Writing robust client-side code using Modern JavaScript

or

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

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Talk Outline

- Part I: 20 years of JavaScript
- Part II: the Good and the Bad parts
- Part III: ECMAScript 5 and Strict Mode
- Part IV: ECMAScript 6
- Part V: 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)

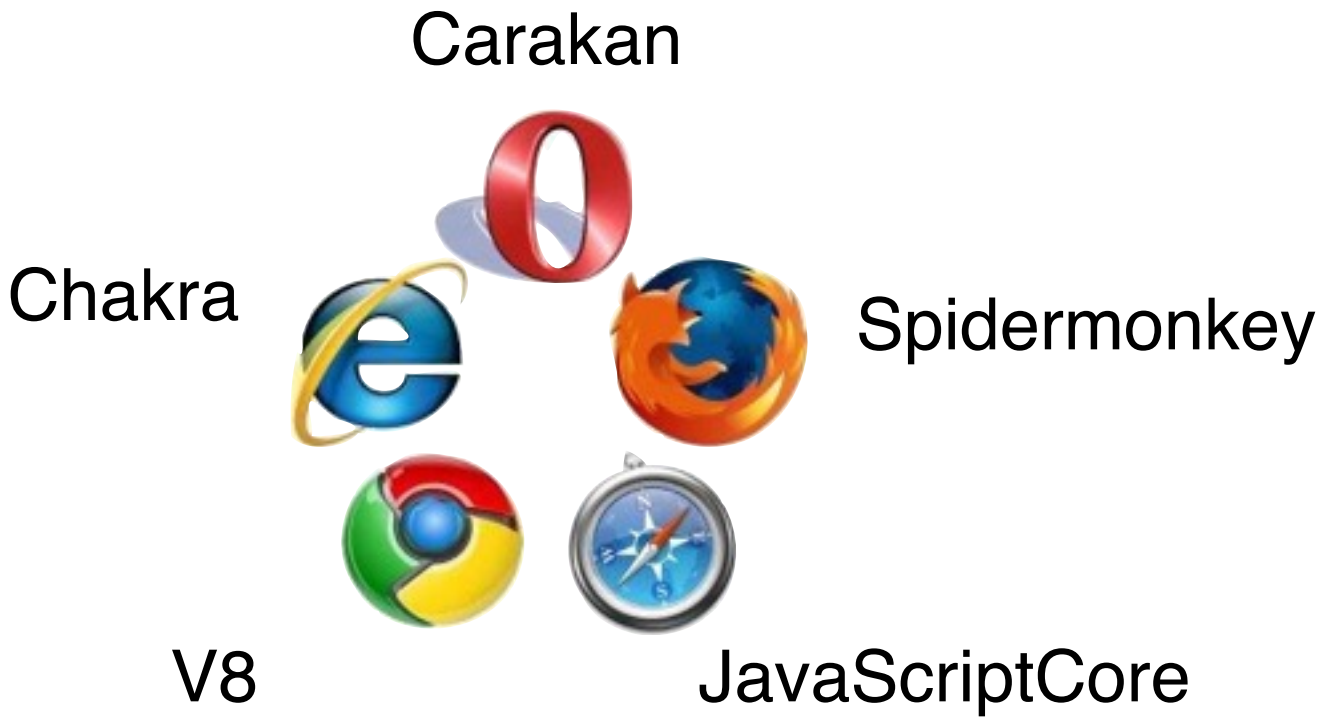
Part I: 20 years of Javascript

JavaScript's origins

- Invented by Brendan Eich in 1995, to support client-side scripting in Netscape Navigator
- First called *LiveScript*, then *JavaScript*, then standardized as *ECMAScript*
- Microsoft "copied" JavaScript in IE JScript, "warts and all"

Brendan Eich,
Inventor of JavaScript

ECMAScript: “Standard” JavaScript



ECMAScript: “Standard” JavaScript

~~Carakan~~ V8

Chakra

Spidermonkey

V8

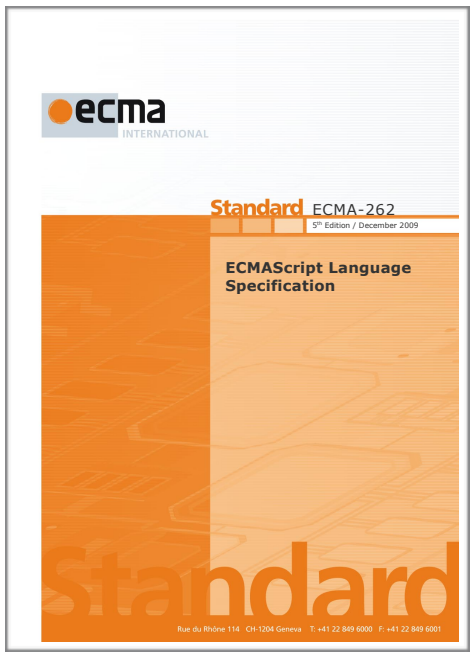
JavaScriptCore

(170.000+ npm packages!)

