# Writing robust JavaScript code

or

## JavaScript: the Good, the Bad, the Strict and the Secure Parts

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# Talk Outline

- Part I: JavaScript, the Good and the Bad parts
- Part II: ECMAScript 5 and Strict Mode
- Part III: a glance at upcoming ECMAScript 6 features
- Part IV: Caja and Secure ECMAScript (SES)

# Talk Outline

- This talk is about:
  - The JavaScript language proper
  - Language dialects and features to enable or improve security
- This talk is not about:
  - Security exploits involving JavaScript, or how to avoid specific exploits (e.g. XSS attacks)

# About Me

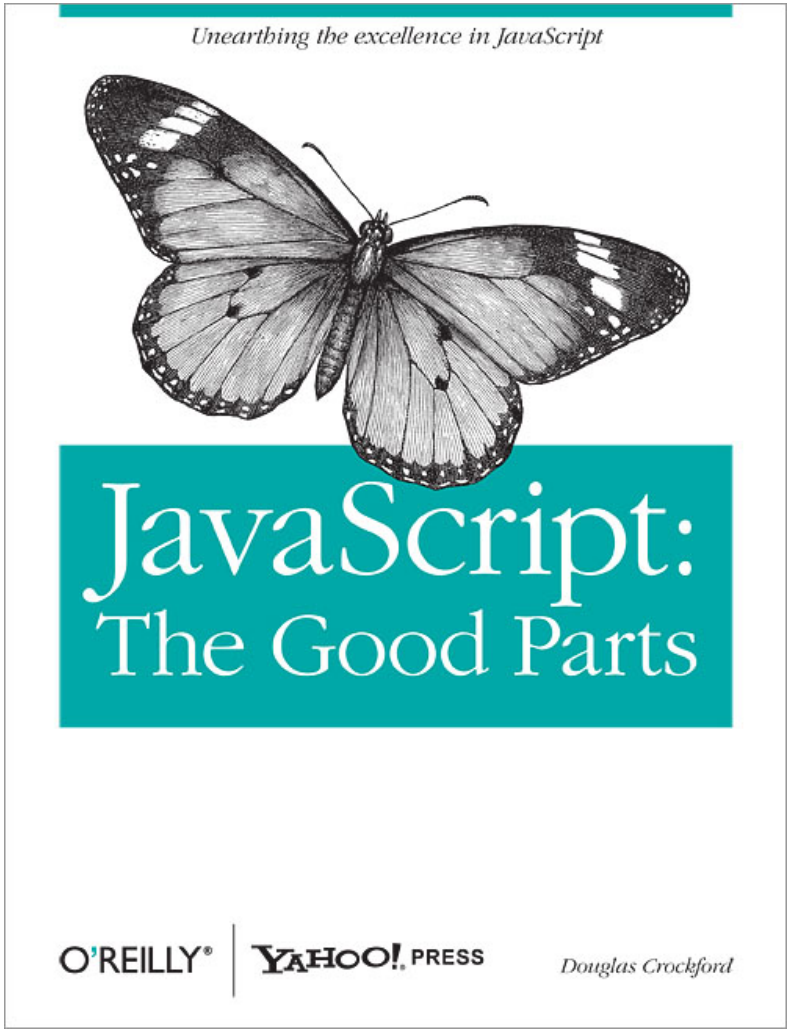
- Professor of Computer Science at Vrije Universiteit Brussel, Belgium
    - Focus on Programming Languages & Distributed Systems
- ECMA TC39 (Javascript standardization committee)
- Visiting Faculty at the Google Caja team (2010)

# Part I: Javascript, the Good and the Bad parts

# What developers think about JavaScript

- Lightning talk Gary Bernhardt at CodeMash 2012
- https://www.destroyallsoftware.com/talks/wat

# The world's most misunderstood language




See also: "JavaScript: The World's Most Misunderstood Programming Language" by Doug Crockford at http://www.crockford.com/javascript/javascript.html

# Good Parts: Functions

- Functions are first-class, may capture lexical variables (closures)

```
var add = function(a,b) {
  return a+b;
}

add(2,3); // 5
```

```
function accumulator(s) {
  return function(n) {
    return s += n;
  }
}

var a = accumulator(0);
a(1); // 1
a(2); // 3
```

```
button.addEventListener('click', function (event) { … });
```

# Good Parts: Objects

- No class declaration needed, literal syntax, arbitrary nesting

```
var bob = {
  name: “Bob”,
  dob: {
    day: 15,
    month: 03,
    year: 1980
  },
  address: {
    street: “Main St.”,
    number: 5,
    zip: 94040,
    country: “USA”
  }
};
```

# Good Parts: combining objects and functions

- Functions can act as object constructors and methods

```
function makePoint(i,j) {
  return {
    x: i,
    y: j,
    toString: function() {
      return ‘(’+ this.x +‘,’+ this.y +‘)’;
    }
  };
}

var p = makePoint(2,3);
var x = p.x;
var s = p.toString();
```

# A dynamic language...

```
// computed property access and assignment
p.x                     p["x"]
p.x = 42;               p["x"] = 42;

// dynamic method invocation
p.toString();           p["toString"].apply(p, [ ]);

// add new properties to an object at runtime
p.z = 0;

// delete properties from an object at runtime
delete p.x;
```

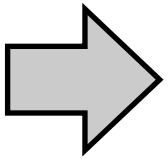
# Bad Parts: global variables

- Scripts depend on global variables for linkage

## Bad

```
<script>
var x = 0; // global
var myLib = {
  inc: function() {
    return ++x;
  }
};
</script>


<script>
var res = myLib.inc();
</script>
```



## Better

```
<script>
var myLib = (function(){
  var x = 0; // local
  return {
    inc: function() {
      return ++x;
    }
  };
}());
</script>
```

# Bad Parts: with statement

- `with`-statement breaks static scoping

```
with (expr) {
   ... x ...
}
```

```
var x = 42;
var obj = {};
with (obj) {
   print(x); // 42
   obj.x = 24;
   print(x); // 24
}
```

# More Bad Parts

- Implicit type coercions
- No integers (all numbers are IEEE 754 floating point)
- “var hoisting”: variables are not block-scoped but function-scoped
- Automatic semicolon insertion
- ...

# Delving Deeper

- Some finer points about JavaScript functions and objects

# Functions

- Functions are objects

```
function add(x,y) { return x + y; }
add(1,2) // 3

add.doc = “returns the sum of two numbers”;
```

# Objects

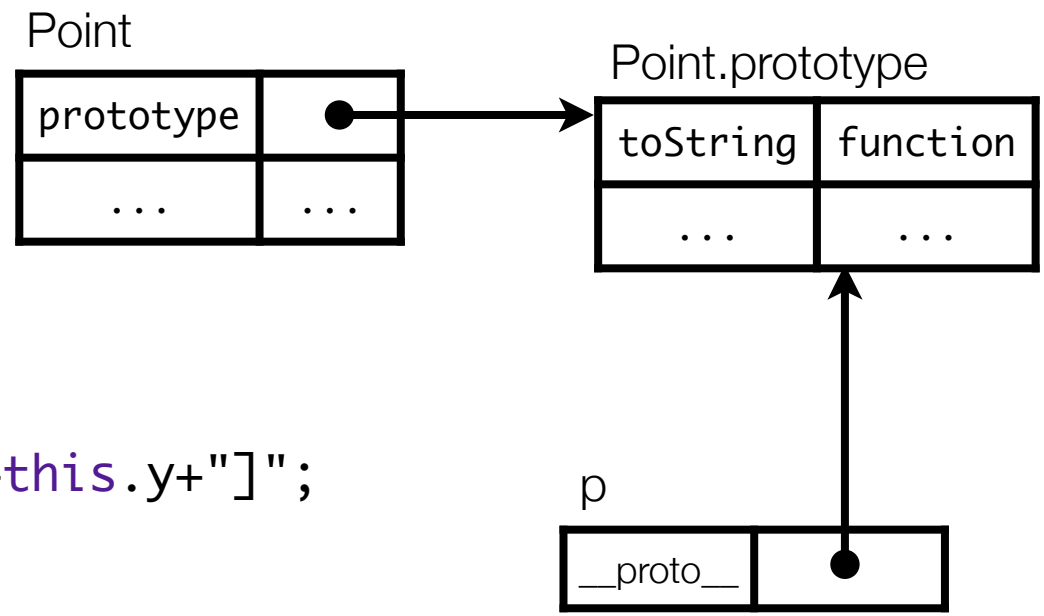
- No classes.
- Instead, functions may be used as object constructors.
- All objects have a “prototype” link
  - Lookup of a property on an object traverses the prototype links
  - Similar to inheritance between classes
  - In some implementations, the prototype is an explicit property of the object named `__proto__`

