Java and C I

CSE 351 Autumn 2016

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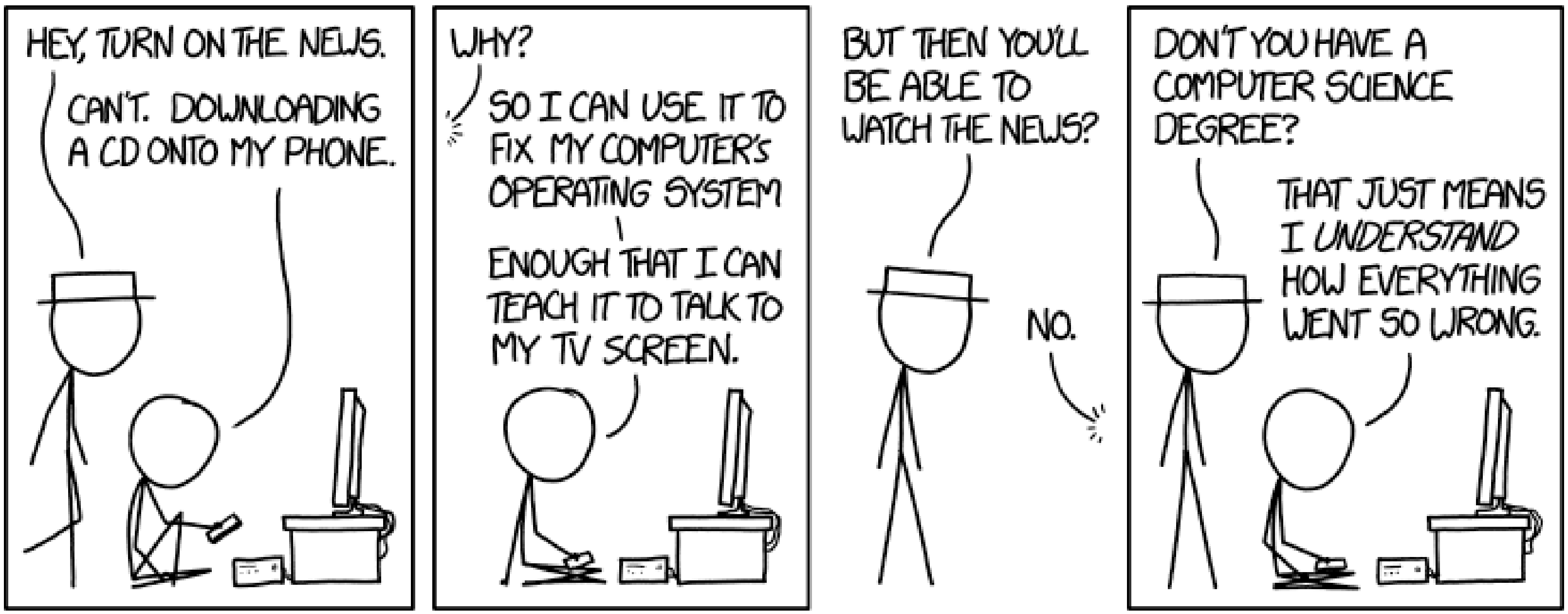


https://xkcd.com/1760/

Administrivia

- Lab 5 due Friday @ 11:45pm
  - Hard deadline on Sunday @ 11:45pm
- Course evaluations now open
  - See Piazza post @465 for links (separate for Lec A/B)
- **Final Exam:** Tue, Dec. 13 @ 12:30pm in Kane 120
  - Review Session: Sun, Dec. 11 @ 1:30pm in EEB 105
  - Cumulative (midterm clobber policy applies)
  - TWO double-sided handwritten 8.5×11" cheat sheets
    - Recommended that you reuse or remake your midterm cheat sheet

Roadmap

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 8 Mac

Computer system:

- Memory & data
- Integers & floats
- Machine code & C
- x86 assembly
- Procedures & stacks
- 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
  - Runtime environment
  - Translation from high-level code to machine code

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` – 4 bytes)
  - `array.length` returns value of this field
- *Since it has this info, what can it do?*

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

??	??	??	??	??

0 4 20

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

5	00	00	00	00	00

0 4 20 24

Data in Java: Arrays

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

C:

int array[5];

??	??	??	??	??

