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: 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

- Senior researcher at Alcatel-Lucent Bell Labs
- Prior: 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;
```

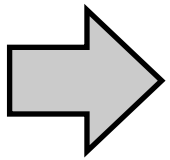
Bad Parts: global variables

- 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>
```



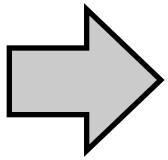
Better

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

Bad Parts: `with` statement

- `with`-statement turns object properties into variables

```
paint(widget.x,
      widget.y,
      widget.color);
```



```
with (widget) {
  paint(x,y,color);
}
```

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 double-precision floats)
- “var hoisting”: variables *appear* block-scoped but are really function-scoped
- “automatic semicolon insertion” implicitly adds semicolons, inadvertently changing the meaning of a program
- ...

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

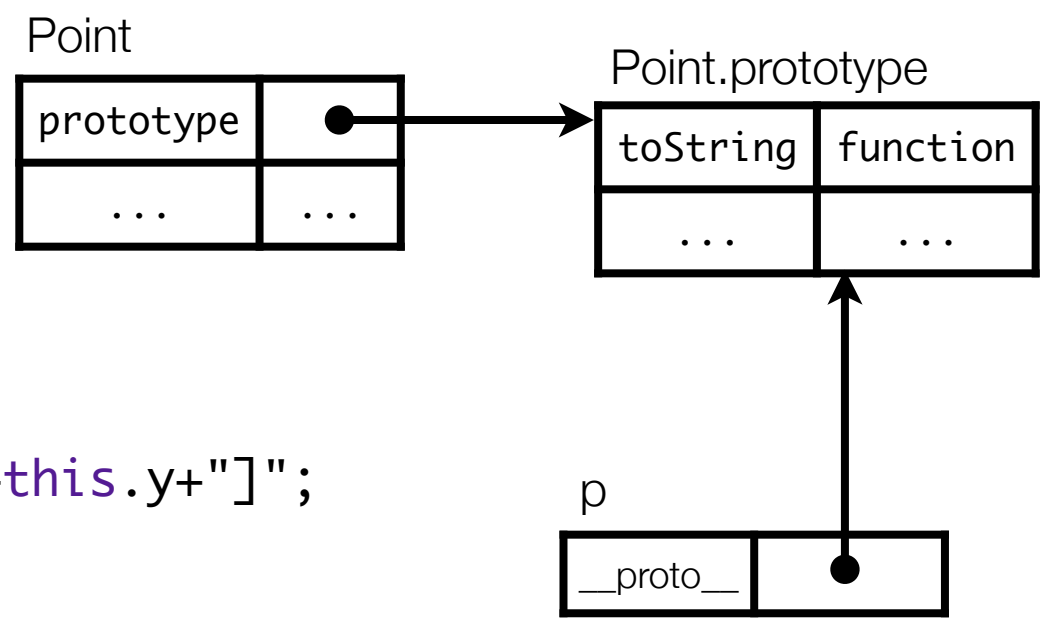
- No classes.
- Instead, functions may be used as object constructors.
- All objects have a “prototype” link
  - Lookup of a property on an object traverses the prototype links
  - Similar to inheritance between classes
  - In some implementations, the prototype is an explicit property of the object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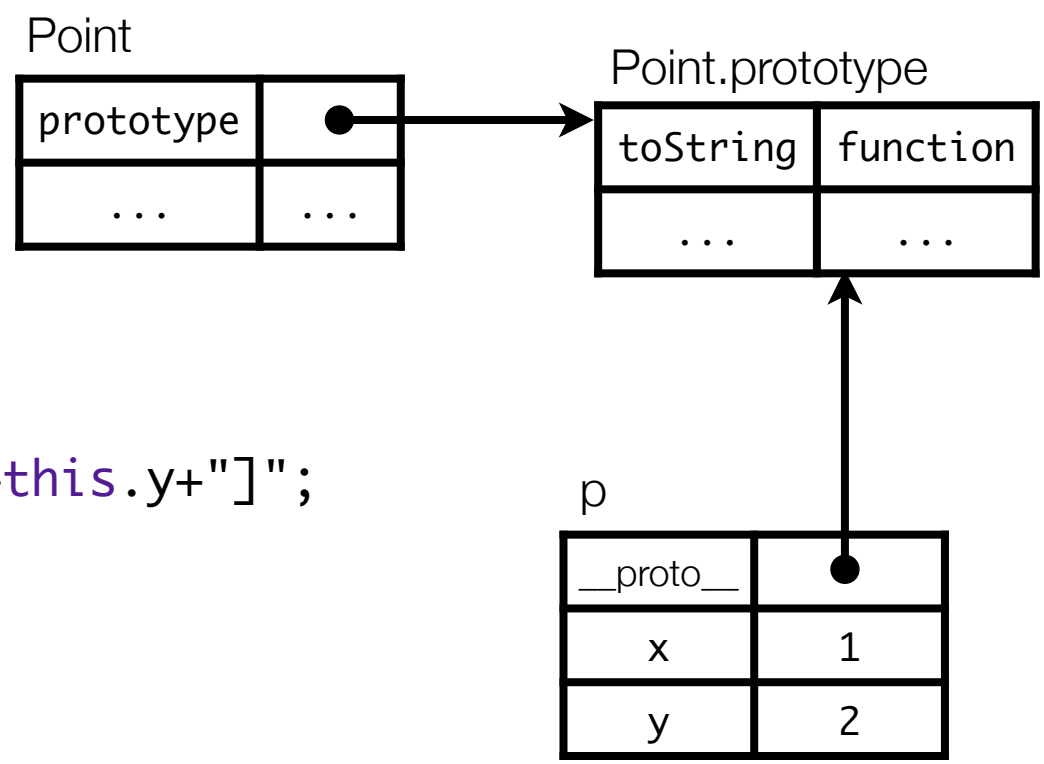
  }
}

