CS 152: *Programming Language Paradigm*

# ES6 JavaScript, Metaprogramming, & Object Proxies

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# Fixing JavaScript

- ECMAScript committee formed to carefully evolve the language.
  - "Don't break the web."
- Involved big players in JS world:
  - Google, Microsoft, Apple, Mozilla, Adobe, and many more

# ECMAScript Schism

- ECMAScript 4 was divisive
- A group broke off to create ECMAScript 3.1
  - more minor updates
  - later became ECMAScript 5
- Adobe left the fold

# Strict Mode

- Turns anti-patterns into errors:
  - Variables must be declared.
  - Using **`with`** not allowed.
  - Many others.
- To use, add **`"use strict";`** (including quotes) to the top of your function or file.
  - Why in a string?

# Forget `var`, variables are global

```
function swap(arr,i,j) {
  tmp = arr[i]; arr[i] = arr[j]; arr[j] = tmp;
}
function sortAndGetLargest (arr) {
  tmp = arr[0]; // largest elem
  for (i=0; i<arr.length; i++) {
    if (arr[i] > tmp) tmp = arr[i];
    for (j=i+1; j<arr.length; j++)
      if (arr[i] < arr[j]) swap(arr,i,j);
  }
  return tmp;
}
var largest = sortAndGetLargest([99,2,43,8,0,21,12]);
console.log(largest); // should be 99, but prints 0
```

# But with "use strict", the error is detected.

```
"use strict";
function swap(arr,i,j) {
  tmp = arr[i]; arr[i] = arr[j]; arr[j] = tmp;
}
function sortAndGetLargest (arr) {
  tmp = arr[0]; // largest elem
  for (i=0; i<arr.length; i++) {
    if (arr[i] > tmp) tmp = arr[i];
    for (j=i+1; j<arr.length; j++)
      if (arr[i] < arr[j]) swap(arr,i,j);
  }
  return tmp;
}
var largest = sortAndGetLargest([99,2,43,8,0,21,12]);
console.log(largest); // should be 99, but prints 0
```

```
$ node sort.js
/Users/taustin/temp/sort.js:6
  tmp = arr[0]; // largest elem
      ^

ReferenceError: tmp is not defined
    at sortAndGetLargest (/Users/taustin/temp/sort.js:6:7)
    at Object.<anonymous> (/Users/taustin/temp/sort.js:14:15)
    at Module._compile (module.js:652:30)
    at Object.Module._extensions..js (module.js:663:10)
    at Module.load (module.js:565:32)
    at tryModuleLoad (module.js:505:12)
    at Function.Module._load (module.js:497:3)
    at Function.Module.runMain (module.js:693:10)
    at startup (bootstrap_node.js:191:16)
    at bootstrap_node.js:612:3
$
```

# ES6 Harmony: Can't we all just get along?

- ECMAScript 6 (ES6) Harmony
  - Later renamed ECMAScript 2015
- New features:
  - classes
  - block scoping
  - arrow functions (lambdas)
  - promises
  - proxies

`let` is the new `var`

```
function makeListOfAdders(lst) {
  var arr = [];
  for (var i=0; i<lst.length; i++) {
    var n = lst[i];
    arr[i] = function(x) { return x + n; }
  }
  return arr;
}

var adders =
     makeListOfAdders([1,3,99,21]);
adders.forEach(function(adder) {
  console.log(adder(100));
});
```

Prints:

121

121

121

121

```
function makeListOfAdders(lst) {
  let arr = [];
  for (let i=0; i<lst.length; i++) {
    let n = lst[i];
    arr[i] = function(x) { return x + n; }
  }
  return arr;
}

var adders =
     makeListOfAdders([1,3,99,21]);
adders.forEach(function(adder) {
  console.log(adder(100));
});
```

Prints:

101
103
199
121

# Arrow functions

- Concise function syntax
- `this` bound lexically
  - Normal functions bind `this` dynamically.

```
function sort (lst, fn) {
  for (let i=0; i<lst.length; i++) {
    for (let j=0; j<lst.length-1; j++) {
      if (fn(lst[i], lst[j])) {
        let tmp = lst[i];
        lst[i] = lst[j];
        lst[j] = tmp;
      }
    }
  }
}

let arr = [1,2,99,10,42,7,-3,88,6];
sort(arr, function(x,y) { return x<y; });
```

```
function sort (lst, fn) {
  for (let i=0; i<lst.length; i++) {
    for (let j=0; j<lst.length-1; j++) {
      if (fn(lst[i], lst[j])) {
        let tmp = lst[i];
        lst[i] = lst[j];
        lst[j] = tmp;
      }
    }
  }
}

let arr = [1,2,99,10,42,7,-3,88,6];
sort(arr, (x,y) => x<y);
```

