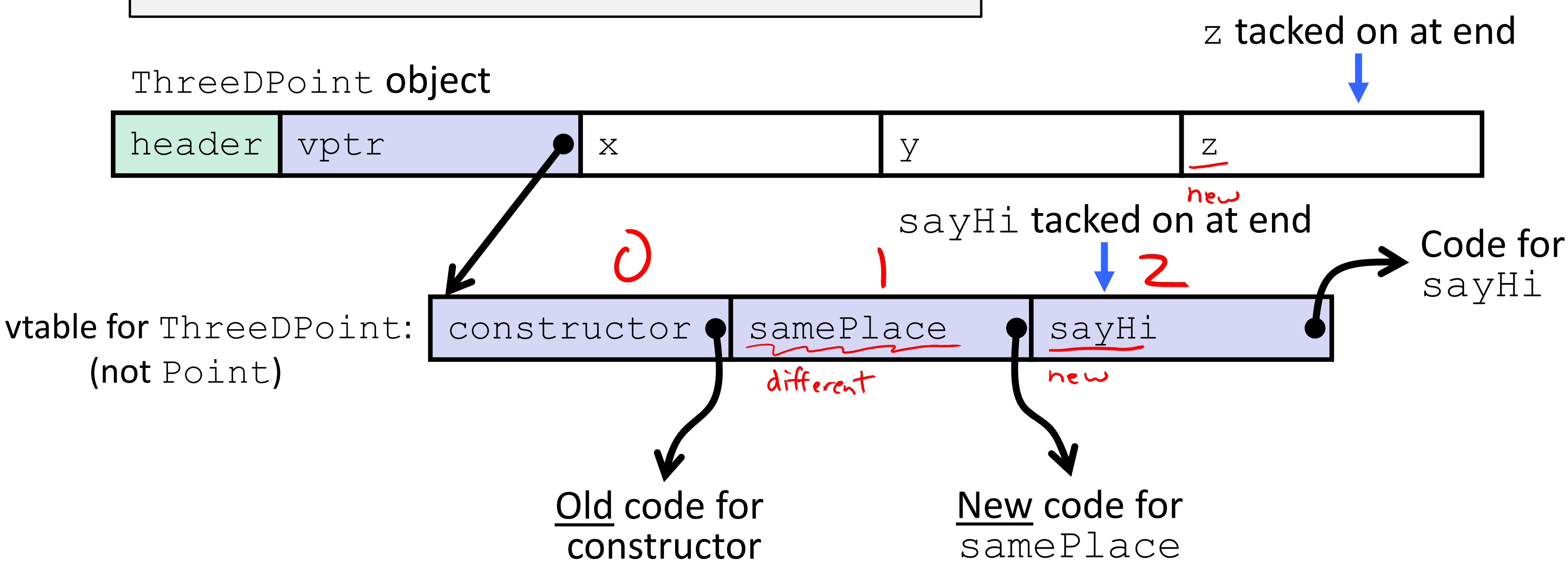
Subclassing

```
class ThreeDPoint extends Point {
    double z;
    boolean samePlace(Point p2) {
        return false;
    }
    void sayHi() {
        System.out.println("hello");
    }
}
```

