CSCI-UA 490 Spring 2020

JavaScript

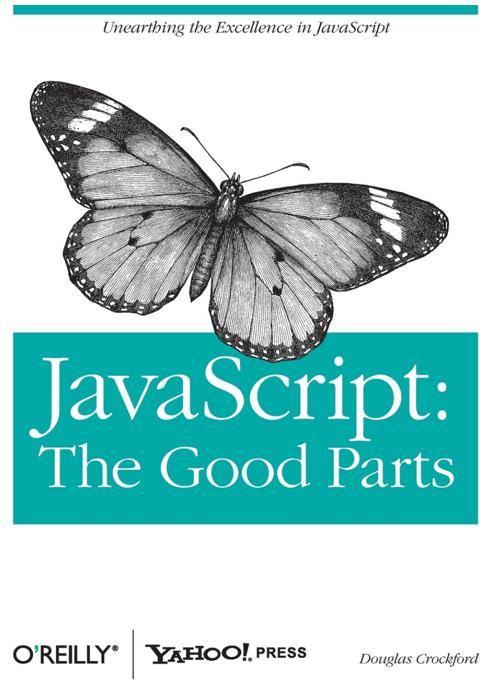
"This class in a nutshell"

Edward Z. Yang

Why JavaScript?

If we want to be concrete, we have to single out a language. CS242 chooses JavaScript as our exemplar. It is certainly not the theoretically most pure language. But its core (the good part) is built off of some of the most important fundamental ideas we want to cover in this course.

- Lingua franca of the Internet
- Illustrates many core concepts
- Interesting trade-offs and consequences



Old iterations of this course used to use Scheme to fill the same role as JavaScript. However, we've found students are far more familiar with JS than Scheme (for obvious reasons), and the two languages have a lot more in common than you might think...

JavaScript will be the setting in which we talk about these highlighted concepts.

JavaScript

Say more with less!

First-class functions

Pattern matching

Type inference

Type classes

Monads

Continuations

Reliability and Reuse!

Objects & Inheritance

Modules

Generics

Cross-cutting concerns

Memory management

Concurrency (ish)

As a preview...

Haskell

Say more with less!

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Say more with less!

First-class functions Pattern matching

Type inference Type classes

Monads Continuations

Reliability and Reuse!

Objects & Inheritance C++

Modules Generics Java

Cross-cutting concerns

Memory management Concurrency

This lecture in a nutshell:

- A Little History
- JS in a nutshell
  - a little lambda calculus
- JS through 490

May 1995

In the spring of 1995, Netscape had captured more than 90% of the browser market share, rebuffing Microsoft's buyout attempt. Java was the hot new language, and Netscape wanted a new scripting language in their browser to compete. They asked Brendan Eich to do an "HTML scripting language"... but

it had to look like Java!

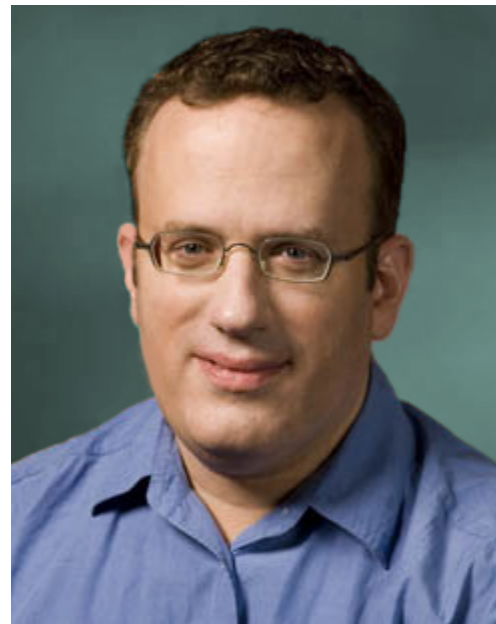
We need an Internet scripting language for our browser!

Can I use Scheme?

No! It has to look like Java.

marketing deal

Brendan Eich



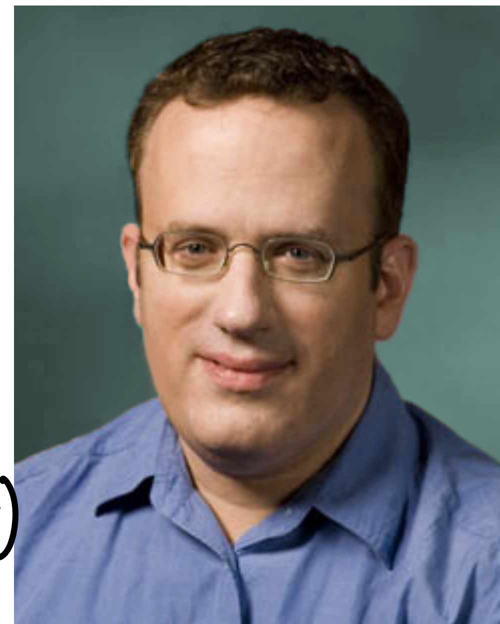
One week later...

Brendan hacked up a prototype in a week, and they spent the rest of the year embedding it in the browser. Mistakes in the language design were frozen early...

