Principles of Software Construction (Design for change, class level)

Starting with Objects (dynamic dispatch, encapsulation, entry points)

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Administrivia (1 / 4): Homework 1 is released

Full assignment is due January 30 (Monday).

Don’t panic, it’s a lot to figure out at first, and we know that.

- Setting up a new (to you) toolchain often involves roadbumps. This is why we released the HW so early: for recitation!
- We encourage you to iron out issues early, ask (publicly!) on Piazza, go to office hours.
- We also list additional language resources, and will cover more about the languages today/Tuesday/Wednesday.

Miscellaneous:

- The rubric is descriptive and intended to be clear.
- *Note the CI doesn’t test, it only check style*
  - And it only runs on code that changed
- The actual programming required is quite minimal!

Administrivia (2 / 4) : Reading, Office Hours, Waitlist

Reading on website for Tuesday. It's short. Expect a quiz.
Office hours are on the calendar and mostly accurate.

- That said: please Google the error message or other symptoms you're seeing and try a few things before asking us in OH or Piazza. This is a CENTRAL skill.

Reminder: if you have waitlist questions or are interested in switching sections, email Jenni Cooper: cooperj@andrew.cmu.edu

- Note: you may have to unregister from other classes that create schedule conflicts. Also from "easiest to get into" to "hardest to get into" the section list is: D, A, E, C, G, F, B

Administrivia (3 / 4) : Late day policy

- See syllabus on course web page for details
- 2 possible late days per deadline (some exceptions may be announced)
  - 5 total free late days for semester (+ separate 2 late days for assignments done in pairs)
  - 10% penalty per day after free late days are used
  - but we won't accept work 3 days late
- Extreme circumstances – talk to us

Administrivia (4 / 4) : Collaboration policy

- See course web page for details!
- We expect your work to be your own
- Do not release your solutions (not even after end of semester)
- Ask if you have any questions
- If you are feeling desperate, please reach out to us
  - Always turn in any work you've completed before the deadline
- We run cheating detection tools. Trust us, academic integrity meetings are painful for everybody

What did we talk about on Tuesday?

Tradeoffs?

```
void sort(int[] list, String order) {
   …
  boolean mustswap;
  if (order.equals("up")) {
    mustswap = list[i] < list[j];
  } else if (order.equals("down")) {
    mustswap = list[i] > list[j];
  }
  …
}
```

This is Java code!

```
void sort(int[] list, Comparator cmp) {
   …
  boolean mustswap;
  mustswap = cmp.compare(list[i], list[j]);
  …
}
interface Comparator {
  boolean compare(int i, int j);
}
class UpComparator implements Comparator {
  boolean compare(int I, int j) { return i<j; }}

class DownComparator implements Comparator {
```

Learning Goals

Develop familiarity with Java and Typescript syntax.

Explain the need to design for change and design for division of labor

Understand subtype polymorphism and dynamic dispatch

Use encapsulation mechanisms

Distinguish object methods from global procedures

Start a program with entry code

Today: Key Features that Support:

- **Design for Change** (flexibility, extensibility, modifiability)
- Design for Division of Labor
- Design for Understandability

Some basics.

Hello, world!

I know, it's corny.

Java

```java
class HelloWorld {
 public static void main(String[] args) {
          System.out.println("Hello world!");
 }
}
```