# A broken JavaScript constructor

```
function Rabbit(name, favFoods) {
  this.name = name;
  this.myFoods = [];
  favFoods.forEach(function(food) {
    this.myFoods.push(food);
  });
}
var bugs = new Rabbit("Bugs",
      ["carrots", "lettuce", "souls"]);
console.log(bugs.myFoods);
```

`this` refers to the global scope

# `this` bound lexically with arrows

```
function Rabbit(name, favFoods) {
  this.name = name;
  this.myFoods = [];
  favFoods.forEach((food) =>
    this.myFoods.push(food);
  );
}
var bugs = new Rabbit("Bugs",
      ["carrots", "lettuce", "souls"]);
console.log(bugs.myFoods);
```

Now `this` refers to the new object

# Promises

- Promise: an object that *may* produce a value in the future.
- Similar to listeners, but
  - can only succeed or fail once
  - callback is called even if event took place earlier
- Simplify writing asynchronous code

# Promise states

- Pending
- Fulfilled (resolved)
- Rejected

```
let fs = require('fs');
let p = new Promise((resolve, reject) => {
  // { "key": "hello" }
  let f = fs.readFileSync('./test.json');
  resolve(f);
});

p.then(JSON.parse)
 .then((res) => res.key)
 .then((res) => console.log(res + " world!"));
```

```
let fs = require('fs');
let p = new Promise((resolve, reject) => {
  // { "key": "hello" }
  let f = fs.readFileSync('./test.json');
  resolve(f);
});

p.then(JSON.parse)
 .then((res) => res.key,
       (err) => console.error(err)))
 .then((res) => console.log(res + " world!"));
```

```
let fs = require('fs');
let p = new Promise((resolve, reject) => {
  // { "key": "hello" }
  let f = fs.readFileSync('./test.json');
  resolve(f);
});

p.then(JSON.parse)
 .then((res) => res.key)
 .then((res) => console.log(res + " world!"))
 .catch((err) => console.error(err));
```

```
let fs = require('fs');
let p = new Promise((resolve, reject) => {
  // { "key": "hello" }
  let f = fs.readFileSync('./test.json');
  resolve(f);
});

p.then(JSON.parse)
 .then((res) => res.key)
 .then((res) => console.log(res + " world!"))
 .catch((err) => console.error(err))
 .finally(() => console.log("All done"));
```

# Proxies

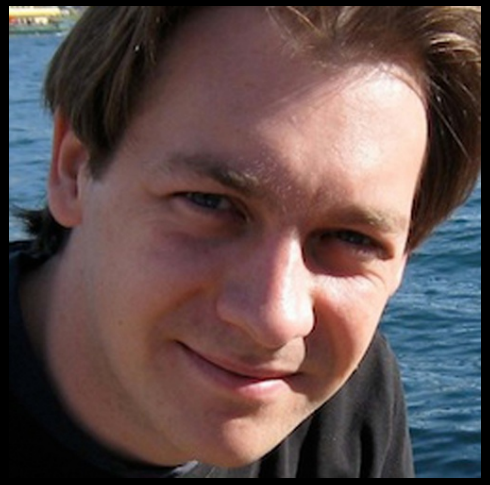
# What is *metaprogramming*?

Writing programs
that manipulate
other programs.

# JavaScript Proxies

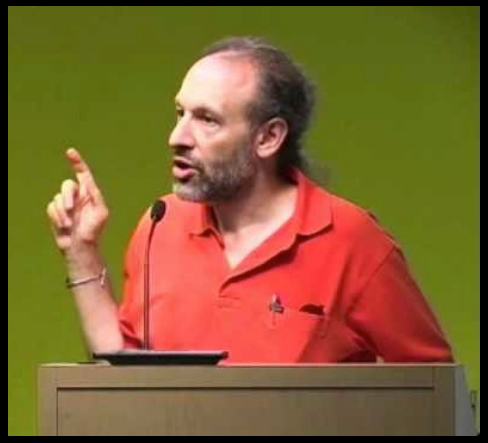
Metaprogramming feature proposed for ECMAScript 6 (Harmony).