# Objects

```
function Point(x, y) {
  this.x = x;
  this.y = y;
}

Point.prototype = {
  toString: function() {
    return "[Point "+this.x+","+this.y+"]";
  }
}

var p = new Point(1,2);
```



# Objects

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  this.x = x;
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Point.prototype = {
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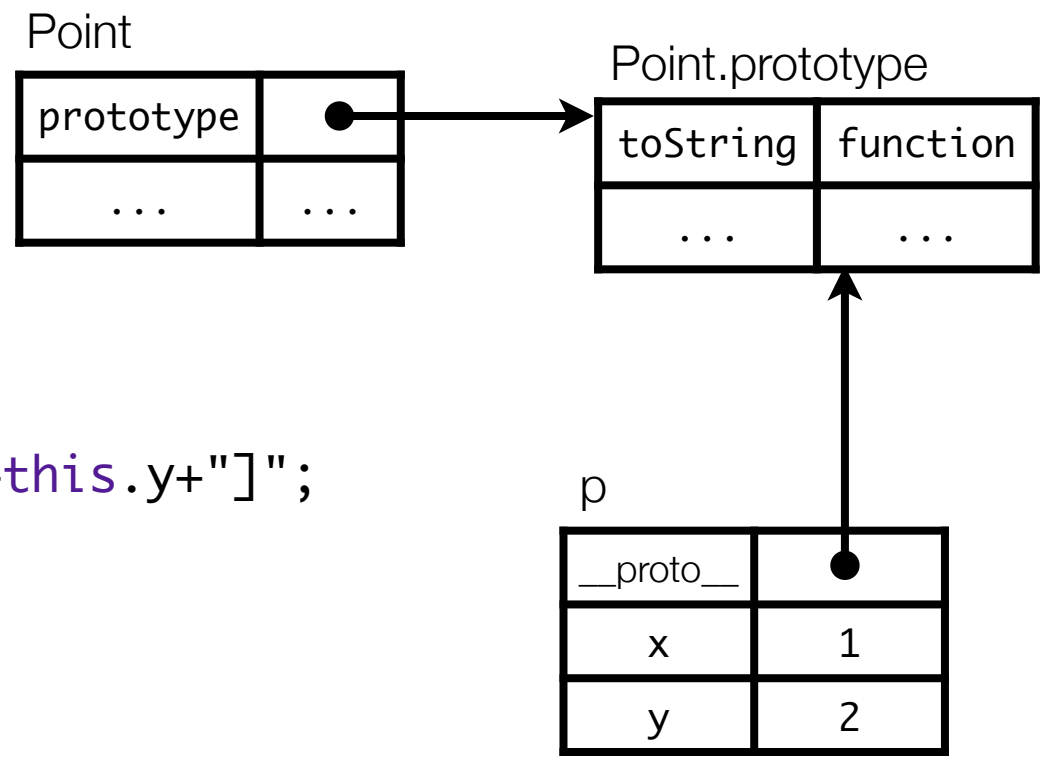
  }
}

var p = new Point(1,2);
p.x;
p.toString();
```

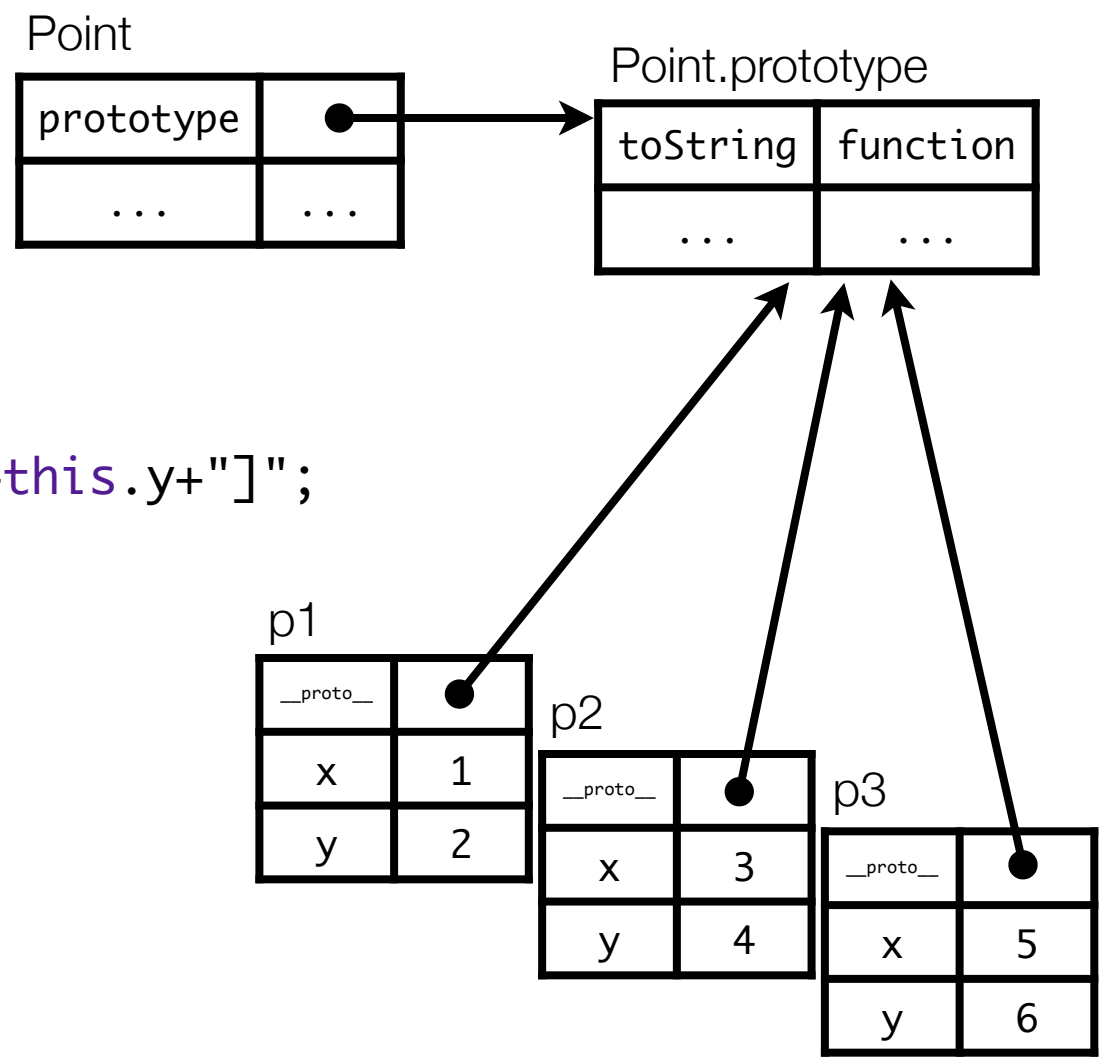


# Objects