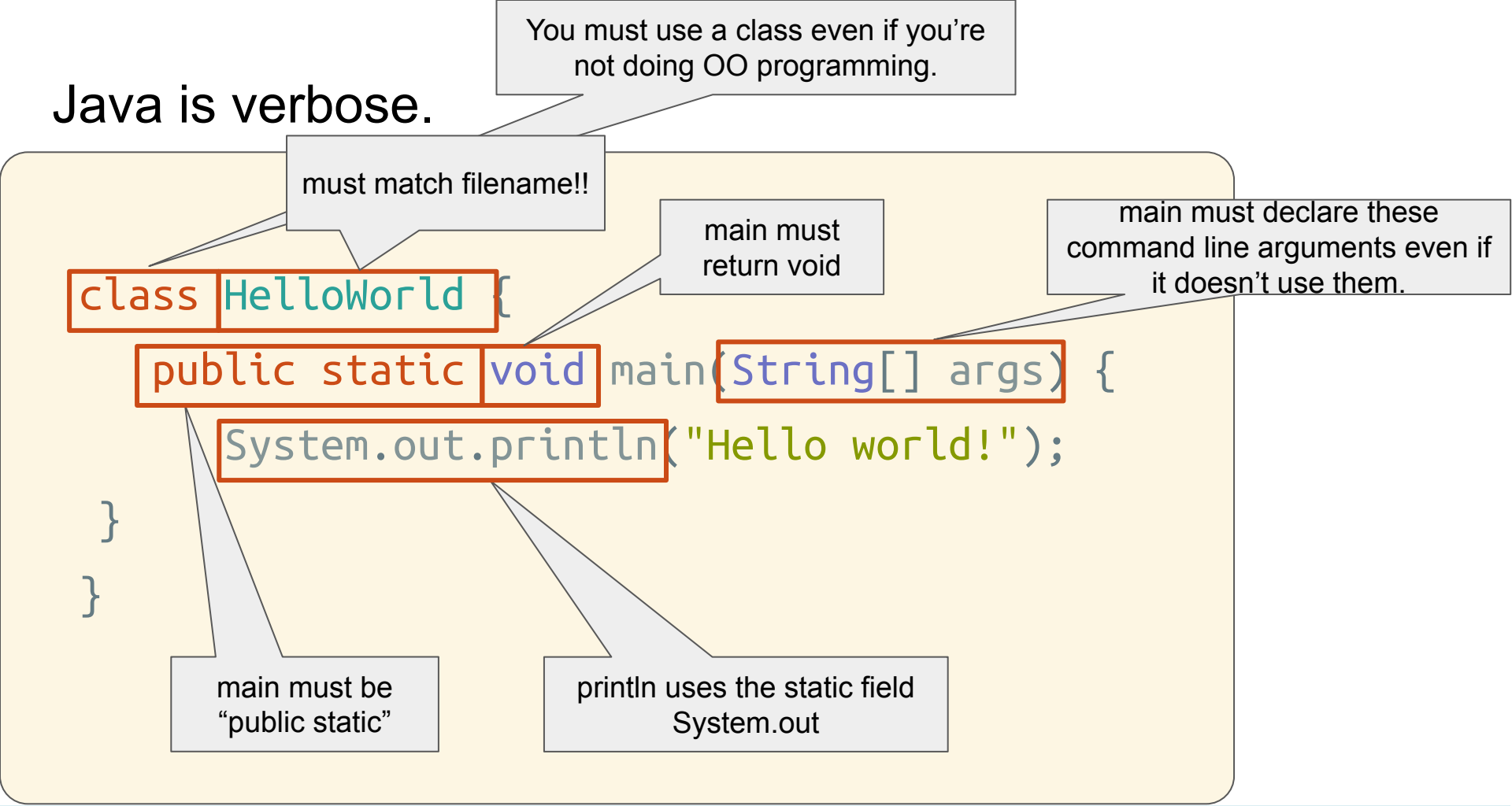
Typescript

```typescript
let message: string = "Hello, World!";
console.log(message);
```

Typescript is Javascript with types.

- Typescript is a strict superset of Javascript.
  - Javascript started as a browser-based scripting language, now it is widespread on both client- and server-side applications, and you can write standalone apps in it. It's reasonably general-purpose.
  - It's also *very* dynamic. Typescript adds a bit of discipline.
- Typescript adds optional static typing to javascript.
  - Step 1 on running a TS program is to compile it to javascript.
  - Existing javascript programs are valid typescript programs by definition.
  - The slides sometimes uses Type/javascript interchangeably.

Java is verbose.



Java and Javascript have 2-part type systems

Java Primitives	Javascript Primitives
`int, long,byte, short, char, float, double, boolean`	`null, undefined, boolean, number, string, symbol, bigint`

Primitive types are immutable and passed by value.