Proposed By:



Tom Van Cutsem

Mark Miller



**Proxies: Design Principles for Robust Object-oriented Intercession APIs**

**Abstract:** Proxies are a powerful approach to implement meta-objects in object-oriented languages without having to resort to metacircular interpretation. We introduce such a meta-level API based on proxies for Javascript…

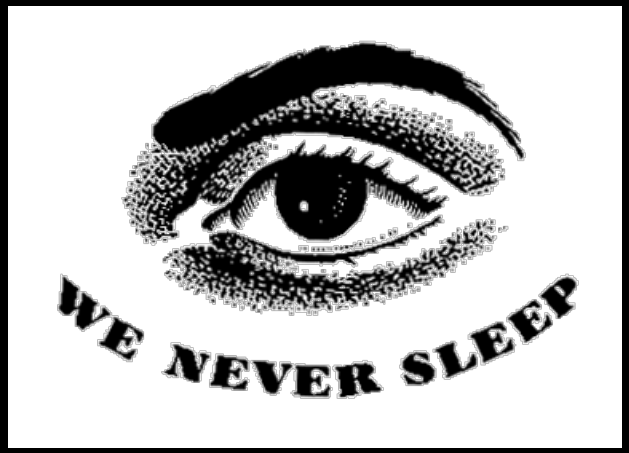
# Metaprogramming terms

- Reflection
  - **Introspection**: examine a program
  - **Self-modification**: modify a program
- **Intercession**: redefine the semantics of operations.
- Reflection is fairly common. Intercession is more unusual.

# Introspection

Ability to examine the structure of a program. In JavaScript:

```
"x" in o;
for (prop in o){ ... }
```




Property lookup

Property enumeration

# Self-modification

Ability to modify the structure of a program.

```
o["x"];   // computed property
o.y = 42; // add new property
delete o.x; // remove property
o["m"].apply(o,[42]);
       // reflected method call
```

Until recently, JavaScript did not support intercession.

JavaScript proxies are intended to fix that.

But first a little history…

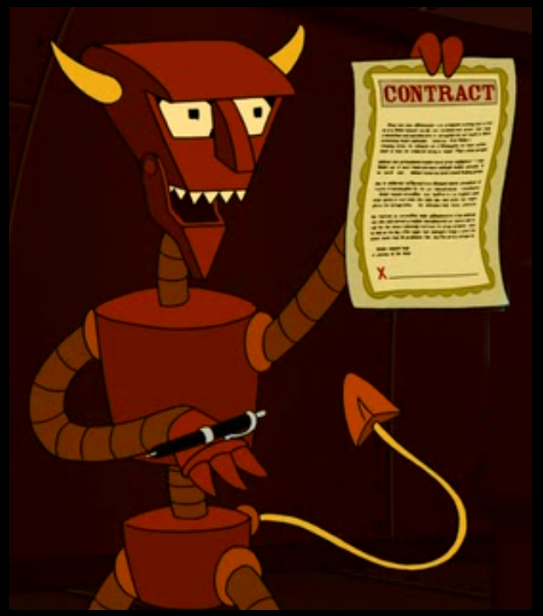
# Common Lisp

- Developed before object-oriented languages were popular.
- Many libraries were created with non-standard OO systems.

# Common Lisp Object System (CLOS)

- Became standard object-oriented system for Lisp
- *What could be done about pre-existing object-oriented libraries?*

# The Devil's Choice




1. Rewrite libraries for CLOS?
   - huge # of libraries
   - infeasible to rewrite them all
2. Make complex API?
   - difficult API to understand.
   - Systems had conflicting features…
   - …But were essentially doing the same things.

# Gregor Kiczales chose option 3:

- Keep API simple.
- Modify object behavior to fit different systems.

*Metaobject protocols were born…*

# JavaScript Object Proxies Intercession API

## Proxy and handler

The behavior of a *proxy* is determined by *traps* specified in its *handler*.

The metaobject

What kind of things do we want to do to an object?