0 4 20

Java:

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

5	00	00	00	00	00

0 4 20 24

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)

Example: the string “CSE351”

C:
(ASCII)

43	53	45	33	35	31	\0

0 1 4 7

Java:
(Unicode)

6	00	43	00	53	00	45	00	33	00	35	00	31

0 4 8 16

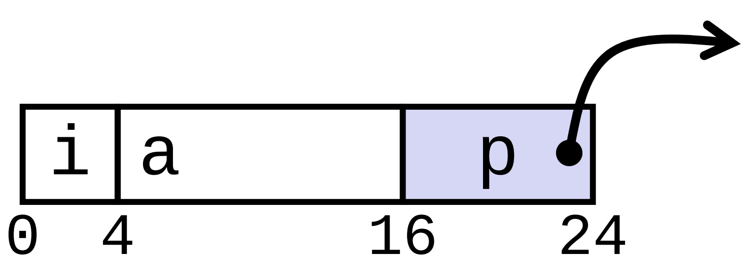
Data in Java: Objects

- 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;
};
```

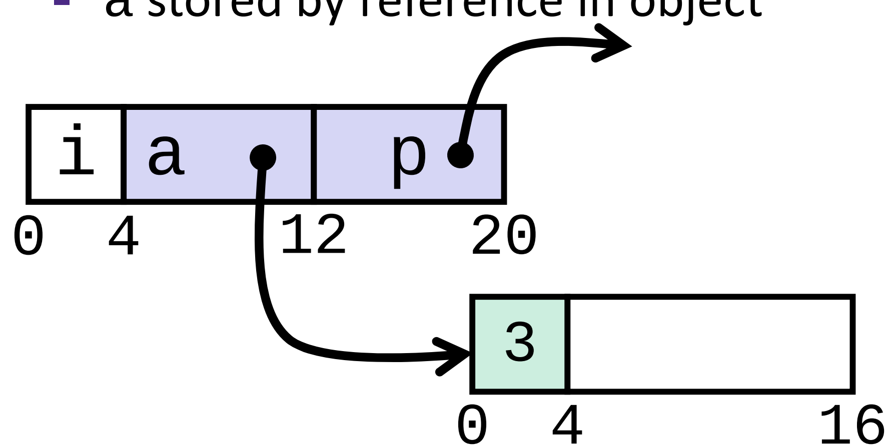
- a[] stored "inline" as part of struct



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

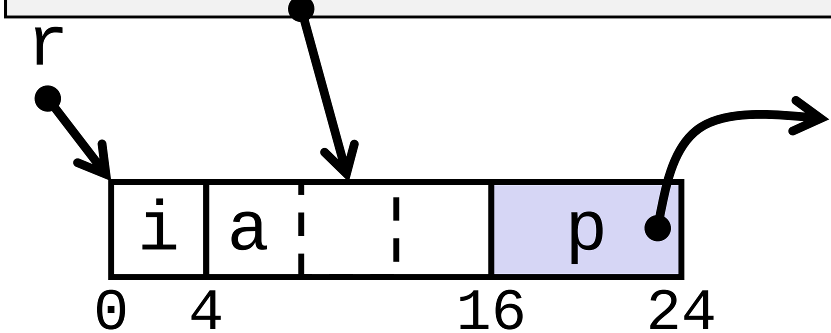
- Pointers in C can point to any memory address
- References in Java can only point to [the starts of] objects
  - Can only be dereferenced to access a field or element of that object

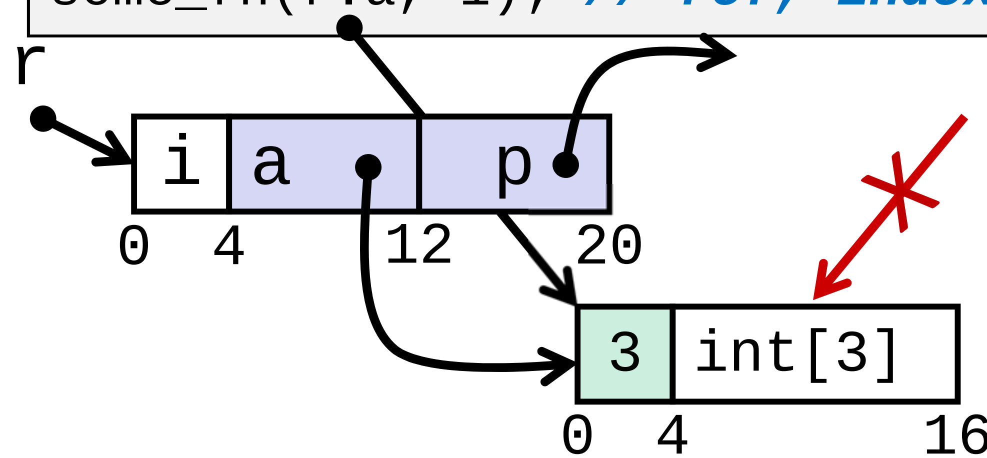
C:

```
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
```





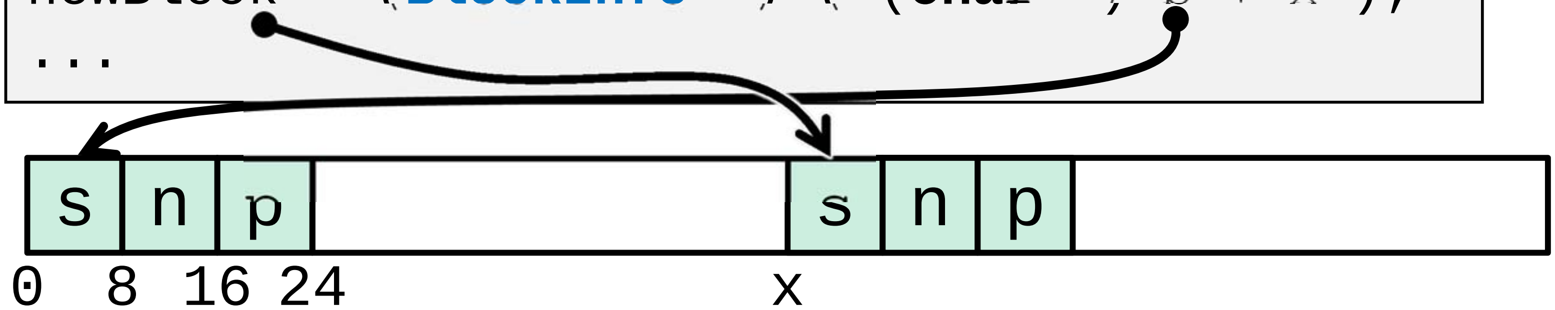
Casting in C (example from Lab 5)

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

```
struct BlockInfo {
        size_t sizeAndTags;
        struct BlockInfo* next;
        struct BlockInfo* prev;
};
typedef struct BlockInfo BlockInfo;
...
int x;
BlockInfo *b;
BlockInfo *newBlock;
...
newBlock = (BlockInfo *) ( (char *) b + x );
...
```

Cast b into char * to do unscaled addition

Cast back into BlockInfo * to use as BlockInfo struct



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;
```

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;
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```

```
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)
- `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();
...
```

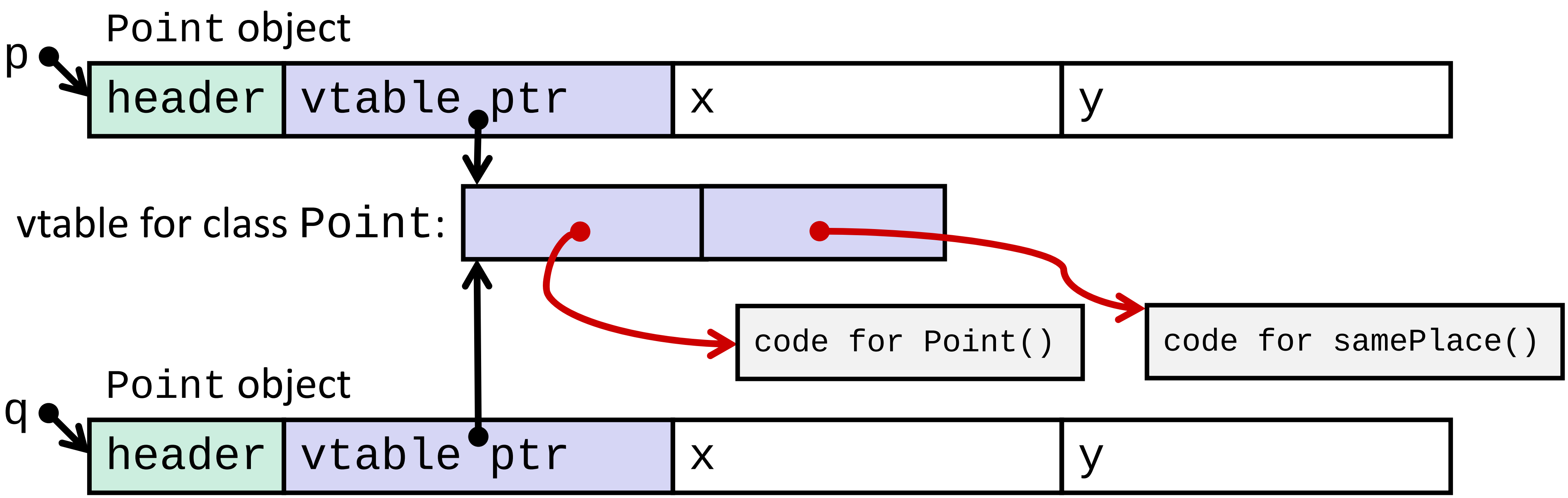
fields

constructor

method(s)