Both also have: Object, a non-primitive type.

- Object *references* are also passed by value to methods. We'll see this play out later.

Programming without Objects

Programming with primitives in Java looks a lot like any other imperative programming.

```java
public class TrailingZeros {
  public static void main(String[] args) {
    int i = Integer.parseInt(args[0]);
    System.out.println(trailingZerosInFactorial(i));
  }
  static int trailingZerosInFactorial(int i) {
    int result = 0; // Conventional name for return value
    while (i >= 5) {
      i /= 5;       // Same as i = i / 5; Remainder discarded
      result += i;
    }
    return result;
  }
}
```

This is JavaScript code!

Objects (JavaScript)

A program abstraction with internal state (data) and behavior (actions, methods)

Interact through messages (*invoking methods*)

- perform an action, update state (e.g., move)
- request some information (e.g., getSize)

```
const obj = {
    print: function() { console.log("Hello, world!"); }
}

obj.print()
// Hello, world!
```

Functions in an object are typically called *methods*

This is a *method invocation* (conceptually by sending a message to the object)

Objects can contain state

```
const obj = {
    v: 1,
    print: function() { console.log(this.v); },
    inc: function() { this.v++; }
}
obj.print()
// 1
obj.print()
// 1
obj.inc()
obj.print()
// 2
```

The object contains a variable *v*, called a *field*, to store state

Multiple methods in the object

This is JavaScript code!

Objects respond to messages, methods define *interface*

```
const obj = {
    v: 1,
    inc: function() { this.v++; },
    get: function() { return this.v; },
    add: function(y) { return this.v + y; }
}
obj.get() + 2
// 3
obj.add(obj.get()+2)
// 4
obj.send()
// Uncaught TypeError: obj.send is not a function
```

Calling a method that does not exist results in an error

This is TypeScript code!

Typescript and Java allow us to explicitly define interfaces

```
interface Counter {
    v: number;
    inc(): void;
    get(): number;
    add(y: number): number;
}
const obj: Counter = {
    v: 1,
    inc: function() { this.v++; },
    get: function() { return this.v; },
    add: function(y) { return this.v + y; }
};

obj.foo();
// Compile-time error: Property 'foo' does not exist
```

receiver

method name

v must be part of the interface in TypeScript. Ways to avoid this later.

The object assigned to *obj* must have all the same methods as the interface.

Yellow background is Java, Black is Typescript

Interfaces and Objects in Ja

```
interface Counter {
    int get();
    int add(int y);
    void inc();
}
Counter obj = new Counter() {
    int v = 1;
    public int get() { return this.v; }
    public int add(int y) { return this.v + y; }
    public void inc() { this.v++; }
};

System.out.println(obj.add(obj.get()));
// 2
```

```
interface Counter {
    v: number;
    inc(): void;
    get(): number;
    add(y: number): number;
}
const obj: Counter = {
    v: 1,
    inc: function() { this.v++; },
    get: function() { return this.v; },
    add: function(y) { return this.v + y; }
}
```

object without a class. This isn't very common, it just looks a lot like the TS.

Object-oriented language feature enabling flexibility

SUBTYPE POLYMORPHISM /

DYNAMIC DISPATCH

Subtype Polymorphism / Dynamic Dispatch

- An interface describes the API/way to interact with an object. It does NOT provide the implementation.
- There may be multiple implementations of an interface!
- Multiple implementations can coexist in the same program
- *Every object has its own data and behavior, internals can be very different*

This is Java code!

Classes as Object Templates

```
interface Point {
    int getX();
    int getY();
}
```

class as template for objects with Point interface

This is Java code!

Classes as Object Templates

```
interface Point {
    int getX();
    int getY();
}
class CartesianPoint implements Point {
    int x,y;
    CartesianPoint(int x, int y) {this.x=x; this.y=y;}
    int getX() { return this.x; }
    int getY() { return this.y; }
}
```

class as template for objects with Point interface

This is Java code!