Here's a hacked up JS prototype!

Great! Ship it!

(It took another year to actually embed it in the browser)



Brenden Eich (ICFP 2005)

Design Goals

- Make it easy to copy/paste snippets of code
- Tolerate "minor" errors (missing semicolons)
- Simplified onclick, onmousedown, etc., event handling, inspired by HyperCard
- Pick a few hard-working, powerful primitives
  - First class functions for procedural abstraction
  - Objects everywhere, prototype-based
- Leave all else out!

Functions (based off Lisp/Scheme)

```
function(x) {return x+1;}
```

JavaScript as a language ecosystem has a lot of moving parts (the web APIs, etc), but JavaScript at its core is only two ideas. First, functions are first class values which can be specified anoymously and passed around as values; second, that objects are simply maps of strings to values (which could be functions.)

Objects (based off Smalltalk/Self)

```
var pt = {x:10,
          move: function(dx) {
                  this.x += dx}}
```

Functions = Full Lexical Closures

First class functions are implemented as full lexical closures: a function definition "captures" variables in its context, which can be used if the function is called later. In this example, the argument x is captured by the inner function (with its value equal to 2), which we can see when we call g later.

```
function curriedAdd(x) {
    return function(y) {return x+y;}
}
g = curriedAdd(2);
console.log(g(3)); // 5
console.log(g(5)); // 7
```

Functions = Full Lexical Closures [Eich]

With lexical closure in an untyped language, you can even do goofy things like define the Y combinator. The Y combinator comes from the lambda calculus, and is a way of implementing recursive functions "purely with functions".

```
function Y(g) {
  return function (f) {return f(f);}(
    function (f) {return g(function(x) {
      return f(f)(x);  }); }); }

var fact = Y(function (fact) {
    return function (n) {
        return (n <= 2) ? n : n * fact(n-1); }});

console.log(fact(5));  // 120
```

First-class functions and closures matter

First-class functions were something that set apart JavaScript from the other competing languages at the time (Tcl, Perl, Python, Java, VBScript). You REALLY want first-class functions if you want to easily script event handlers.

Event handlers in HTML DOM:

easy to use ⇒ first class functions

```
setTimeout(function() { alert("f"); }, 200)
```

Lack of closures hard to work around

(e.g. Java anonymous inner classes)

Closures ~~a~~ the mechanism for information hiding

Closures are in fact the ONLY mechanism in JavaScript that can be used for information hiding (although browser vendors perennially get requests for the ability to access the variables inside a closure. Eek!)

[Eich]

Detour: Lambda calculus

Prelude to Lambda Calculus lecture

Eventually in this course, we are going to talk about the lambda calculus, but here is a taster. The lambda calculus is a notation for representing function definition, using the lambda.

Expressions

$$x+y \qquad x+2*y+z$$

Teaching note: the parentheses here are important! Lambda calculus is unfamiliar syntax and explicitly parenthesizing everything makes it easier for students to see how things group together.

Functions

$$\lambda x.\,(x+y) \qquad \lambda z.\,(x+2*y+z)$$

Functions are defined using the lambda notation. \x. (x + y) reads as "a function taking an argument x, which returns x + y." Application is done by juxtaposition; (\x. x) 2 reads as, "Apply \x. x with arg 2."

Application

$$(\lambda x.\,(x+y))\,(3) \Rightarrow 3+y$$

Note: in text I will use backslash \ to represent lambda.

$$(\lambda z.\,(x+2*y+z))\,(5) \Rightarrow x+2*y+5$$

Application operates by *substituting* each occurrence of the variable with the argument, e.g., in the first expression, we replace x with 3.

Higher-order functions

that's function composition!

Given a function f, return $f \circ f$

$$\lambda f.(\lambda x.(f\ (f\ x)))$$

How does this work?

So in the lambda calculus, you can easily define higher order functions: that is, functions which return functions. For example, you can define the function that takes a function as an argument, and returns a new function equivalent to applying that function *twice*.

$$(\lambda f.(\lambda x.(f\ (f\ x))))\ (\lambda y.(y+1))$$

Here is an example to demonstrate how this actually works.

Higher-order functions

that's function composition!

Given a function f, return f∘f

$\lambda f.(\lambda x.(f\ (f\ x)))$

How does this work?

$$(\lambda f.(\lambda x.(f\ (f\ x))))(\lambda y.(y+1))$$

The first thing we do is reduce the first function application, replacing all occurrences of f with (\y. y + 1)

Higher-order functions

that's function composition!

Given a function f, return $f \circ f$

$$\lambda f.(\lambda x.(f\ (f\ x)))$$

How does this work?

$$\lambda x.\big((\lambda y.(y+1))\ ((\lambda y.(y+1))\ x)\big)$$

Higher-order functions

that's function composition!

Given a function f, return f∘f

$$\lambda f.(\lambda x.(f\ (f\ x)))$$

How does this work?

$$\lambda x.((\lambda y.(y+1))\ ((\lambda y.(y+1))\ x))$$

Now that we have a new expression, we can pick another set of the expressions to reduce. Here, we have decided to apply the function (\y. y + 1) with the argument x.