```
function Point(x, y) {
  this.x = x;
  this.y = y;
}

Point.prototype = {
  toString: function() {
    return "[Point "+this.x+","+this.y+"]";
  }
}

var p1 = new Point(1,2);
var p2 = new Point(3,4);
var p3 = new Point(5,6);
```



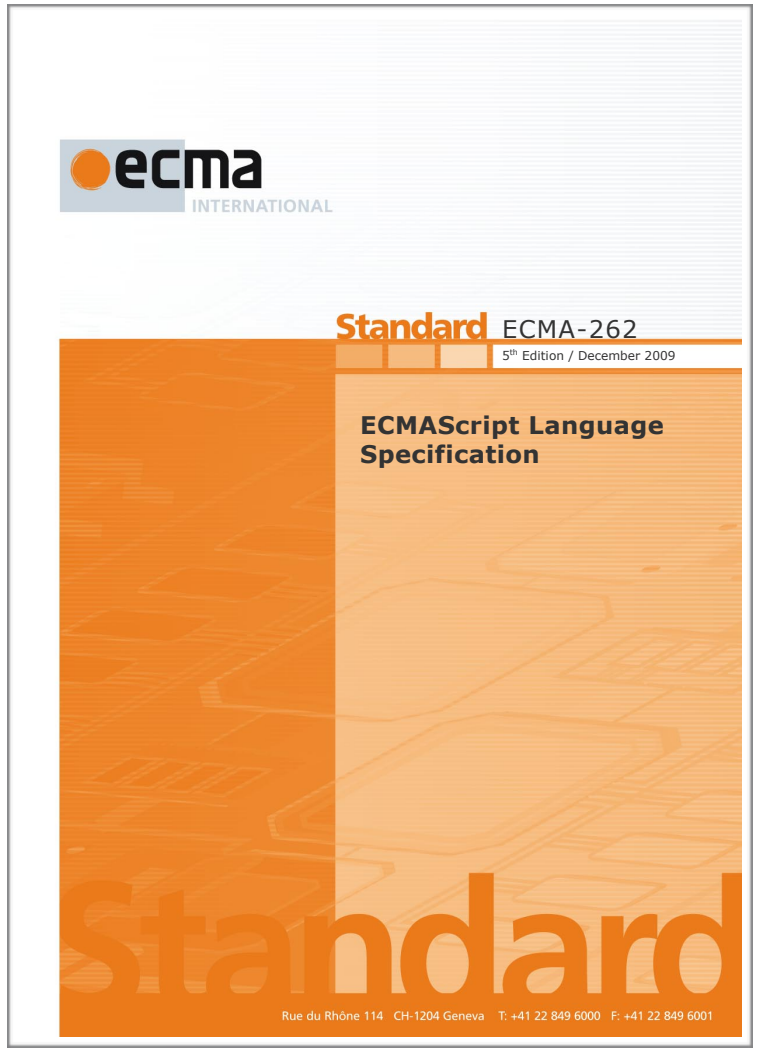
# Summary so far

- Javascript: “a Lisp in C’s clothing” (D. Crockford)
- Good parts: functions, object literals
- Bad parts: global vars, lack of static scoping, …
- Functions and objects work well together

# Part II: ECMAScript 5 and Strict Mode

# ECMAScript

- “Standard” Javascript
  - 1st ed. 1997
  - 2nd ed. 1998
  - 3rd ed. 1999
  - ~~4th ed.~~
  - 5th ed. 2009
  - *6th ed. end of 2014 (tentative) (draft already available)*



# ECMAScript 5 Themes

- New APIs, including JSON
- Support for more robust programming
  - Tamper-proof objects
  - Strict mode

# ECMAScript 5 Themes

- **New APIs, including JSON**
- Support for more robust programming
  - Tamper-proof objects
  - Strict mode

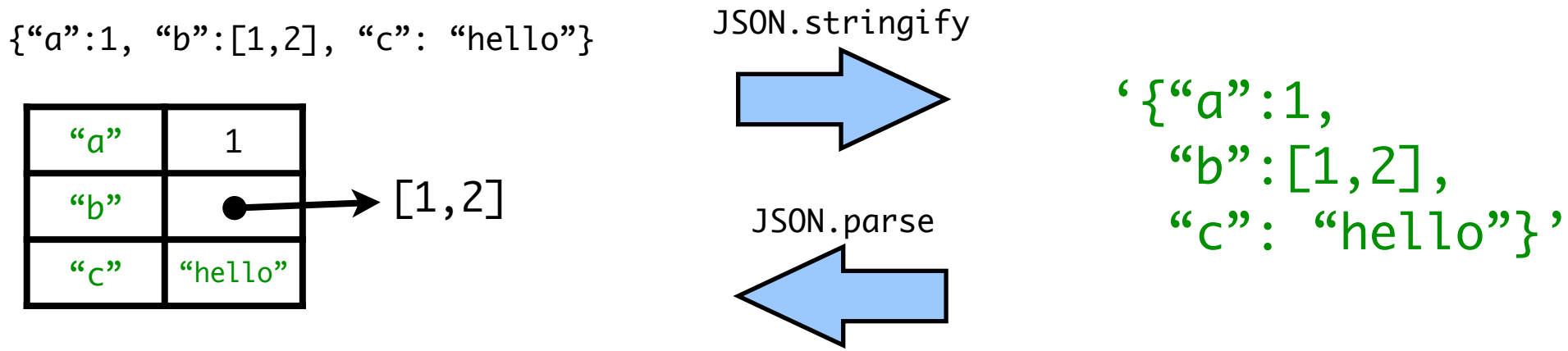
# JSON

- **J**ava**S**cript **O**bject **N**otation
- A subset of Javascript to describe *data* (numbers, strings, arrays and objects without methods)
- Formal syntax literally fits *in a margin*. See http://json.org/

```
{ “name” : “Bob”,
  “age” : 42,
  “address” : {
    “street” : “Main st.”
  }
}
```

# ECMAScript 5 and JSON

- Before ES5, could either parse quickly or safely
- Unsafe: `eval(jsonString)`
- In ES5: use `JSON.parse`, `JSON.stringify`



# ECMAScript 5 Themes

- New APIs, including JSON
- **Support for more robust programming**
  - Tamper-proof objects
  - Strict mode

# Tamper-proof Objects: motivation

- Objects are *mutable* bags of properties
- No way to protect an object from modifications by its clients
- *Unsafe* to share objects across trust boundaries on a single page
- Problematic when embedding third-party scripts on your page
- Necessary first step: protect objects from third-party modifications

# Tamper-proof Objects

```
var point =
  { x: 0,
    y: 0  };


  Object.preventExtensions(point);
  point.z = 0; // error: can't add new properties


  Object.seal(point);
  delete point.x; // error: can't delete properties


  Object.freeze(point);
  point.x = 7; // error: can't assign properties
```

# Ecmascript 5 Strict mode

- Safer, more robust, subset of the language
- Why?
  - No silent errors
  - True static scoping rules
  - No global object leakage

# Ecmascript 5 Strict mode

- Explicit opt-in to avoid backwards compatibility constraints
- How to opt-in
  - Per “program” (file, script tag, ...)
  - Per function
- Strict and non-strict mode code can interact (e.g. on the same web page)

```
<script>
"use strict";
...
</script>
```

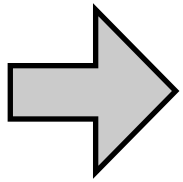
```
function f() {
  "use strict";
  ...
}
```

# Strict-mode opt-in: gotcha's

- Beware: minification and deployment tools may concatenate scripts