Classes as Object Templates

```
interface Point {
    int getX();
    int getY();
}
class CartesianPoint implements Point {
    int x,y;
    CartesianPoint(int x, int y) {this.x=x; this.y=y;}
    int getX() { return this.x; }
    int getY() { return this.y; }
}
Point p = new CartesianPoint(3, -10);
```

class as template for objects with Point interface

Constructor initializes the object

Calling *constructor* of class to create object

This is TypeScript code!

Note that Typescript lets us do this, too! Remember this?

```
interface Counter {
    v: number;
    inc(): void;
    get(): number;
    add(y: number): number;
}
const obj: Counter = {
    v: 1,
    inc: function() { this.v++; },
    get: function() { return this.v; },
    add: function(y) { return this.v + y; }
}
obj.foo();
// Compile-time error: Property 'foo' does not exist
```

Here we create an object using an object literal, declaring fields and methods inside { curly braces }

This is Typescript code!

TS/JS also allow classes explicitly, similar to Java

```
interface Counter {
    v: number;
    inc(): void;
    get(): number;
    add(y: number): number;
}
class C implements Counter = {
    v = 1;
    inc () { this.v++; }
    get () { return this.v; }
    add (y : number) { return this.v + y; }
}
const obj = new C();
// …
```

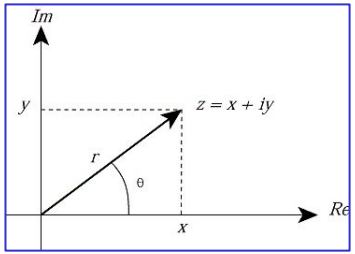
…but we can do things this way, too.

While using classes makes the code more similar to Java, object literals are used *all over* JS/TS, so it's worth being comfortable with them.

This is Java code!

Multiple Implementations of Interface

```
interface Point {
    int getX();
    int getY();
}
class PolarPoint implements Point {
    double len, angle;
    PolarPoint(double len, double angle)
        {this.len=len; this.angle=angle;}
    int getX() { return this.len * cos(this.angle);}
    int getY() { return this.len * sin(this.angle); }
    double getAngle() {…}
}
Point p = new PolarPoint(5, .245);
```



This is Java code!

Multiple Implementations of Interface

```
interface Point {
    int getX();
    int getY();
}
class MiddlePoint implements Point {
    Point a, b;
    MiddlePoint(Point a, Point b) { this.a = a; this.b = b; }
    int getX() { return (this.a.getX() + this.b.getX()) / 2; }
    int getY() { return (this.a.getY() + this.b.getY()) / 2; }
}
Point p = new MiddlePoint(new PolarPoint(5, .245),
                          new CartesianPoint(3, 3));
```

Works with a imple-mentations of Point

This is Java code!

Clients work with all implementations of Interface

```
interface Point {
    int getX();
    int getY();
}
r = new Rectangle() {
    Point origin;
    int width, height;
    void draw() {
    this.drawLine(this.origin.getX(), this.origin.getY(),
        this.origin.getX()+this.width, this.origin.getY());
    … // more lines here
    }
};
```

Works with all imple-mentations of Point

Subtype Polymorphism / Dynamic Dispatch

- An interface describes the API/way to interact with an object. It does NOT provide the implementation.
- There can/may be multiple implementations of any interface!
- Multiple implementations can coexist in the same program
- *Every object has its own data and behavior, internals can be very different*

This is Java code!

Points and Rectangles: Interface

```
interface Point {
    int getX();
    int getY();
}
interface Rectangle {
    Point getOrigin();
    int getWidth();
    int getHeight();
    void draw();
}
```

What are possible implementations of the Rectangle interface?

This is Java code!

Sets: Interface

```
interface IntSet {

    boolean contains(int element);

    boolean isSubsetOf(IntSet otherSet);

}
```

What are possible implementations of the IntSet interface?

This is Java code!