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

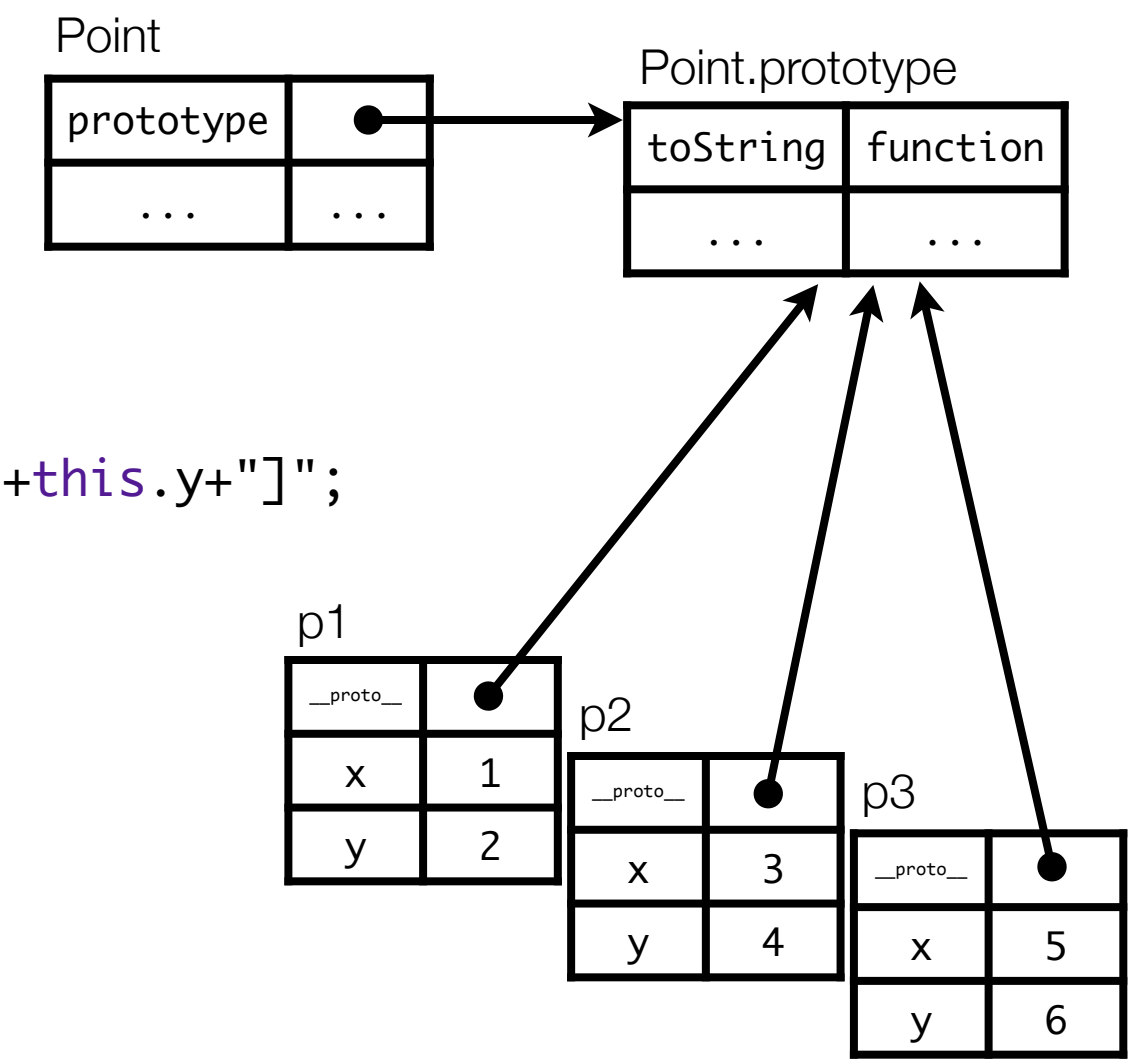


Objects

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

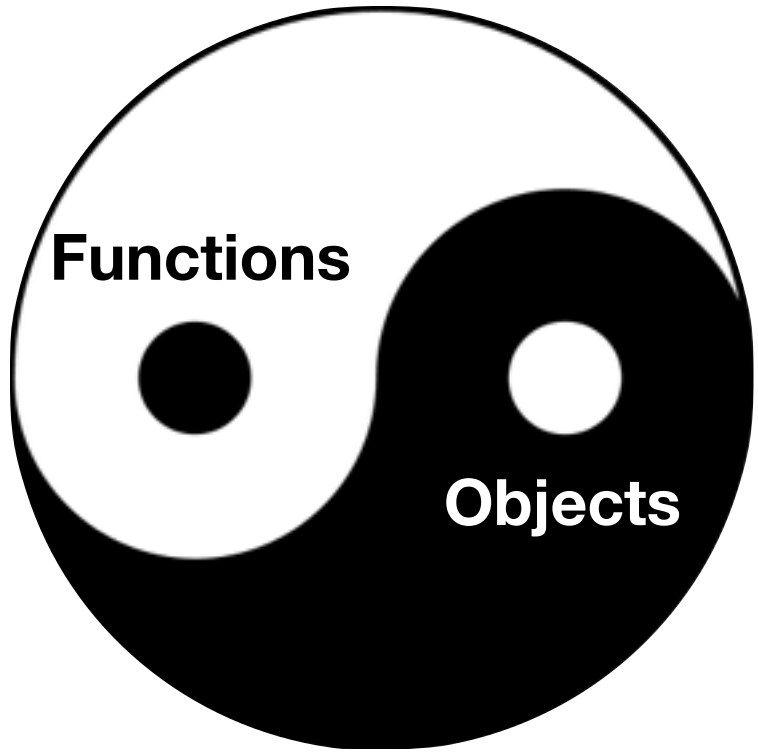
Point.prototype = {
  toString: function() {
    return "[Point "+this.x+","+this.y+"]";
  }
}