creation

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
- *Object header* : GC info, hashing info, lock info, etc.
  - Why no size?

Java Constructors

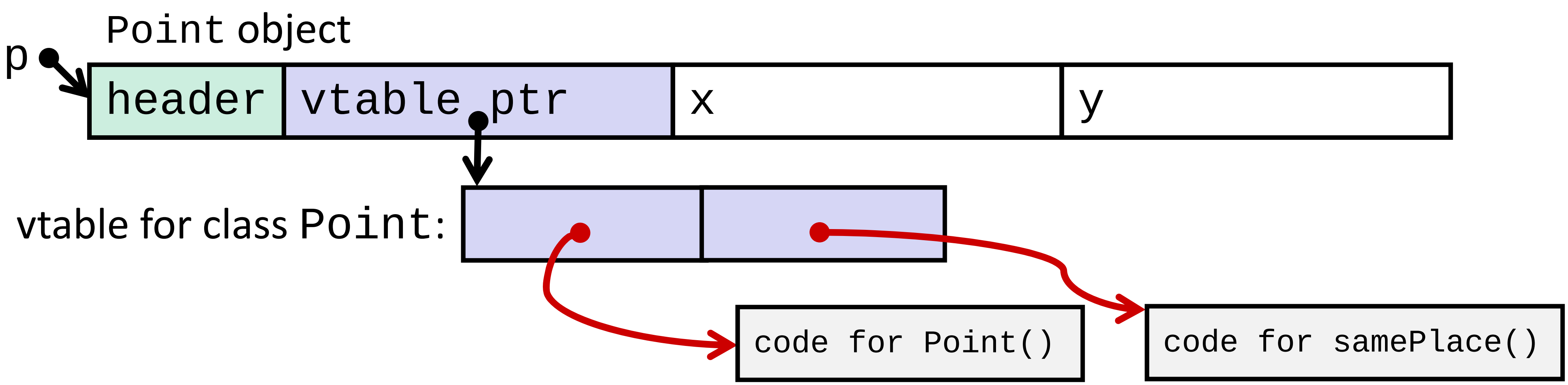
- **When we call new:** allocate space for object (data fields and references), initialize to zero/null, and run constructor method

Java:

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

C pseudo-translation:

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



Java Methods

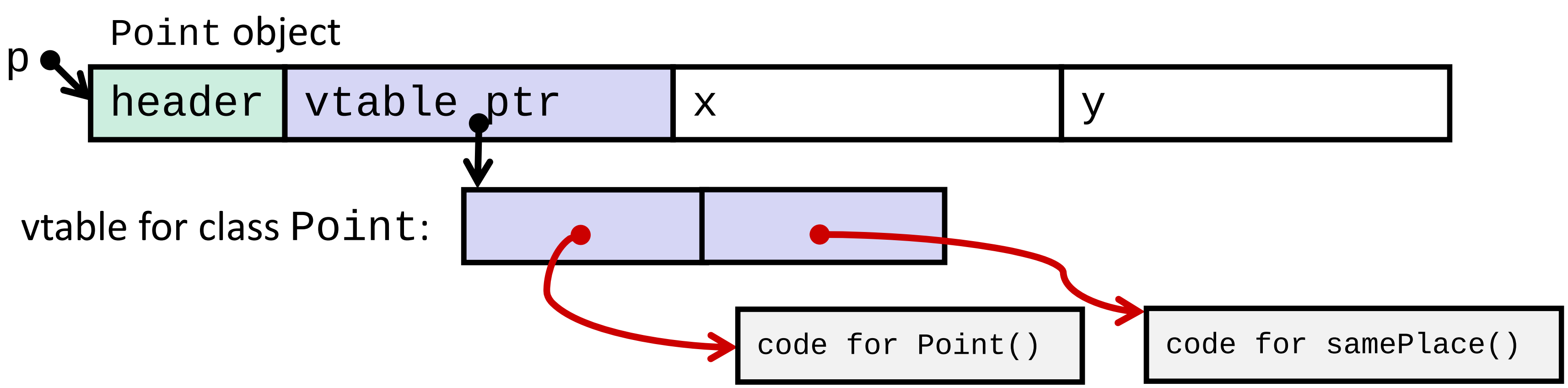
- Static methods are just like functions
- Instance methods:
  - Can refer to *this;*
  - Have an implicit first parameter for *this;* and
  - Can be overridden in subclasses
- The code to run when calling an instance method is chosen *at runtime* by lookup in the vtable