Higher-order functions

that's function composition!

Given a function f, return $f \circ f$

$$\lambda f.(\lambda x.(f\ (f\ x)))$$

How does this work?

$$\lambda x.((\lambda y.(y+1))\ (x+1))$$

That gives us x+1. Now we do it again...

Higher-order functions

that's function composition!

Given a function f, return $f \circ f$

$$\lambda f.(\lambda x.(f\ (f\ x)))$$

How does this work?

$$\lambda x.((x+1)+1)$$

And we get the function that adds TWO to its argument, which is simply the function that adds one to its argument, twice!

Higher-order functions in Javascript

Given a function f, return f∘f

```
function (f) { return function (x) {
      return f(f(x)); }}
```

JavaScript supports these higher order functions! The syntax is a little more cumbersome than the lambda calculus, but you can define and return functions just as you do in the lambda calculus.

Objects

As I stated earlier, the second big idea of JavaScript is objects. We said previously said that objects are just maps of strings to values. So what are methods? Well, they are simply *function-valued properties*: values which happen to be functions!

[Eich]

Objects are maps of strings to values...

```
var obj = new Object;
obj["prop"] = 42;        (obj.prop)
obj["0"] = "boo";        (obj[0])
```

...so methods are function-valued properties

```
obj.frob = function (n) { this.prop += n; }
obj.frob(6);   ⇒ obj.prop == 48
```

Objects (Self influence)

[Eich]

Smalltalk dialect

Function to construct an object

```
function Car(make, model) {
    this.make=make;
    this.model=model; }
myCar = new Car("Porsche", "Boxter");
```

Like Self, an object oriented Smalltalk dialect that came before it, objects in JS are created using the "new" keyword with a function. The function has "this" set to the newly created object.

All functions have prototype property

```
Car.prototype.color = "black"
old = new Car("Ford", "T")
myCar.color = "silver"
```

⇒ default

⇒ black

⇒ override color

JavaScript has *prototype-based inheritance*; which allows objects to defer to a "parent" object if a value is not defined.

More about "this"

Prelude to lecture on objects

We used this in a few of the examples. If you have programmed in Java or another OO language, the this parameter seems to make sense: it's just the object the method belongs to. But given what we've stated further, this idea merits further examination. It is not as simple as that!

Intuitively, this points to the object which has the function as a method

```
var o = {x:10,
         f:function() {return this.x}}

o.f();
```

⇒ 10

It is bound upon method invocation.

(but methods are just fields that are functions? More complexity)

More goofiness

For example, we stated that methods are function valued fields. As functions are first-class, we can assign the method of an object to its own variable. When we run it, something unexpected happens! And if we subsequently set a global variable, something even more surprising happens!

```
var o = {x:10,
         f:function(){return this.x}}
g = o.f
g()        => undefined
x = 20        (set global property)
g()        => 20
```

(What is happening is that this is bound by a "method invocation", which does not occur when we just call g(). Furthermore, if you don't make a method invocation, this defaults to the top-level window object, which is where all global properties get set.)

More and more goofiness

nested function

```
var o = {x:10,
  f:function() {
    function g() {
      return this.x;
    }
    return g();
  }}

x=20;

o.f();  ⇒ 20
```

Indeed, the this keyword is very strange. Consider this example, where it would seem this would refer to object o, but it does not. The goal of this class is to avoid falling into a pit of learned helplessness when strange things happened. Things happen for reasons, and if you know the conceptual principles operating behind the scenes, it will be easier to understand behavior in edge cases.

GOAL

Learn the conceptual principles so you can anticipate and understand language complexity.

~~490~~ language features in JS

- Stack memory management
- Closures
- Exceptions
- Continuations
- Objects
- Garbage collection
- Concurrency (though not parallelism*)

At this point, we'll just quickly preview all of the topics that we are going to discuss in CSCI-UA 490, under the lens of JavaScript.

Stack memory management

```
function f(x) {
    var y = 3;
    function g(z) { return y+z; }
    return g(x);
}
var x = 1; var y = 2;
f(x) + y        ⇒ 6
```

(You take this for granted...
but it wasn't always this way!)

Closures

(Return fn from fn call)

```
function f(x) {
    var y = x;
    return function(z) { y += z; return y; }
}
var h = f(5);
h(3);
```

⇒ 8

Exceptions

```
try {
    throw "Error2";
} catch (e if e == "Error1") {
    // do something
} catch (e if e == "Error2") {
    // do something else
} catch (e) {
    // catch all
}
```

Continuations "Callback hell"

```
button.onMouseDown = function(event) {
    if (event.button == 1) {
        setTimeout(function() {...}, 200);
    } else {
        setTimeout(function() {...}, 300);
    }
}
```

Objects

- → Dynamic lookup
- → Encapsulation
- → Subtyping ← clearer in a typed language!
- → Inheritance

Garbage collection

2 No GC! Memory reclaimed when page changed.

3 Reference counted

4 Mark-and-sweep collector

Concurrency

JavaScript is single threaded

but cooperatively concurrent

The Big Ideas

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Type classes
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Cross-cutting concerns

Memory management
Concurrency