# No-op forwarding proxy

No-op handler:
All ops forwarded to target without change

```
var target = {};
var p = new Proxy(target,{});
p.a = 37;   // op forwarded
console.log(target.a); // 37.
```

# Available traps

- has
- get
- set
- deleteProperty
- apply
- construct
- getOwnPropertyDescriptor
- getPrototypeOf
- setPrototypeOf
- isExtensible
- preventExtensions
- defineProperty
- ownKeys

# Available traps

- `has`
- `get`
- `set`
- `deleteProperty`
- **`apply`**
- **`construct`**
- `getOwnPropertyDescriptor`
- `getPrototypeOf`
- `setPrototypeOf`
- `isExtensible`
- `preventExtensions`
- `defineProperty`
- `ownKeys`

Only for proxied functions

# Another use case for proxies

- Share a reference to an object, but do not want it to be modified.
  - Reference to the DOM, for instance
- We can modify the forwarding handler to provide this behavior:

# Read-only handler

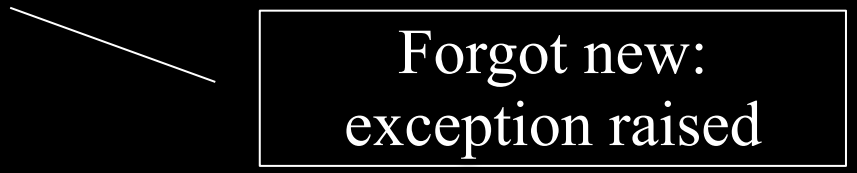
```
let roHandler = {
  deleteProperty: function(t, prop) { return false;},
  set: function(t, prop, val, rcvr) { return false;},
  setPrototypeOf: function(t,p) { return false; } };

var constantVals = {
  pi: 3.14,
  e: 2.718,
  goldenRatio: 1.30357 };

var p = new Proxy(constantVals, roHandler);
console.log(p.pi);
delete p.pi;
console.log(p.pi);
p.pi = 3;
console.log(p.pi);
```

# Safe constructor handler

```
function Cat(name) {
  this.name = name;
}
Cat = new Proxy(Cat, {
  apply: function(t,thisArg,args){
    throw Exception("Forgot new");
  }
});
var g = new Cat("Garfield");
console.log(g.name);
var n = Cat("Nermal");
```



# Aspect-oriented programming (AOP)

- Some code not well organized by objects
  - *Cross-cutting concern*
- Canonical example: logging statements
  - littered throughout code
  - Swap out logger = massive code changes

# Tracing Updates

```
let obj = { foo: 'bar' };

let o = new Proxy(obj, {
  set: (target, name, val) => {
    console.log(`Setting ${name} to ${val}`);
    target[name] = val;
    return true; // Indicates successful update.
  },
});

// Prints 'Setting foo to fighters'
o.foo = "fighters";
```

# Tracing Updates, using Reflect API

```
let obj = { foo: 'bar' };

let o = new Proxy(obj, {
  set: (target, name, val) => {
    console.log(`Setting ${name} to ${val}`);
    return Reflect.set(target, name, val);

  },
});

// Prints 'Setting foo to fighters'
o.foo = "fighters";
```

# Tracing Updates, using Reflect API and spread syntax

```
let obj = { foo: 'bar' };

let o = new Proxy(obj, {
  set: (target, name, val) => {
    console.log(`Setting ${name} to ${val}`);
    return Reflect.set(...arguments);

  },
});

// Prints 'Setting foo to fighters'
o.foo = "fighters";
```

# Tracing Gets and Sets

```
let obj = { foo: 'bar' };

let o = new Proxy(obj, {
  set: (target, name, val) => {
    console.log(`Setting ${name} to ${val}`);
    return Reflect.set(...arguments);
  },
  get: (target, name) => {
    console.log(`Getting ${name}`);
    return Reflect.get(...arguments);
  }
});

o.foo = "fighters"; // Prints 'Setting foo to fighters'
let ff = "foo" + o.foo; // Prints 'Getting foo'
```

# Lab: SmartArray

In this lab, we will use the Proxy API to create special arrays with extra features:

- *Ranges* (e.g. `arr['2-5']` gets elements 2,3,4,5)
- Get from end
  (e.g. `arr[-1]` returns last element of array)
- No non-numerical keys may be set
  (e.g. `arr['foo']=42` is an error)

More details in Canvas.