Java:

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

C pseudo-translation:

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



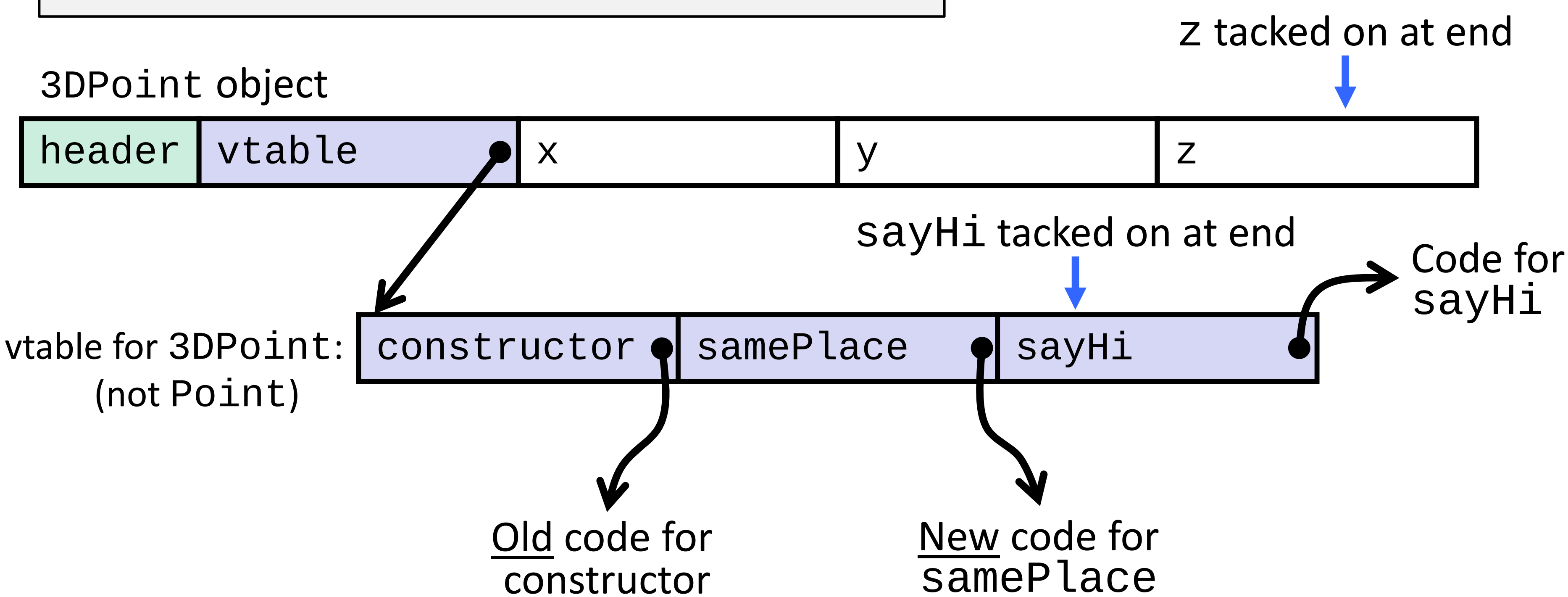
Subclassing

```
class 3DPoint extends Point {
    double z;
    boolean samePlace(Point p2) {
        return false;
    }
    void sayHi() {
        System.out.println("hello");
    }
}
```