Programming against interfaces, not internals

```
interface Point {
    int getX();
    int getY();
    void moveUp(int y);
    Point copy();
}

Point p = …
int x = p.getX();
```

```
interface IntSet {
    boolean contains(
        int element);
    boolean isSubsetOf(
        IntSet otherSet);
}

IntSet a = …; IntSet b = …
boolean s = a.isSubsetOf(b);
```

Java Twist: Classes implicitly have Interfaces

Classes can be used as types, like interfaces

All (public) methods can be called

No alternative implementations of class type

Prefer interfaces over class types!

```
class PolarPoint implements Point {
    double len, angle;
    ...
    int getX() {…}
    int getY() {…}
    double getAngle() {…}
}
PolarPoint pp = new PolarPoint(5, .245);
Point p = new PolarPoint(5, .245);
pp.getAngle(); // okay
p.getAngle(); // compilation error
```

This is JavaScript code!

JavaScript and Classes

All methods of objects can be called

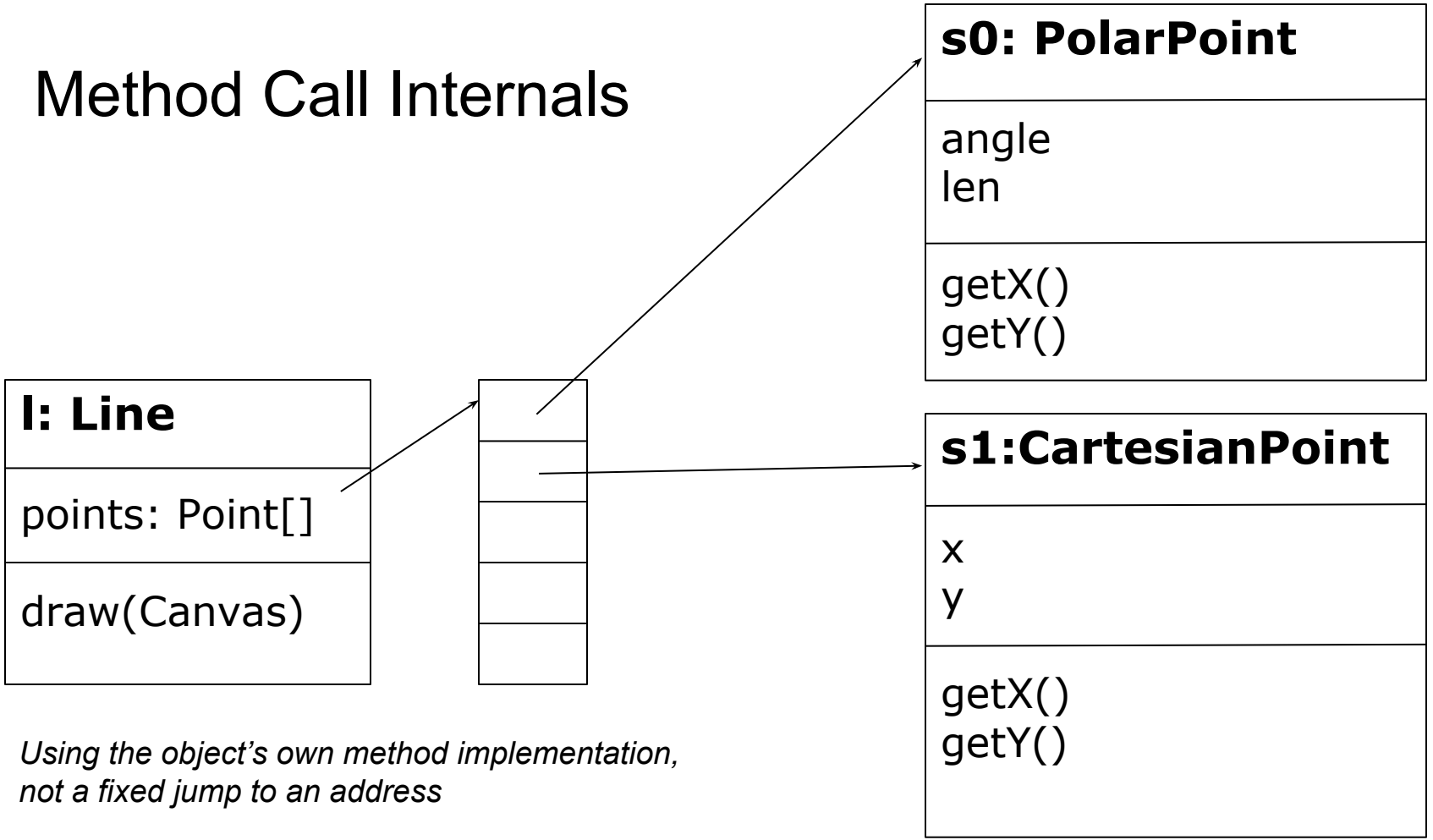
Objects with the same method can be called