```
<script>
"use strict";
// in strict mode
</script>
```

```
<script>
// not in strict mode
function f(){...}
</script>
```



```
<script>
"use strict";
// in strict mode

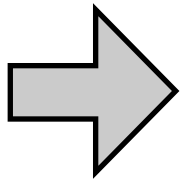


// f is now
// accidentally strict!
function f(){...}
</script>
```

# Strict-mode opt-in: gotcha's

- Suggested refactoring is to wrap script blocks in function bodies

```
<script>
(function(){
  "use strict";
  // in strict mode
}())
</script>
```



```
<script>
(function(){
  "use strict";
  // in strict mode
}())
```

```
<script>
// not in strict mode
function f(){...}
</script>
```

```
// not in strict mode
function f(){...}
</script>
```

# Static scoping in ES5

- ECMAScript 5 non-strict is not statically scoped
- Four violations:
  - `with (obj) { x }` statement
  - `delete x;` // may delete a statically visible var
  - `eval('var x = 8');` // may add a statically visible var
  - Assigning to a non-existent variable creates a new global variable

    ```
    function f() { var xfoo; xFoo = 1; }
    ```

# Ecmascript 5 Strict: syntactic restrictions

- The following are forbidden in strict mode (signaled as syntax errors):

```
with (expr) {
  ...x...
}
```

```
{ a: 1,
  b: 2,
  b: 3 } // duplicate property
```

```
function f(a,b,b) {
  // repeated param name
}
```

```
delete x; // deleting a variable
```

```
if (a < b) {
  // declaring functions in blocks
  function f(){}
}
```

```
var n = 023; // octal literal
```

```
function f(eval) {
  // eval as variable name
}
```

# Ecmascript 5 Strict

- Runtime changes (fail silently outside of strict mode, throw an exception in strict mode)

```
function f() {
  "use strict";
  var xfoo;
  xFoo = 1;  // error: assigning to an undeclared variable
}
```

```
"use strict";
var p = Object.freeze({x:0,y:0});
delete p.x; // error: deleting a property from a frozen object
```

# Ecmascript 5 Strict: avoid global object leakage

- Runtime changes: default `this` bound to `undefined` instead of the global object

```
function Point(x, y) {
  this.x = x;
  this.y = y;
}

var p = new Point(1,2);
var p = Point(1,2);
// window.x = 1;
// window.y = 2;
print(x) // 1 (bad!)
```

```
"use strict";
function Point(x, y) {
  this.x = x;
  this.y = y;
}

var p = new Point(1,2);
var p = Point(1,2);
// undefined.x = 1;
// error (good!)
```

# Direct versus Indirect Eval

- ES5 runtime changes to eval (both in strict and non-strict mode)
- `eval` “operator” versus `eval` “function”

## Direct Eval

```
function f() {
  var x = 0;
  eval(“x = 5”);
  return x;
}
f() // returns 5
```

## Indirect Eval

```
function f(g) {
  var x = 0;
  g(“x = 5”);
  return x;
}
f(eval) // returns 0
```

# ECMAScript 5 Themes: summary

- New APIs, including JSON
- Support for more robust programming
  - Tamper-proof objects
  - Strict mode

# Part III: ECMAScript 6

# ECMAScript 6

- Many new additions (too many to list here *)
- Classes
- Modules
- String Templates
- Proxies

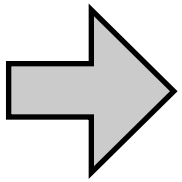
* see http://kangax.github.io/es5-compat-table/es6/ for an overview of ES6 features

# ECMAScript 6 classes

- All code inside a class is implicitly opted into strict mode!

```
function Point(x, y) {
  this.x = x;
  this.y = y;
}

Point.prototype = {
  toString: function() {
    return "[Point...]";
  }
}
```



```
class Point {
  constructor(x, y) {
    this.x = x;
    this.y = y;
  }

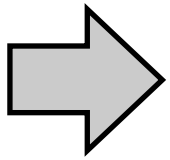
  toString() {
    return "[Point...]";
  }
}
```

```
var p = new Point(1,2);
p.x;
p.toString();
```

# ECMAScript 6 modules

- All code inside a module is implicitly opted into strict mode!

```
<script>
var x = 0; // global
var myLib = {
  inc: function() {
    return ++x;
  }
};
</script>
```



```
<script type="module"
        name="myLib">
var x = 0; // local!
export function inc() {
  return ++x;
}
</script>
```

```
<script>
var res = myLib.inc();
</script>
```

```
<script type="module">
import { inc } from 'myLib';
var res = inc();
</script>
```

# ECMAScript 6 string templates

- String interpolation (e.g. for templating) is very common in JS
- Vulnerable to injection attacks

```
function createDiv(input) {
  return "<div>"+input+"</div>";
};

createDiv("</div><script>…");
// "<div></div><script>…</div>"
```

# ECMAScript 6 string templates

- String templates combine convenient syntax for interpolation with a way of automatically building the string

```
function createDiv(input) {
  return html`<div>${input}</div>`;
};

createDiv("</div><script>…");
// "<div>&lt;/div&gt;&lt;script&gt;…</div>"
```

# ECMAScript 6 string templates

- User-extensible: just sugar for a call to a template function
- Expectation that browser will provide html, css template functions

```
function createDiv(input) {
  return html(["<div>","</div>"], input);
};

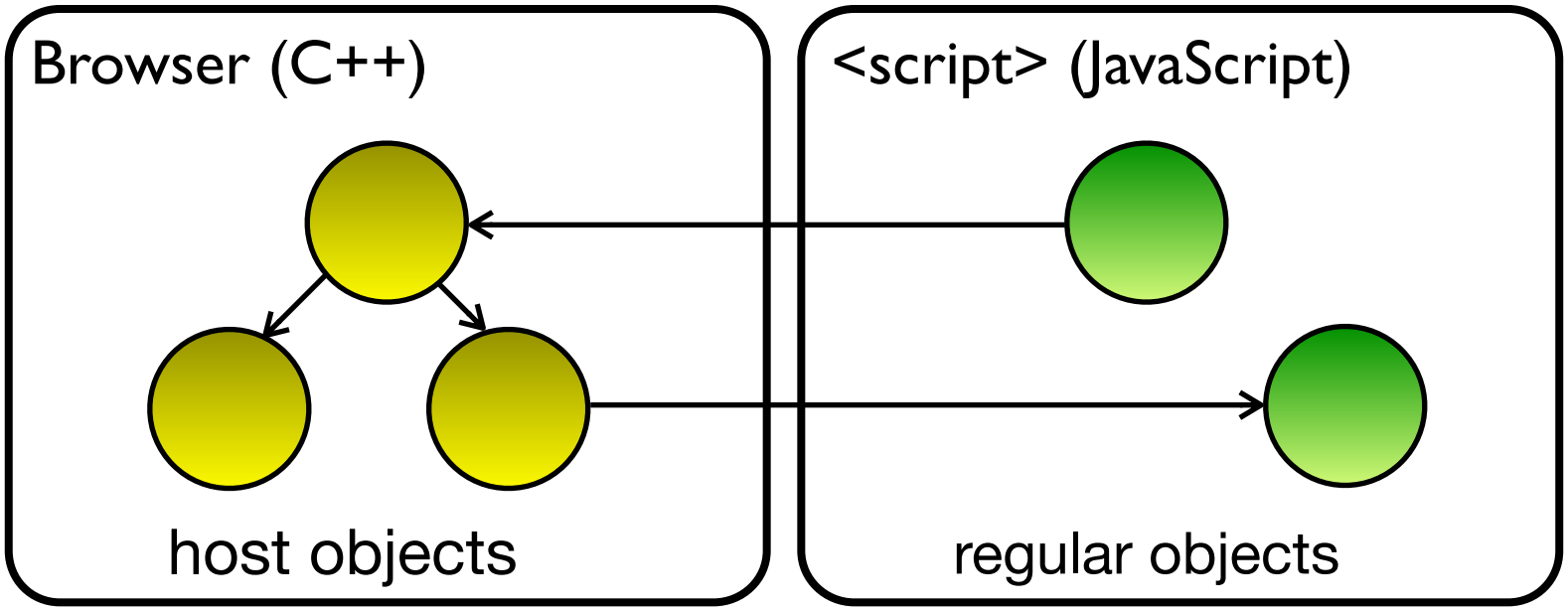
createDiv("</div><script>…");
// "<div>&lt;/div&gt;&lt;script&gt;…</div>"
```

# ECMAScript 6 proxies

- Dynamic proxy objects: objects whose behavior can be controlled in JavaScript itself
- Goals:
  - Create generic object wrappers
  - Emulate host objects

# Host objects

- Objects provided by the host platform
- E.g. the **DOM**: a tree representation of the HTML document
- Appear to be Javascript objects, but not implemented in Javascript
- Can have odd behavior that regular JavaScript objects cannot emulate



# Proxy example: log all property accesses