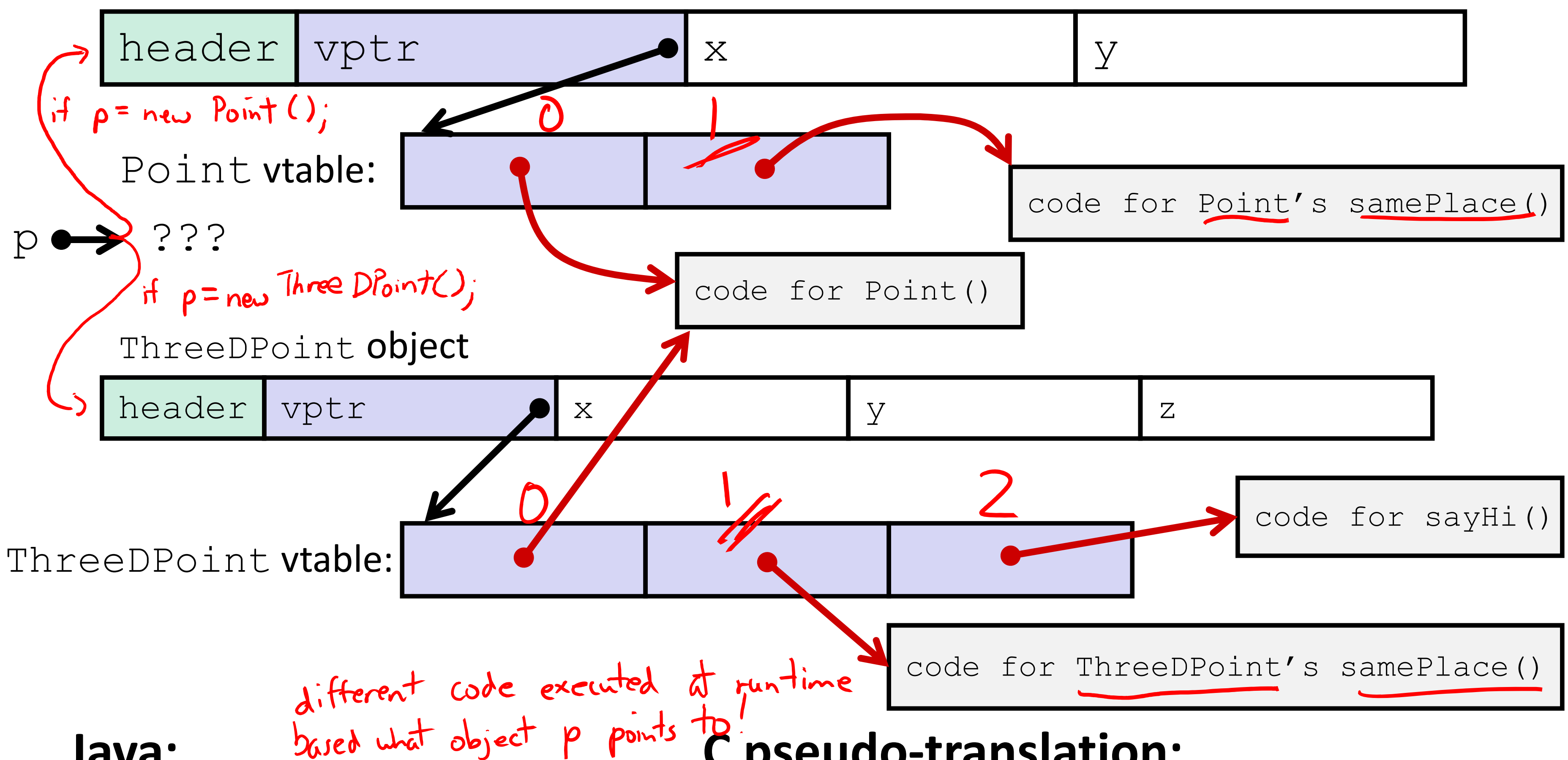

- Where does "`z`" go? At end of fields of `Point`
  - `Point` fields are always in the same place, so `Point` code can run on `ThreeDPoint` objects without modification
- Where does pointer to code for two new methods go?
  - No constructor, so use default `Point` constructor
  - To override "`samePlace`", use same vtable position
  - Add new pointer at end of vtable for new method "`sayHi`"

Subclassing

```
class ThreeDPoint extends Point {
    double z;
    boolean samePlace(Point p2) {
        return false;
    }
    void sayHi() {
        System.out.println("hello");
    }
}
```



Dynamic Dispatch



Java:

```
Point p = ???;
return p.samePlace(q);
```

C pseudo-translation:

```
// works regardless of what p is
return p->vtr[1](p, q);
```

Ta-da!

- In CSE143, it may have seemed "magic" that an *inherited* method could call an *overridden* method

- The "trick" in the implementation is this part:

  `p->vptr[i](p,q)`

  - In the body of the pointed-to code, any calls to (other) methods of `this` will use `p->vptr`
  - Dispatch determined by `p`, not the class that defined a method