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



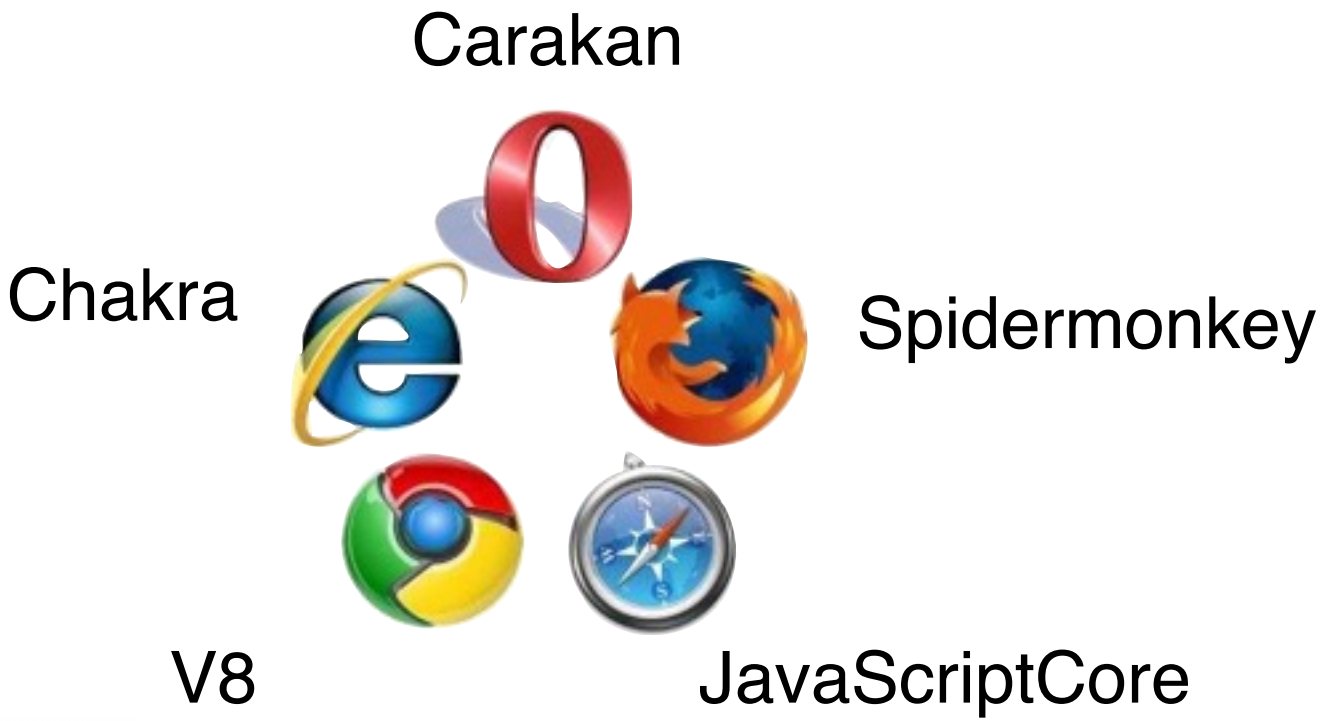
Summary so far

- Javascript: “a Lisp in C’s clothing” (D. Crockford)
- Good parts: functions, object literals
- Bad parts: global vars, no static scoping, …
- Functions and objects work well together



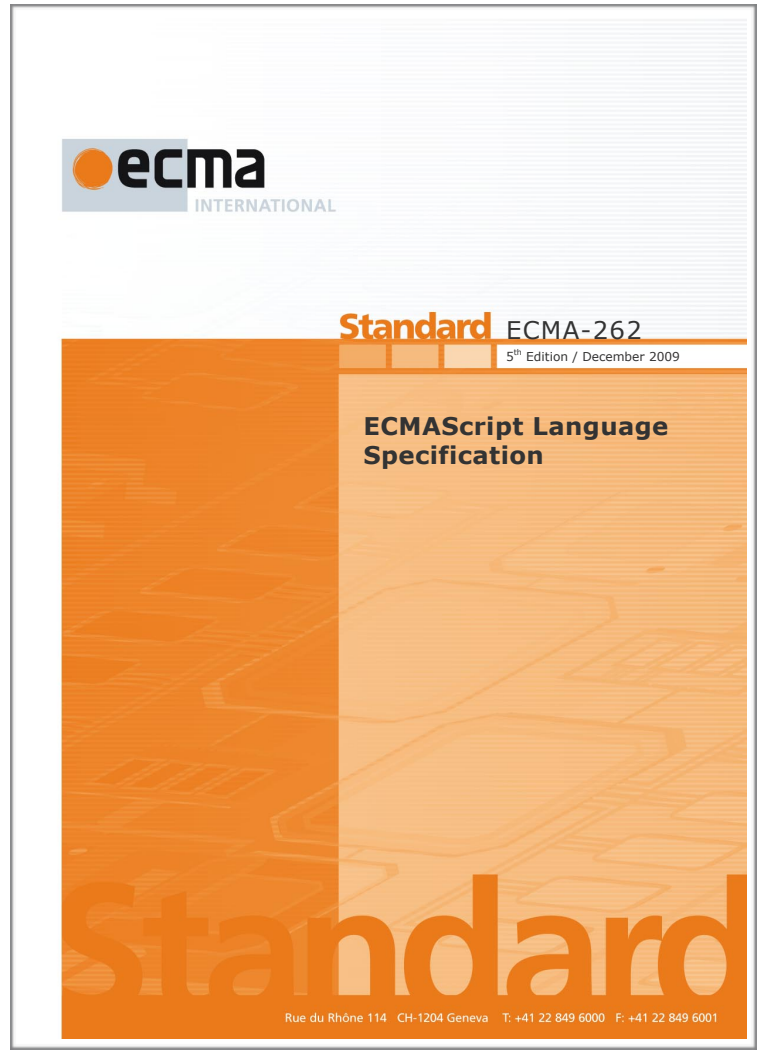
Part II: ECMAScript 5 and **Strict** Mode