```
function makePoint(x, y) {
  return {
    x: x,
    y: y
  };
}
```

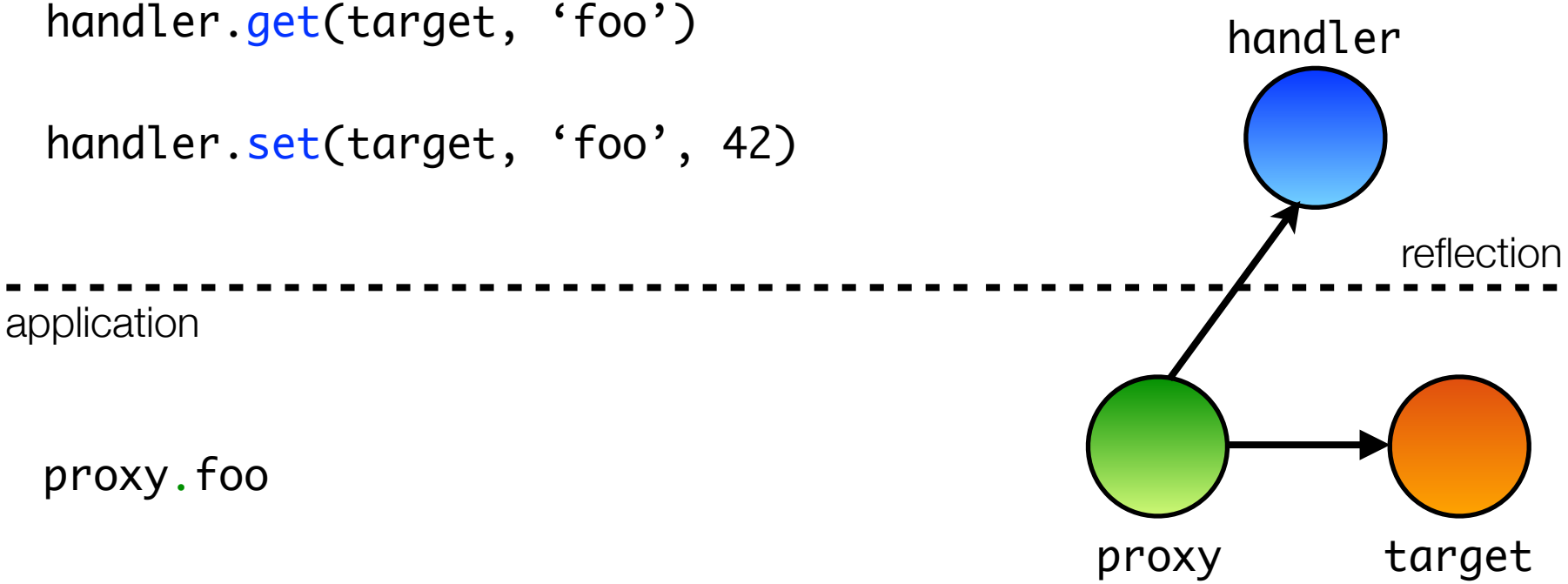
```
var p = makePoint(2,2);
var lp = makeLogger(p);
lp.x
// log: get x
// returns 2
lp.y = 3
// log: set y 3
```

# ECMAScript 6 proxies

```
var proxy = new Proxy(target, handler);
```

```
handler.get(target, 'foo')
```

```
handler.set(target, 'foo', 42)
```




```
proxy.foo
```

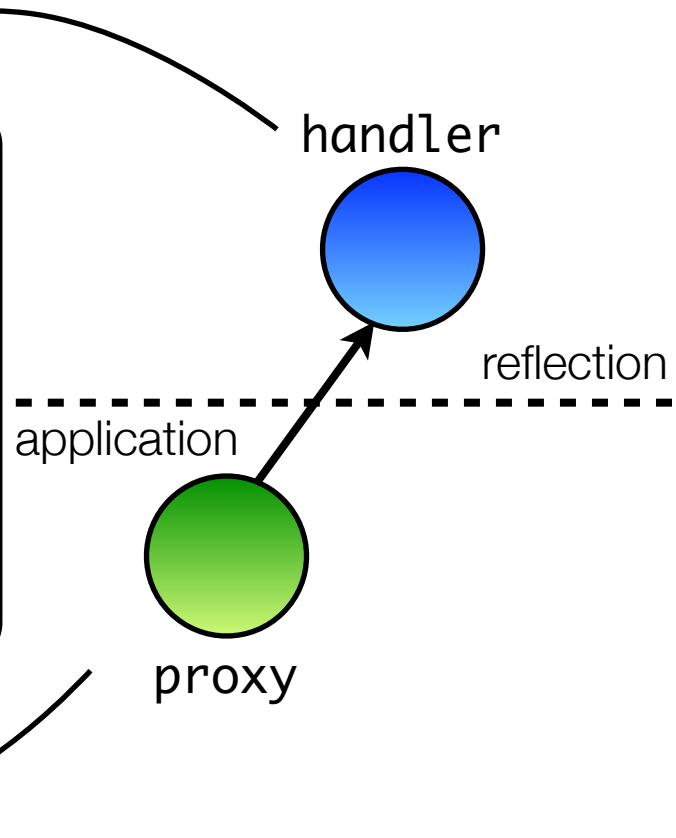
```
proxy.foo = 42
```

# Example: logging all property accesses

```
function makeLogger(target) {
  var proxy = new Proxy(target, {
    get: function(target, name) {
      console.log('get', name);
      return target[name];
    },
    set: function(target, name, val) {
      console.log('set', name, val);
      return target[name] = val;
    },
  });
  return proxy;
}
```

# Example: logging all property accesses