No static checking by compiler; runtime error if method not exist

TypeScript added type system with interfaces

```
const pp = {
    len: 1, angle: 0,
    getX: function() {…}
    getAngle: function() {…}
}
const p = {
    x: 1, y: 0;
    getX: function() {…}
}
pp.getX(); p.getX(); // okay
pp.getAngle(); // okay
p.getAngle() // runtime error
```

Method Call Internals



Using the object's own method implementation, not a fixed jump to an address

Check your Understanding

This is Java code!

```
interface Animal {
    void makeSound();
}
class Dog implements Animal {
    public void makeSound() { System.out.println("bark!"); } }
class Cow implements Animal {
    public void makeSound() { moo(); }
    public void moo() {System.out.println("moo!"); } }
Animal x = new Animal() {
    public void makeSound() { System.out.println("chirp!"); }}
x.makeSound();

Animal d = new Dog();
d.makeSound();
Animal b = new Cow();
b.makeSound();
b.moo();
```

Check your Understanding

```
interface Animal {
    void makeSound();
}
class Dog implements Animal {
    public void makeSound() { System.out.println("bark!"); } }
class Cow implements Animal {
    public void makeSound() { moo(); }
    public void moo() {System.out.println("moo!"); } }
Animal x = new Animal() {
    public void makeSound() { System.out.println("chirp!"); }}
x.makeSound(); // “chirp”

Animal d = new Dog();
d.makeSound(); // “bark!”
Animal b = new Cow();
b.makeSound(); // “moo!”
b.moo(); // compile-time error
```

```
Animal a = new Animal();
a.makeSound(); // compile-time error
```

Dynamic Dispatch

Object Methods vs Global Functions/Procedures

This is Typescript code!

Flexibility of dynamic dispatch (JavaScript)

Each object decides implementation,
client does not care

Method is decided at runtime

Only single implementation of global function (and module)

```
// top-level function
function movePoint(p, x, y) { ... }

// create object, implementation unknown
const p = createPoint(...)

// call object's method
// object determines implementation
p.move(3, 5);

// single global implementation
// less flexibiliy
movePoint(p, 3, 5)
```

This is Java code!

Flexibility of dynamic dispatch (Java)

Each class decides implementation, client does not care

The "`main`" function is defined this way!

Static methods are *global functions*, only single copy exists; class provides only namespace

Java does *not* allow global functions outside of classes

```
interface Point {
    void move(int x, int y) { ... }
}
class Helper {
    static void movePoint(Point p,
                          int x, int y) {...}
}

Point p = createPoint(...);
// dynamic dispatch, object's method
p.move(4, 5);

// single global method, less flexible
Helper.movePoint(p, 4, 5);
```

Dynamic Dispatch

Benefits of Dynamic Dispatch

Discussion Dynamic Dispatch

- A user of an object does not need to know the object's implementation, only its interface
- All objects implementing the interface can be used interchangeably
- Allows flexible **change** (modifications, extensions, reuse) later without changing the client implementation, even in unanticipated contexts

Design for Change!

Why multiple implementations?