ECMAScript: “Standard” JavaScript



ECMAScript specification

- 1st ed. 1997
- 2nd ed. 1998
- 3rd ed. 1999
- ~~4th ed.~~
- 5th ed. 2009
- *6th ed. June 2015*



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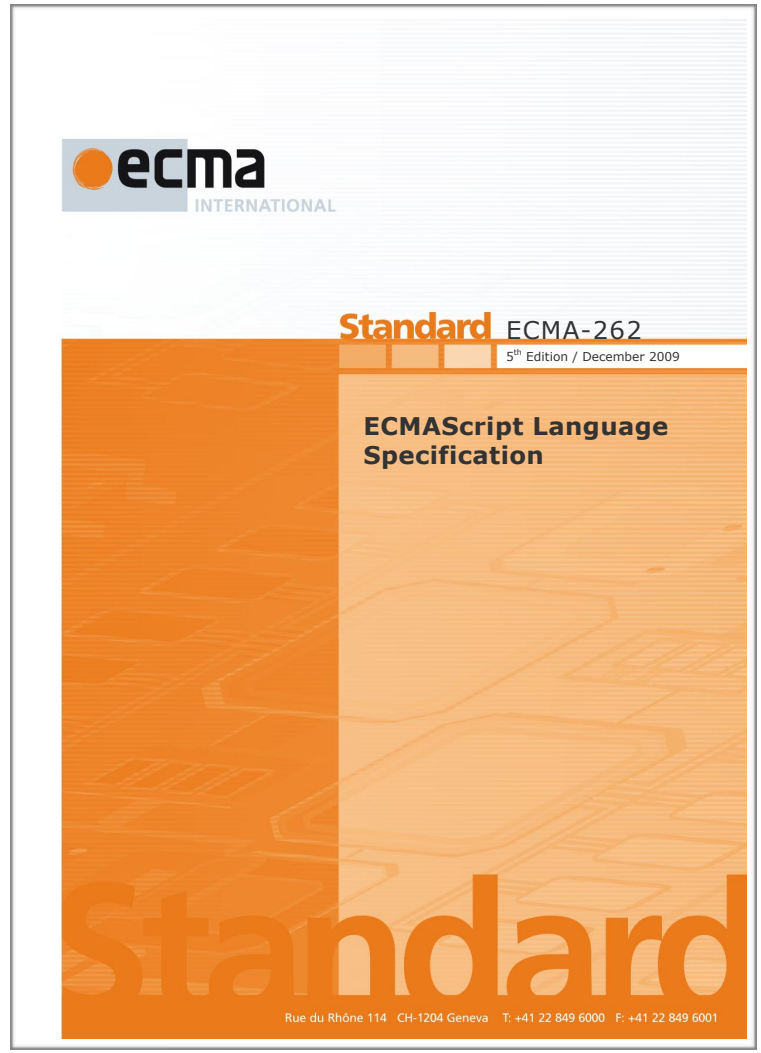


ECMAScript 5 Themes

- 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

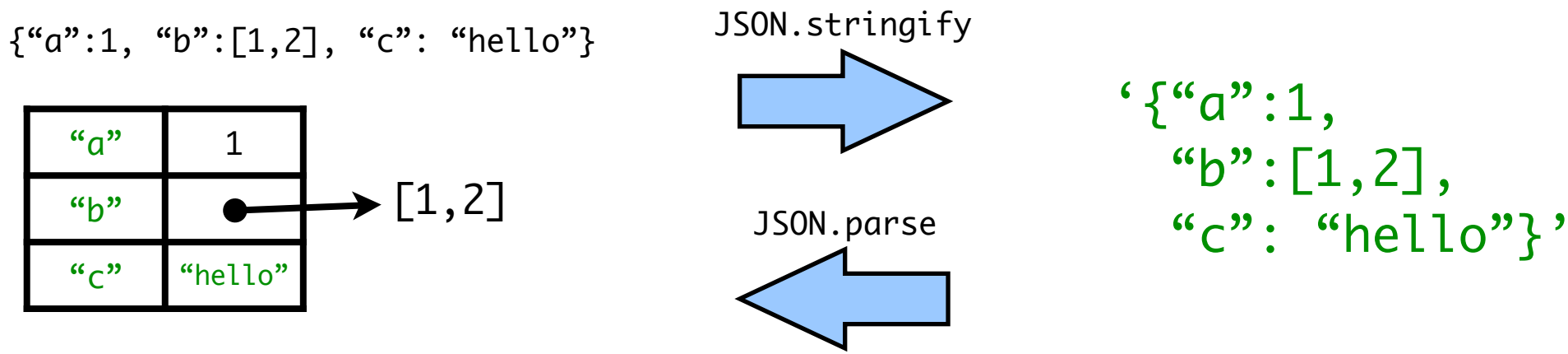
JSON

- **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
- Cannot protect an object from modifications by its clients
- Client code may *monkey-patch* shared objects
  - Powerful: allows to fix bugs or extend objects with new features
  - Brittle: easily leads to conflicting updates
  - Insecure: third-party scripts can deliberately modify shared objects

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>
```

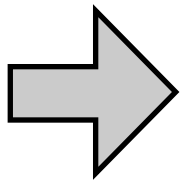
```
function f() {
  "use strict";
  ...
}
```

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

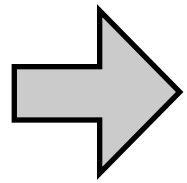



// f is now
// accidentally strict!
function f(){...}
</script>
```

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 https://github.com/lukehoban/es6features for an overview of ES6 features