```
function makeLogger(target) {
  var proxy = new Proxy(target, {
    get: function(target, name) {
      console.log('get', name);
      return target[name];
    },
    set: function(target, name, val) {
      console.log('set', name, val);
      return target[name] = val;
    },
  });
  return proxy;
}
```



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```
function makeLogger(target) {
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    get: function(target, name) {
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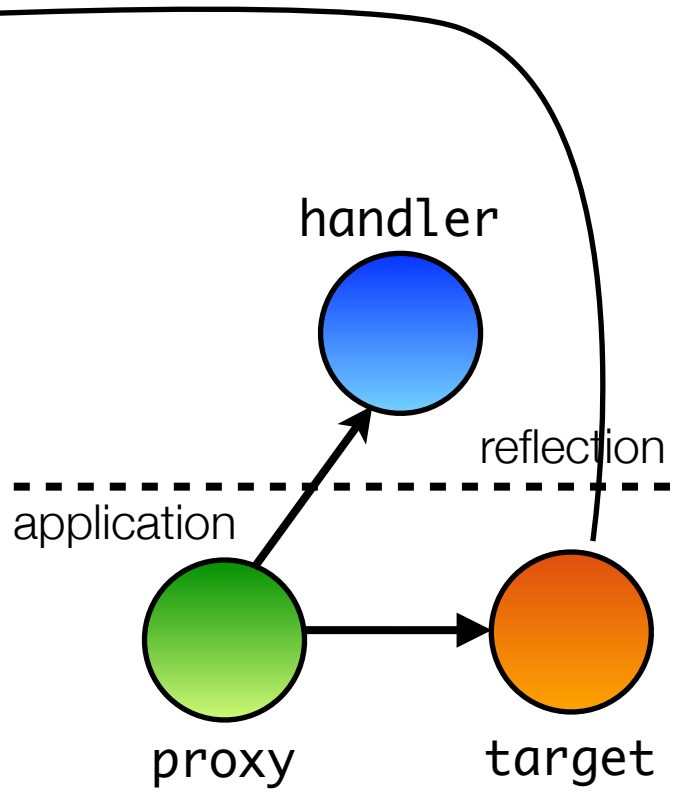
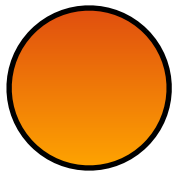
      return target[name];
    },
    set: function(target, name, val) {
      console.log('set', name, val);
      return target[name] = val;
    },
  });
  return proxy;
}
```



# Another Proxy example: a revocable reference

- revocable reference: limit the lifetime of an object reference

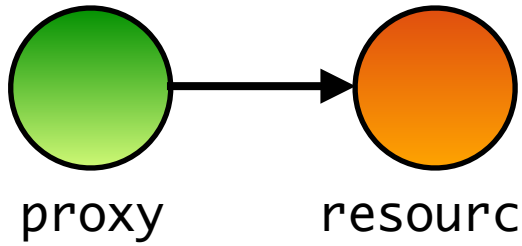


resource

```
var {proxy,revoke} = makeRevocable(resource);
plugin.run(proxy);
// later
revoke();
```

# Another Proxy example: a revocable reference

- revocable reference: limit the lifetime of an object reference

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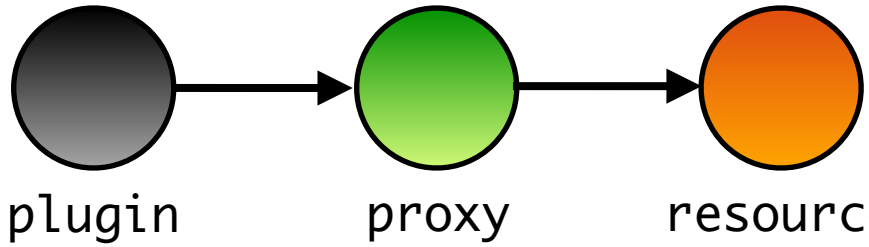


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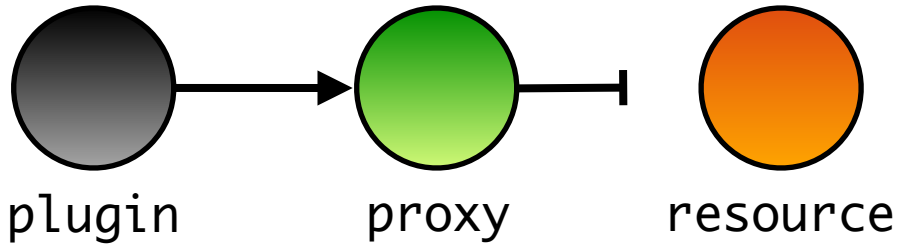



```
var {proxy,revoke} = makeRevocable(resource);
plugin.run(proxy);
// later
revoke();
```

# Another example: a revocable reference

```
function makeRevocable(resource) {
  var enabled = true;
  return {
    proxy: new Proxy(resource, {
      get: function(target, name) {
        if (enabled) { return target[name]; }
        throw new Error("revoked");
      }
    }),
    revoke: function() { enabled = false; };
  }
}
```

# Proxies: availability

- Firefox
- `node --harmony`
- Chrome (enable experimental JS flag in chrome://flags )
- Library that implements the latest ES6 specification

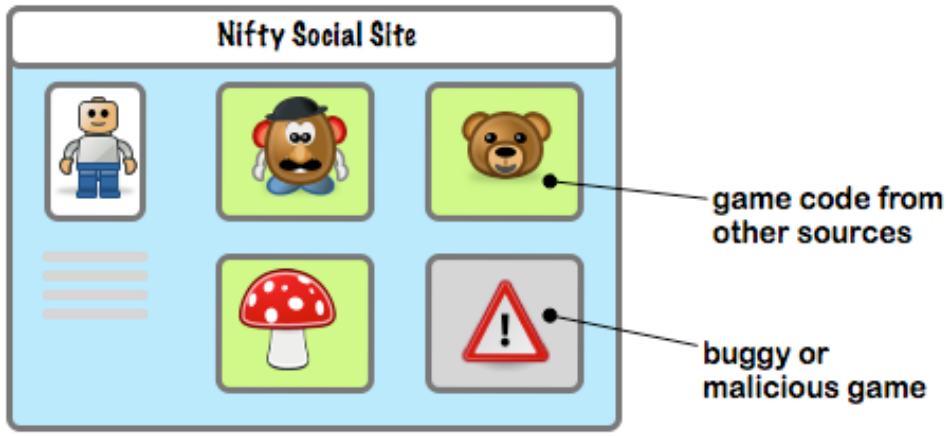
```
<script src="reflect.js"></script>
```

- Available on Github: https://github.com/tvcutsem/harmony-reflect

# Part IV: Caja and Secure ECMAScript (SES)

# Caja

- Caja enables the safe embedding of third-party active content inside your website
  - Secures Google Sites
  - Secures Google Apps Scripts
- More generally: Gadgets, Mashups:



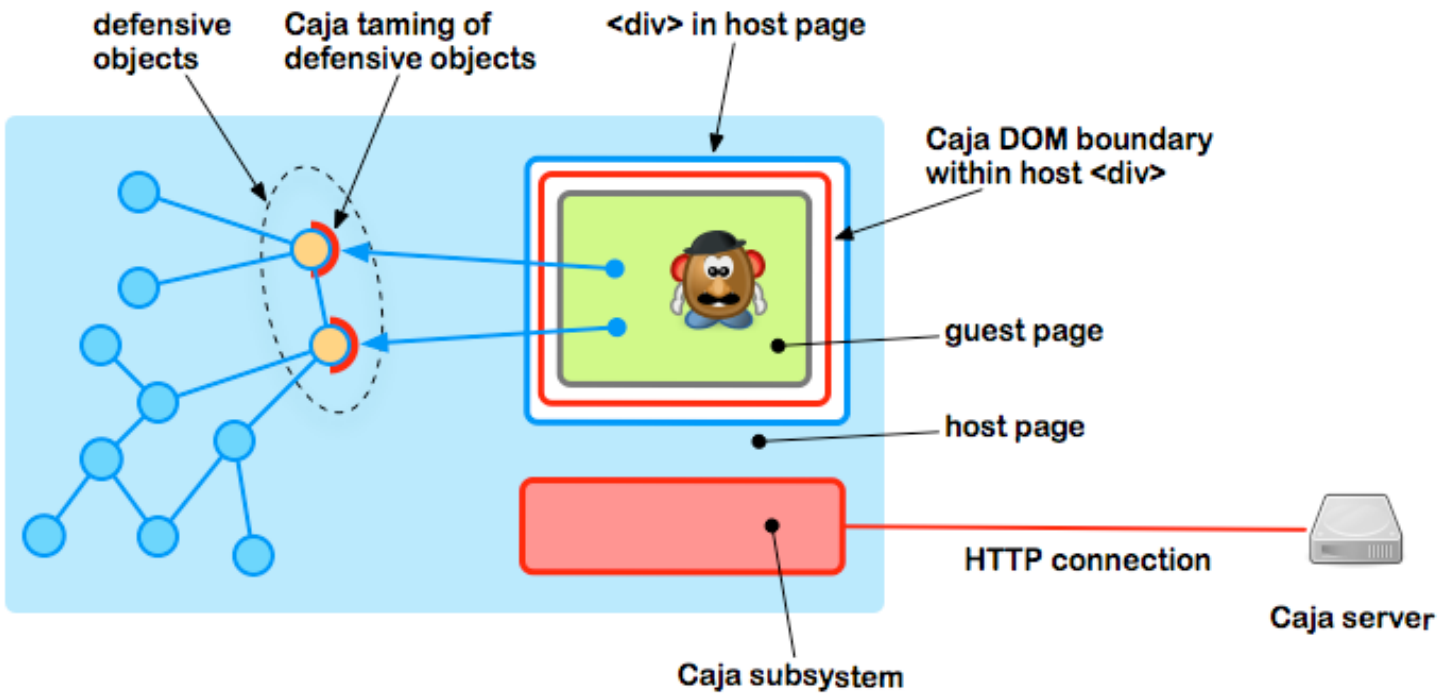

https://developers.google.com/caja/docs/about/

# Caja 

- Not a traditional sandbox. Caja-compiled code is safe to inline directly in a webpage . No iframes. No web workers.
- Can put multiple third-party apps into the same page and allow them to directly exchange JavaScript objects
  - Great for writing mash-ups
- The host page is protected from the embedded apps
  - E.g. embedded app can't redirect the host page to phishing sites, or steal cookies from the host page

# Caja : Taming

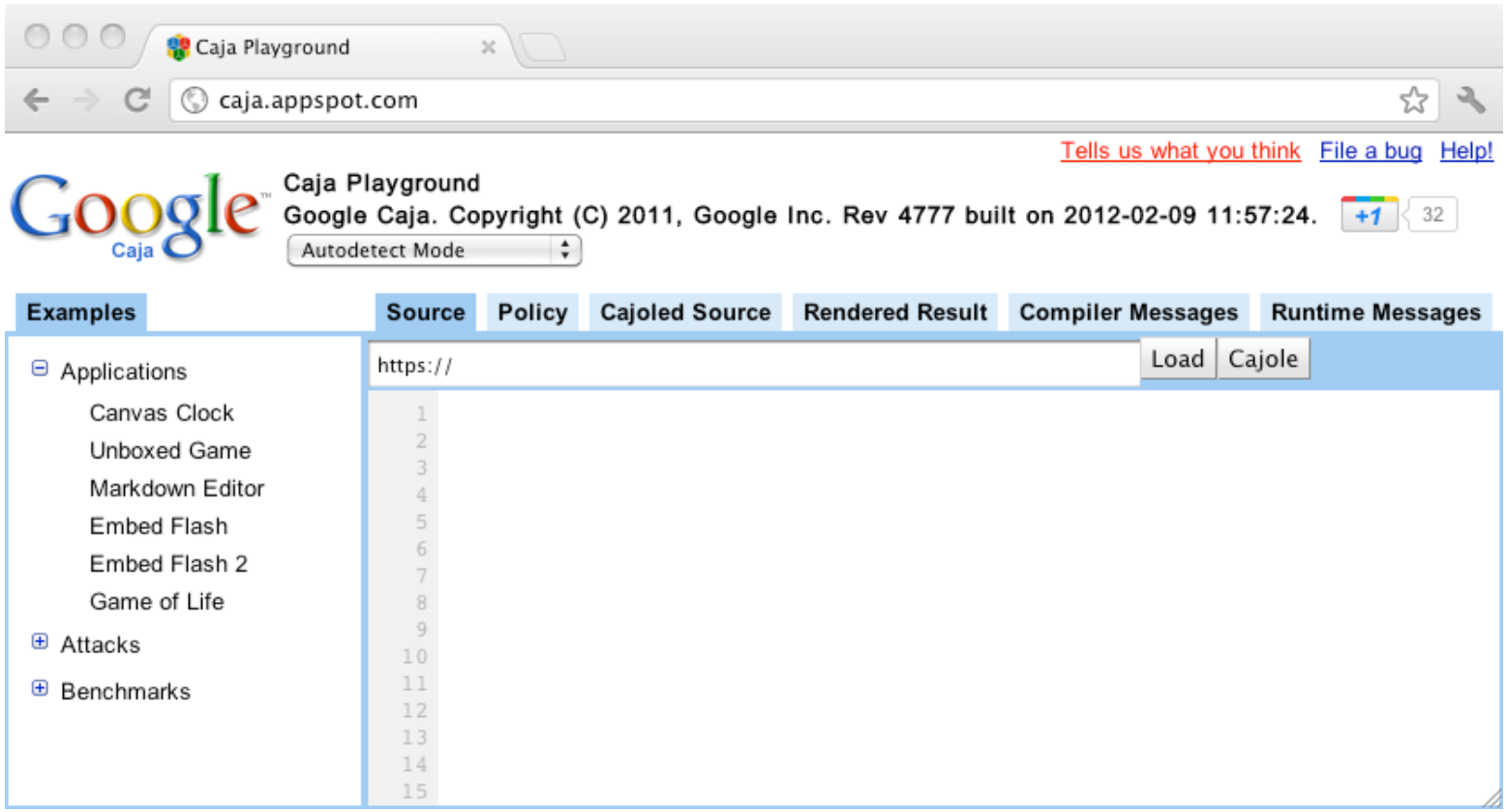
- Caja proxies the DOM. Untrusted content interacts with a virtual DOM, never with the real DOM.




https://developers.google.com/caja/docs/about/

# Caja

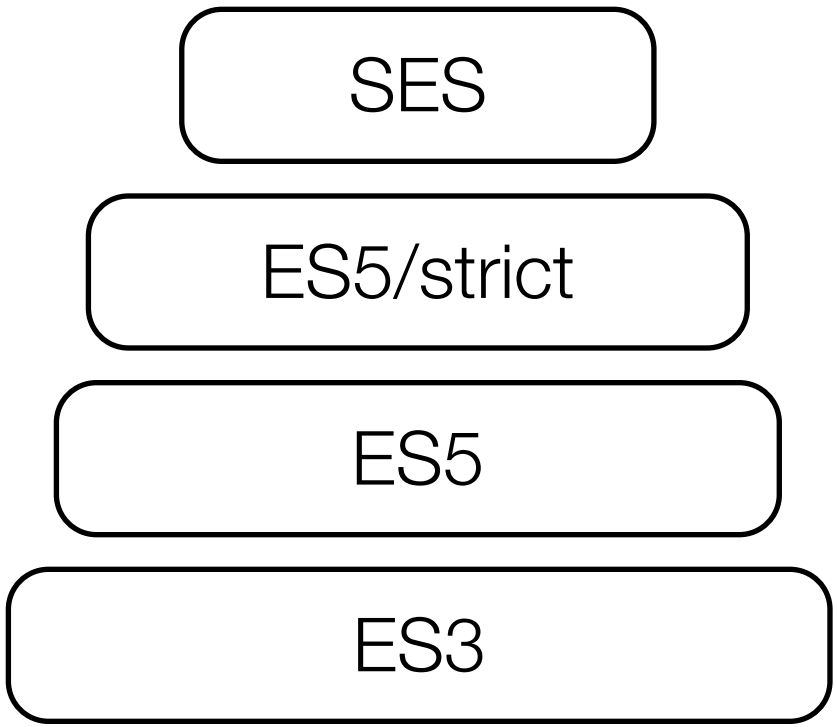
- Example: Caja Playground
- http://caja.appspot.com