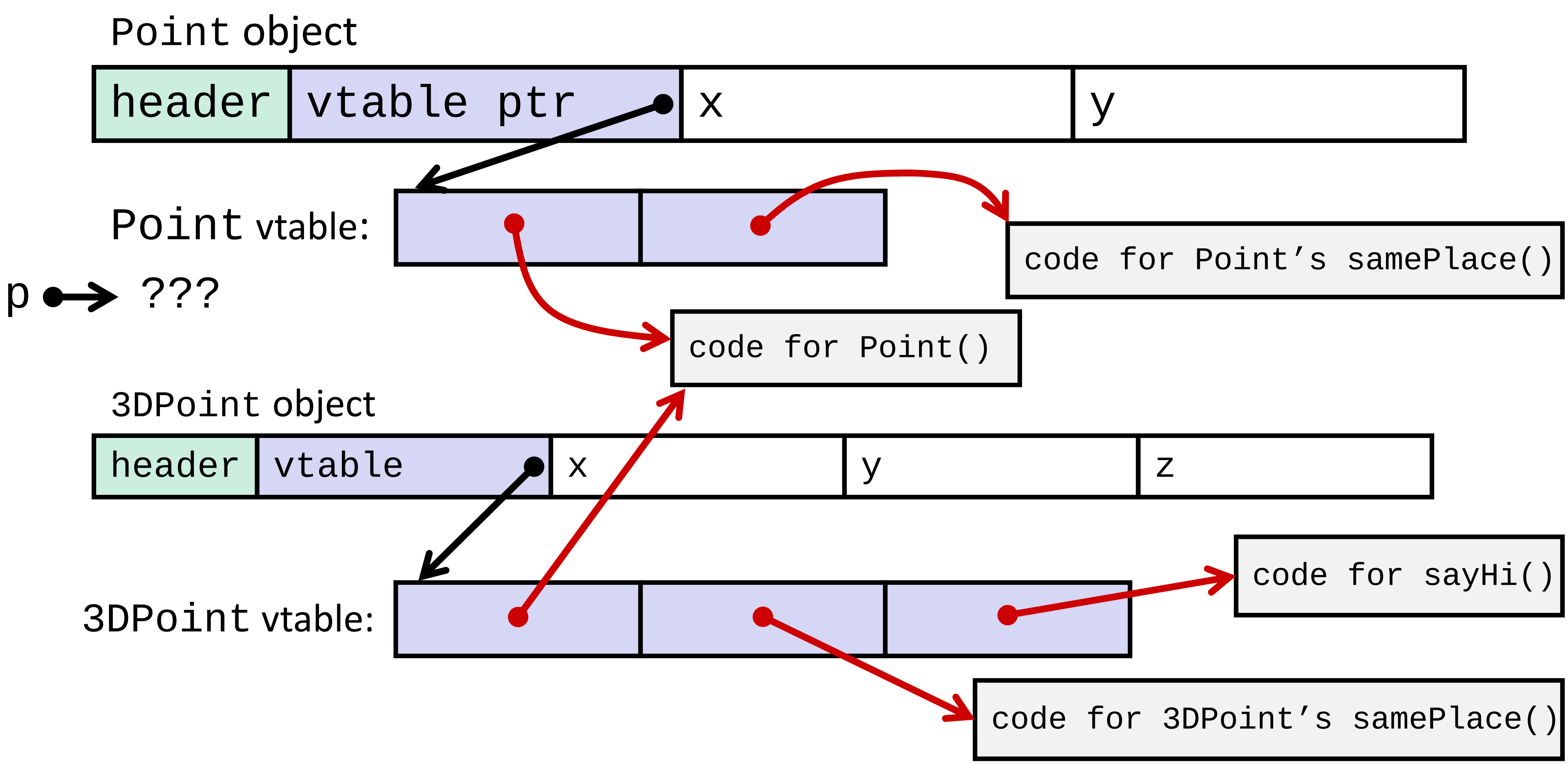
- Where does "`z`" go? At end of fields of `Point`
  - `Point` fields are always in the same place, so `Point` code can run on `3DPoint` objects without modification
- Where does pointer to code for two new methods go?
  - No constructor, so use default `Point` constructor
  - To override "`samePlace`", use same vtable position
  - Add new pointer at end of vtable for new method "`sayHi`"

Subclassing

```
class 3DPoint 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->vtable[1](p, q);
```

Ta-da!

- In CSE143, it may have seemed "magic" that an *inherited* method could call an *overridden* method
  - You were tested on this endlessly
- The "trick" in the implementation is this part:

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

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

Practice Question

- Assume: 64-bit pointers and that a Java object header is 8 B
- What are the sizes of the things being pointed at by `ptr_c` and `ptr_j`?

```
struct c {
  int i;
  char s[3];
  int a[3];
  struct c *p;
};
struct c* ptr_c;
```

```
class jobj {
  int i;
  String s = "hi";
  int[] a = new int[3];
  jobj p;
}
jobj ptr_j = new jobj();
```