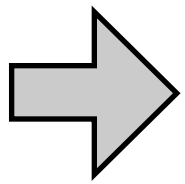
ECMAScript 6: classes

- 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...]";
  }
}

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



```
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: 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() {
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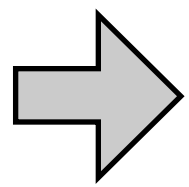
  }
}

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



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

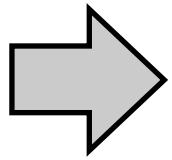
  toString() {
    return "[Point...]";
  }
}

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: modules

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

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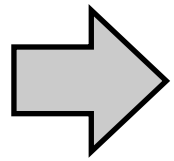
  }
};
</script>
```



```
<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

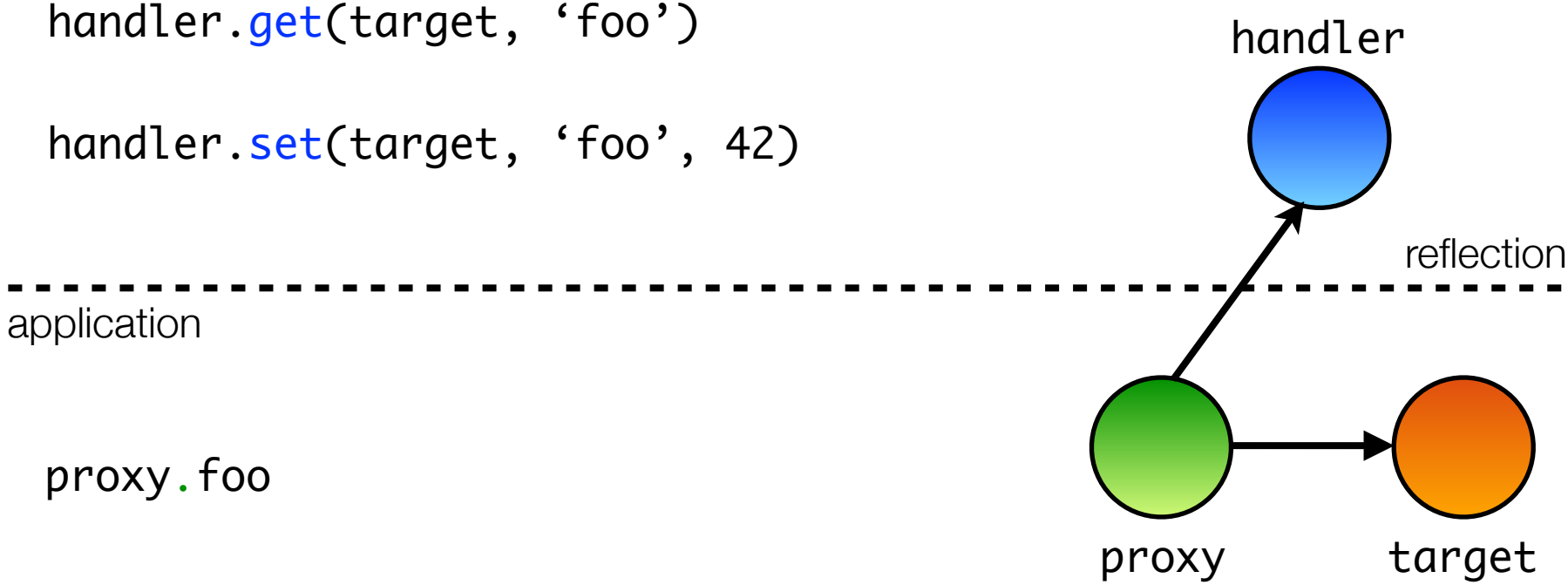
- Dynamic proxy objects: objects whose behavior can be controlled in JavaScript itself
- Useful to create *generic* (i.e. type-independent) object wrappers

ECMAScript 6 proxies

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

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

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

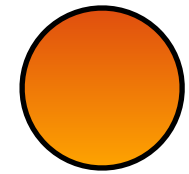



```
proxy.foo
```

```
proxy.foo = 42
```

Example: a revocable reference proxy

- revocable reference: limit the lifetime of an object reference



resource

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

Example: a revocable reference proxy

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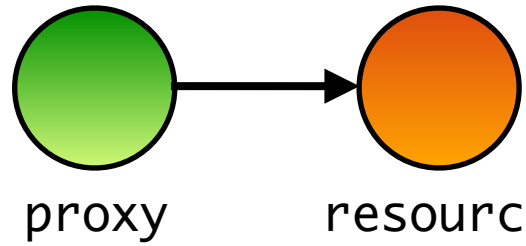


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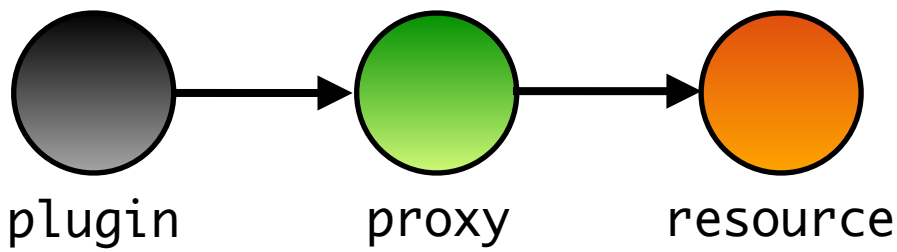

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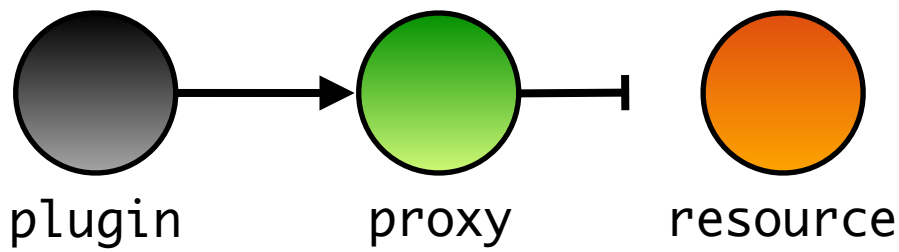