Different performance

- Choose implementation that works best for your use

Different behavior

- Choose implementation that does what you want
- Behavior must comply with interface spec (“contract”)

Often performance and behavior both vary

- Provides a functionality – performance tradeoff
- Example: HashSet, TreeSet

This is Java code!

```
interface Order {
  boolean lessThan(int i, int j);
}

class AscendingOrder implements Order {
  public boolean lessThan(int i, int j) { return i < j; }
}
class DescendingOrder implements Order {
  public boolean lessThan(int i, int j) { return i > j; }
}

static void sort(int[] list, Order order) {
  …
  boolean mustSwap =
    order.lessThan(list[j], list[i]);
  …
}
```

Historical note: simulation and the origins of OO programming

Simula 67 was the first object-oriented language

Developed by Kristin Nygaard and Ole-Johan Dahl at the Norwegian Computing Center

Developed to support discrete-event simulation

- Application: operations research, e.g. traffic analysis
- Extensibility was a key quality attribute for them
- Code reuse was another

Dahl and Nygaard at the time of Simula's development

Information Hiding

Encapsulation

Encapsulation / Information hiding

- Well designed objects project internals from others
  - both internal state and implementation details
- Well-designed code hides all implementation details
  - Cleanly separates interface from implementation
  - Modules communicate only through interfaces
  - They are oblivious to each others' inner workings
- Hidden details can be changed without changing client!
- Fundamental tenet of software design

How to hide information?

```java
class CartesianPoint {
    int x,y;
    CartesionPoint(int x, int y) {
        this.x=x;
        this.y=y;
    }
    int getX() { return this.x; }
    int getY() { return this.y; }
    int helper_getAngle();
}
```

```typescript
const point = {
    x: 1, y: 0,
    getX: function() {…}
    helper_getAngle:
        function() {…}
}
```

This is Java code!

Java: Access modifier to hide private details

```
public class PolarPoint implements Point {
    private double len, angle;
    private int xcache = -1;
    public PolarPoint(double len, double angle)
        {this.len=len; this.angle=angle; computeX(); }
    public int getX() { return xcache; }
    public int getY() {...}
    private int computeX() {
        xcache = this.len * cos(this.angle);
    }
}
```

This is Java code!

Java: Access modifier to hide private details

```
public class PolarPoint implements Point {
    private double len, angle;
    private int xcache = -1;
    public PolarPoint(double len, double angle)
        {this.len=len; this.angle=angle; computeX(); }
    public int getX() { return xcache; }
    public int getY() {...}
    private int computeX() {
        xcache = this.len * cos(this.angle);
    }
}
PolarPoint p = new PolarPoint(5, .245);
```

This is Java code!

Java: Access modifier to hide private details

```
public class PolarPoint implements Point {
    private double len, angle;
    private int xcache = -1;
    public PolarPoint(double len, double angle)
        {this.len=len; this.angle=angle; computeX(); }
    public int getX() { return xcache; }
    public int getY() {...}
    private int computeX() {
        xcache = this.len * cos(this.angle);
    }
}
PolarPoint p = new PolarPoint(5, .245);
p.xcache // type error, trying to access private member
p.computeX(); // type error, private method
```

Benefits of information hiding

Decouples the objects that comprise a system: Allows them to be developed, tested, optimized, used, understood, and modified in isolation

Speeds up system development: Objects can be developed in parallel

Eases **maintenance burden**: Objects can be understood more quickly and debugged with little fear of harming other modules

Enables effective **performance tuning**: “Hot” classes can be optimized in isolation

Increases software **reuse**: Loosely-coupled classes often prove useful in other contexts

Java: Information hiding with interfaces

```
public interface Point { … }
private class PolarPoint implements Point {
    private double len, angle;
    public void computeX() { … }
    public int getX() { return xcache; }
}
```

This is Java code!

Java: Information hiding with interfaces

```
public interface Point { … }
public class Factory {
    private class PolarPoint implements Point {
    private double len, angle;
    public void computeX() { … }
    public int getX() { return xcache; }
    }
    public Point createPoint(int x, int y) {
    return new PolarPoint(x, y);
    }
}
```

This is Java code!