# Caja 

- Caja consists of:
  - A capability-secure JavaScript subset (SES)
  - A safe DOM wrapper (Domado)
  - A HTML and CSS sanitizer (sandbox scripts embedded in HTML/CSS)
- SES is the portion of Caja responsible for securing JavaScript

# Secure ECMAScript




adds confinement

adds proper static scoping

adds tamper-proof objects

# Secure ECMAScript

- Implemented as a library on top of ES5/strict
- Include as first script, before any other JavaScript code runs:

```
<script src="startSES.js"></script>
```

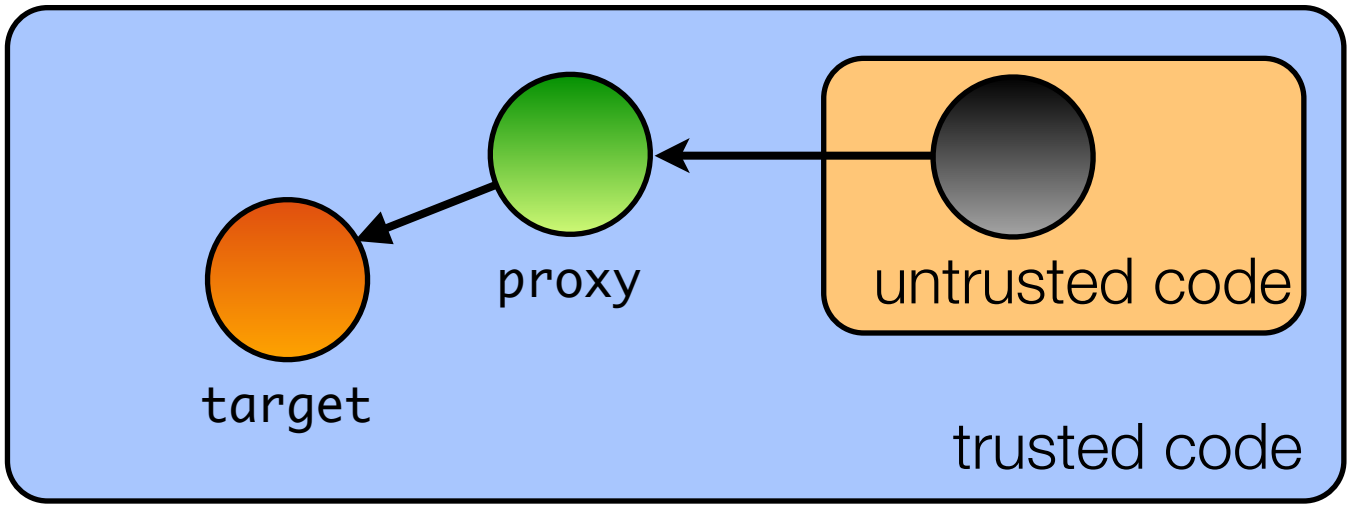
# Secure ECMAScript

```
<script src="startSES.js"></script>
```

- Deep-frozen global environment (incl. frozen global object)
  - Can't update properties of `Object`, `Array`, `Function`, `Math`, `JSON`, etc.
- Whitelisted global environment
  - No "powerful" non-standard globals
    (e.g. `document`, `window`, `XMLHttpRequest`, ...)
  - Code that spawns an SES environment may provide selective access to these
- Patches `eval` and `Function` to accept only ES5/strict code that can only name global variables on the whitelist

# Proxies again

- Caja uses object capabilities to express security policies
- In the object-capability paradigm, an object is powerless unless given a reference to other (more) powerful objects
- Common to wrap objects with proxies that define a security policy
  - E.g. revocable reference: limit the lifetime of an object reference



# Wrap-up

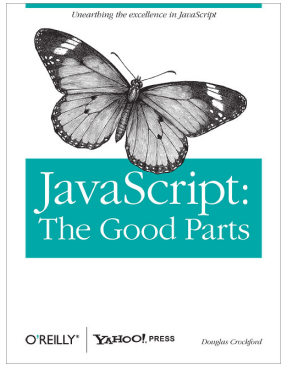
# Wrap-up

ES3

ES5

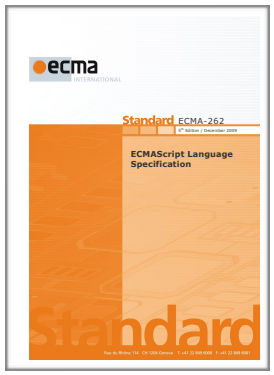
ES5/strict

SES




JavaScript:

the Good,
the Bad,




the Strict,

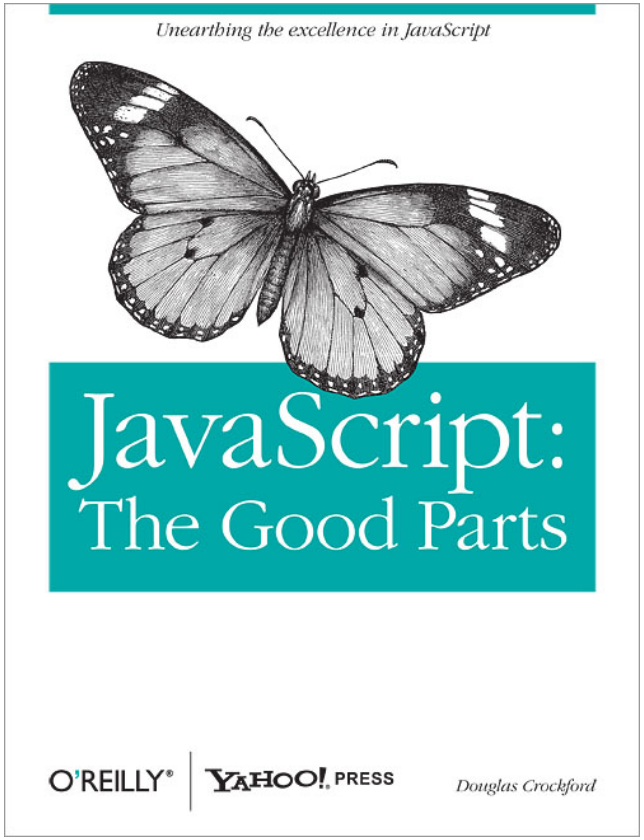
and
the Secure parts.

# Take-home messages

- Strict mode: a saner JavaScript (opt-in in ES5)
- ES6 builds on strict mode (classes and modules)
- Secure ECMAScript (SES) builds on strict mode
- If you want your code to be *securable*, opt into strict mode
- Proxies are a power-tool to express fine-grained security policies

# References

- Warmly recommended: Doug Crockford on JavaScript http://goo.gl/FGxmM (YouTube playlist)



# References

- ECMAScript 5:
  - “Changes to JavaScript Part 1: EcmaScript 5” (Mark S. Miller, Waldemar Horwat, Mike Samuel), Google Tech Talk (May 2009)
  - “Secure Mashups in ECMAScript 5” (Mark S. Miller), QCon 2012 Talk http://www.infoq.com/presentations/Secure-Mashups-in-ECMAScript-5
- Caja: https://developers.google.com/caja
- SES: http://code.google.com/p/google-caja/wiki/SES
- Proxies: http://soft.vub.ac.be/~tvcutsem/invokedynamic/proxies_tutorial
- ES6 latest developments: http://wiki.ecmascript.org and the es-discuss@mozilla.org mailing list.
  ES6 Modules: http://www.2ality.com/2013/07/es6-modules.html