```
var {proxy,revoke} = makeRevocable(resource);
plugin.run(proxy);
// later
revoke();
```

Example: a revocable reference proxy

```
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; };
  }
}
```

ECMAScript 6: timeline

- Current draft is nearly feature-complete. Available online: http://people.mozilla.org/~jorendorff/es6-draft.html
- Spec needs to be ratified by ECMA, targeting June 2015
- However: browsers will not support ES6 overnight
- Parts of ES6 already supported on some browsers today*
- Use “transpilers” in the meantime to bridge the ES5-ES6 gap

* see http://kangax.github.io/es5-compat-table/es6/ for current compatibility status

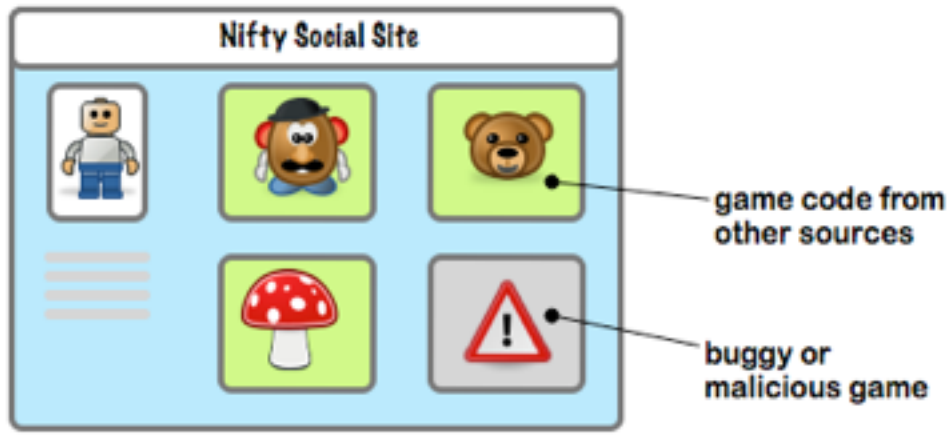
ECMAScript 6 transpilers

- Compile ECMAScript 6 to ECMAScript 5