Java: Information hiding with interfaces

```
public interface Point { … }
public class Factory {
    private class PolarPoint implements Point {
    private double len, angle;
    public void computeX() { … }
    public int getX() { return xcache; }
    }
    public Point createPoint(int x, int y) {
    return new PolarPoint(x, y);
    }
}
Point p = new Factory().createPoint((5, .245);
p.computeX(); // type error, method not in interface Point
```

Principles of Information hiding with interfaces (Java)

Declare variables using interface types, not class types

- Client can use only interface methods
- Fields and implementation-specific methods not accessible from client code

Use `private` for fields and internal methods to restrict access also in class types; accessible only from within same class

Interface methods must be `public`.

Other modifiers `protected` (for inheritance, more later) and package

JavaScript: Closures for Hiding

All methods and fields are public, no language constructs for access control

TypeScript added them, so it's quite similar to Java!

In JS: Encoding hiding with closures (the "module pattern")

```
function createPolarPoint(len, angle) {
    let xcache = -1;
    let internalLen=len;
    function computeX() {…}
    return {
        getX: function() {
            computeX(); return xcache; },
        getY: function() {
            return len * sin(angle); }
    };
}
const pp = createPolarPoint(1, 0);
pp.getX(); // works
pp.computeX(); // runtime error
pp.xcache // undefined
pp.len // undefined
```

This is Javascript code!

Closures

In nested functions/classes, inner functions/classes can access variables and arguments of outer functions

Frequently used in JavaScript

In Java: Closures for nested classes and lambda functions, but outer variables need to be final

```
function a(x) {
    const z = 3;
    function b(y) {
    x++;
    console.log(x+y+z);
    }
    b(5);
    console.log(x);
}
a(3);
// 12
// 4
```

This is Typescript code!

Type/JavaScript: Modules

Information hiding at the file level!

Decide what functions, variables, classes to keep private in a file

Historically, all code was in one file; later, multiple competing module systems
Standardized since ECMAScript 2015 (ES6)

In general, it is good practice to use files/modules to organize your code and do this kind of information hiding.

import interfaces / functions from other modules

```
import { f, b }
    from 'dir/file'
import fs from 'fs'

interface Point { ... }

function createP(a, b) {...}

function helper() { ...  }

export { Point, createP }
```

decide what functions / interfaces can be access from other modules

Java: Packages and classes

Each class is in a file with same name; classes grouped in packages (directories)

Fully qualified name = Package + Class name (e.g. `java.lang.String`)

All public classes from all packages can be used

Imports simplify names

```
import me.util.PolarPoint;
PolarPoint p = new PolarPoint(...);
```

instead of

```
me.util.PolarPoint p = new me.util.PolarPoint(...);
```

Best practices for information hiding

- Carefully design your API
- Provide only functionality required by clients
  - All other members should be private / hidden through interfaces or closure
- *You can always make a private member public later (or export an additional method) without breaking clients, but not vice-versa!*

Objects do not do anything on their own; they wait for method calls…

Starting a Program

This is Typescript code!

Starting a Program: Javascript

Objects do not do anything on their own, they wait for method calls

Every program needs a starting point, or waits for events

```
// start with: node file.js
function createPrinter() {
    return {
        print: function() { console.log("hi"); }
    }
}
const printer = createPrinter();
printer.print()
// hi
```

Defining interfaces, functions, classes

Starting:
Creating objects and calling methods

This is Java code!

Starting a program: Java

All Java code is in classes, so how to create an object and call a method?

Special syntax for *main* method in class (`java X` calls *main* in *X*)

```
// start with: java Printer
class Printer {
    void print() {
    System.out.println("hi");
    }
    public static void main(String[] args) {
    Printer obj = new Printer();
    obj.print();
    }
}
```

in Java, everything is a class

main must be public and static

Main method to be executed, here used to create object and invoke method

Static methods belong to class not the object, generally avoid them

Summary

Need to divide work, divide and conquer

Objects encapsulate state and behavior

Static/global functions: Only a single function provided, less flexibility

Dynamic dispatch: Each object's own method is executed, multiple implementations possible

Encapsulation: Hide object internals behind interface

Tuesday: *how to actually run code in an IDE.*