- Google Traceur: mature and quite feature-complete
- Microsoft TypeScript: roughly a superset of ES6. Bonus: type inference and optional static typing.
- 6to5: not feature-complete but aims to produce readable ES5 code

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:



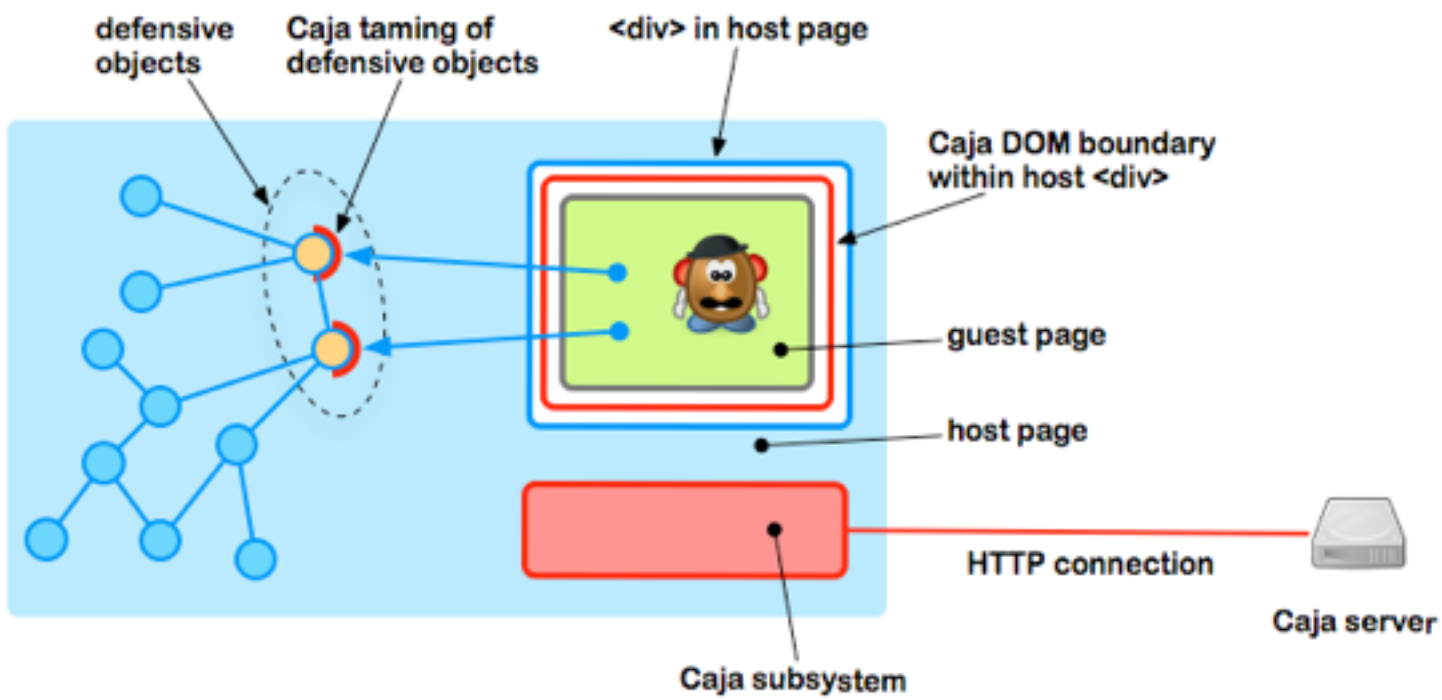
https://developers.google.com/caja/docs/about/

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

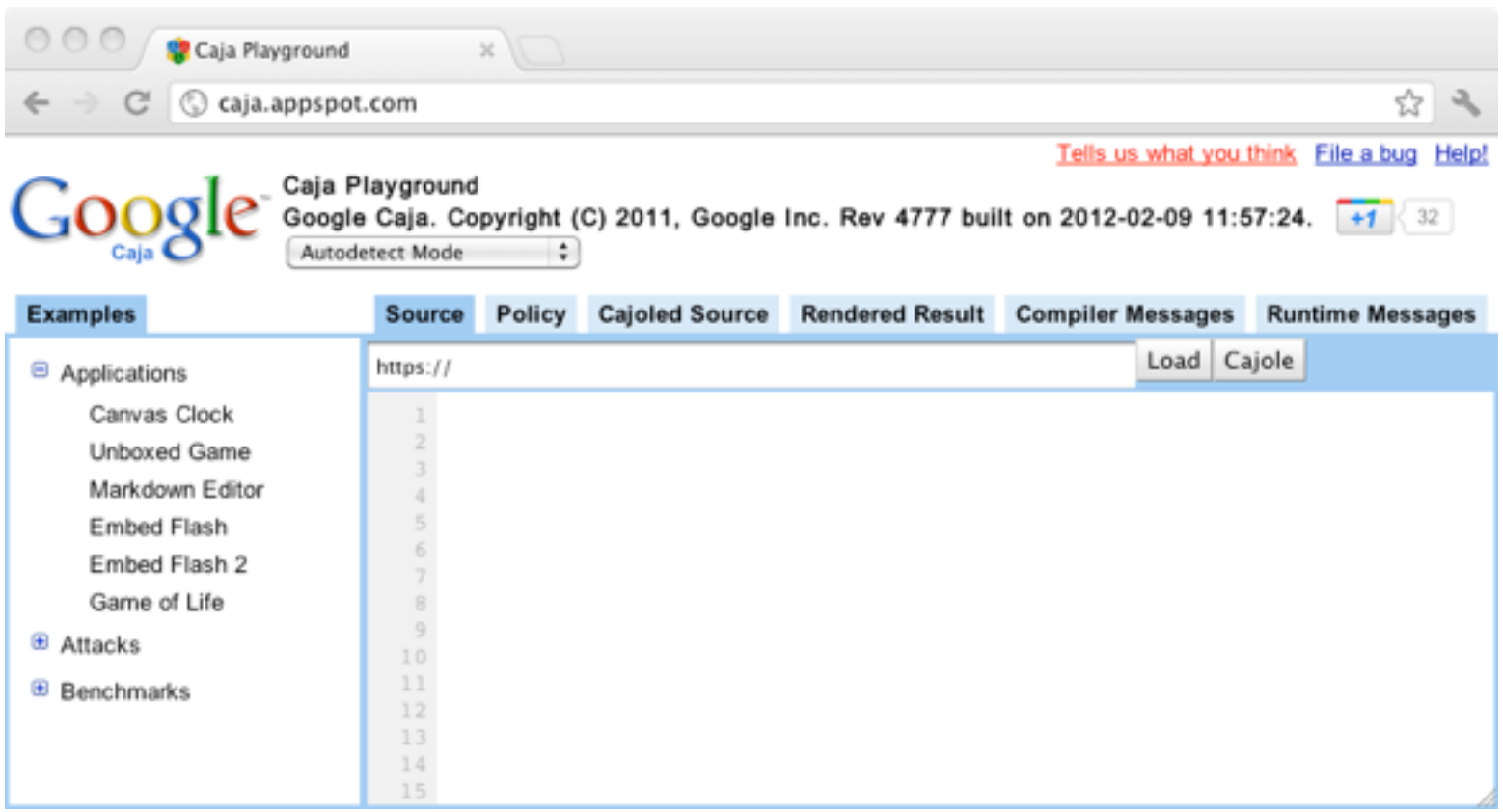
- Caja proxies the DOM. Untrusted content interacts with a virtual DOM, never with the real DOM.



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

Caja

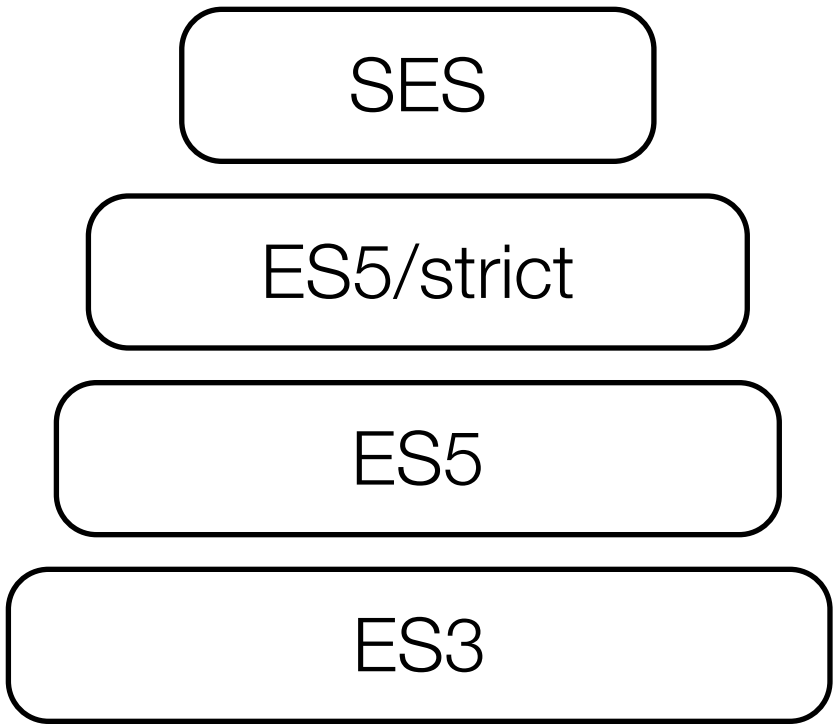
- Example: Caja Playground
- http://caja.appspot.com



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>
```

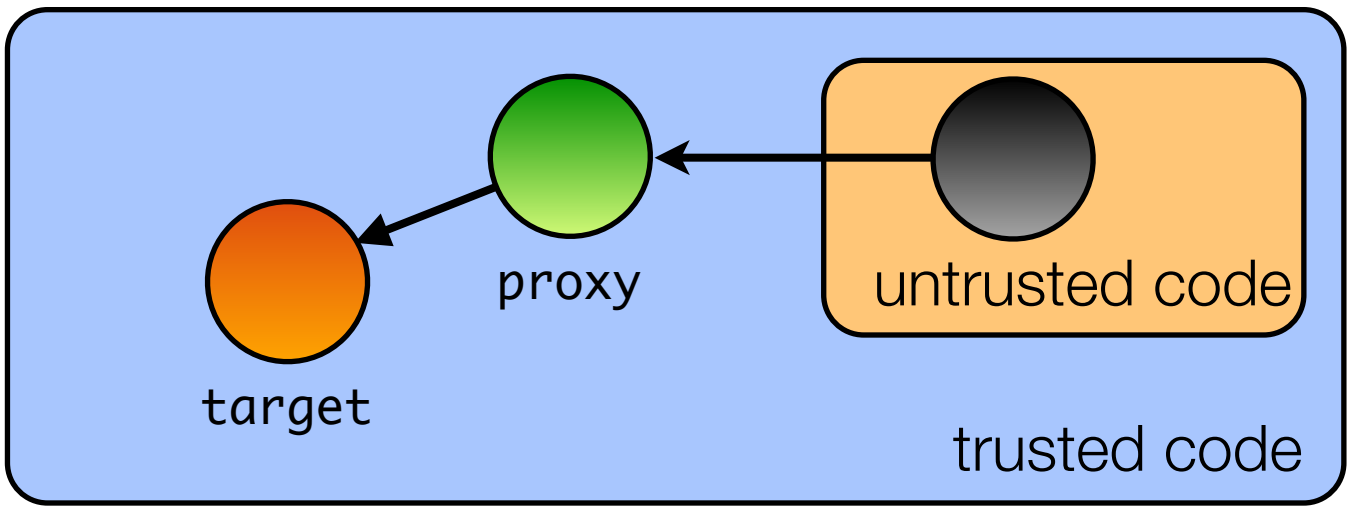
Secure ECMAScript

```
<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

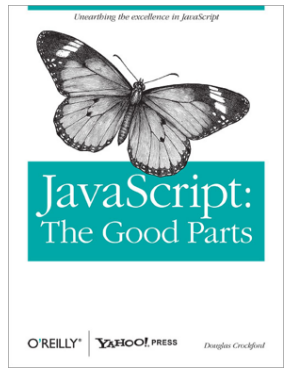
Wrap-up

ES3

ES5

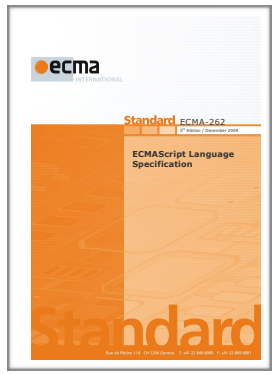
ES5/strict

SES



JavaScript:

the Good,
the Bad,



the Strict,

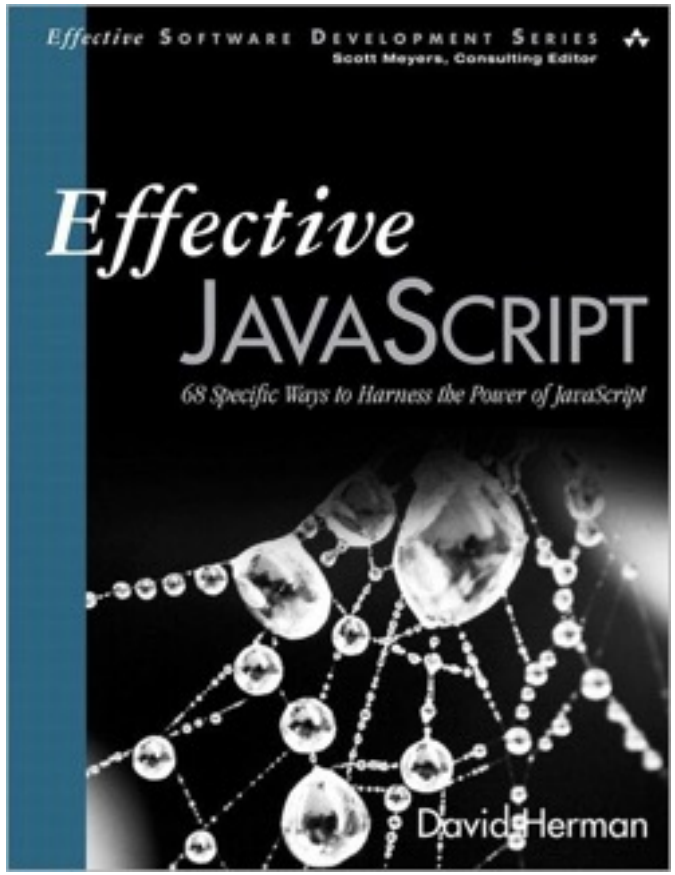
and
the Secure parts.

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
- ES6 latest developments: http://wiki.ecmascript.org and the es-discuss@mozilla.org mailing list.
  ES6 Modules: http://www.2ality.com/2014/09/es6-modules-final.html
  ES6 Proxies: http://www.2ality.com/2014/12/es6-proxies.html
  R. Mark Volkmann: “Using ES6 Today!”: http://sett.ociweb.com/sett/settApr2014.html

Thanks for listening!

Writing robust JavaScript code

or

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

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