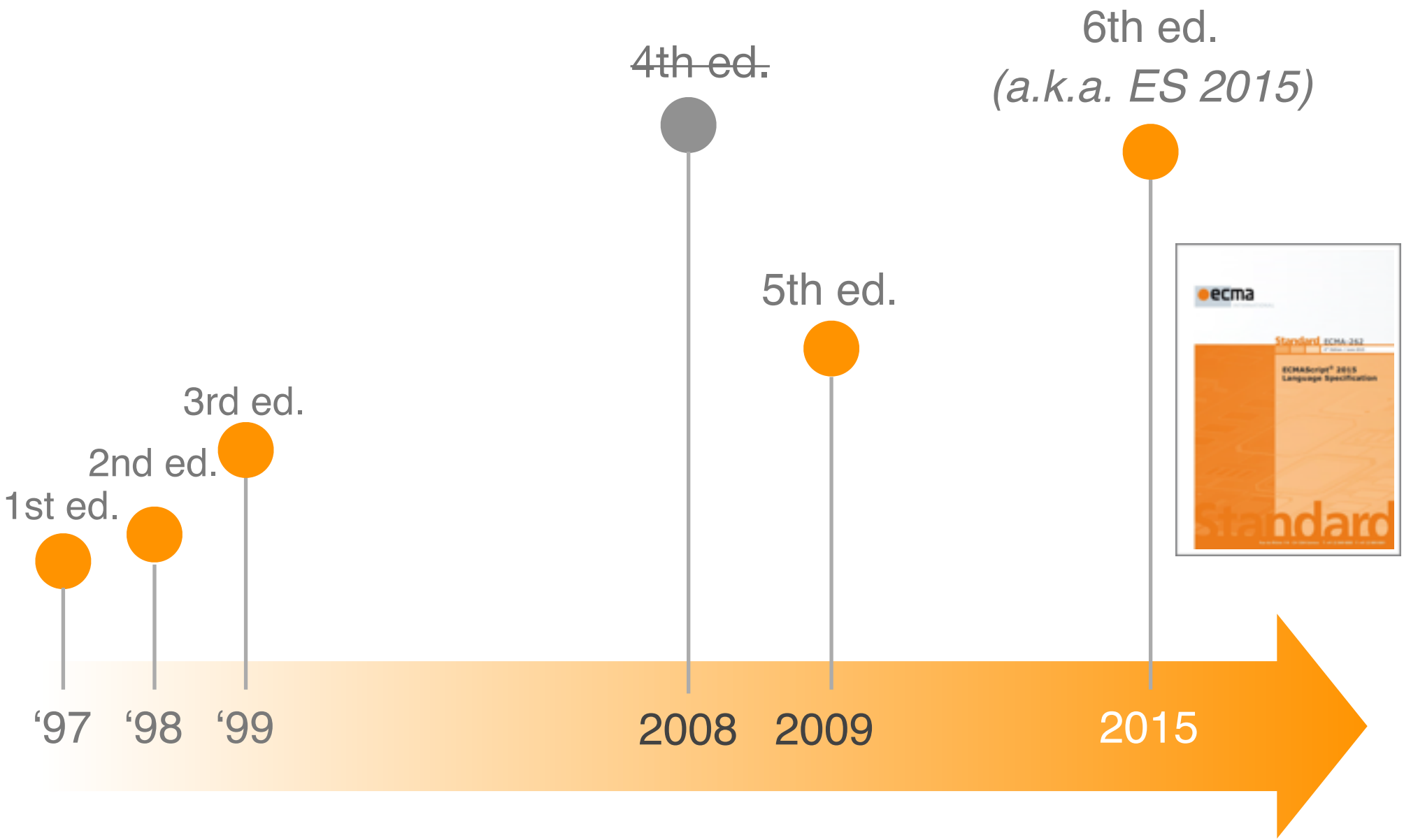
TC39: the JavaScript “standardisation committee”

- Representatives from major Internet companies, browser vendors, web organisations, popular JS libraries and academia. Meets bi-monthly.
- Maintains the ECMA-262 specification.
- The spec is a handbook mainly intended for language implementors.

Allen Wirfs-Brock,
ECMA-262 5th & 6th ed. editor



A brief history of the ECMAScript spec



Part II: the **Good** and the **Bad** parts

The world's most misunderstood language

Douglas Crockford,
Inventor of JSON

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;
```

The Good Parts

- Functions as first-class objects
- Dynamic objects with prototype-based inheritance
- Object literals
- Array literals

The Bad Parts

- Global variables (no modules)
- `with` statement (breaks lexical scoping)
- Implicit type coercion (‘’ == 0)
- No integers (all numbers are IEEE 754 double-precision floats)
- “var hoisting”: variables *appear* block-scoped but are really function-scoped
- …

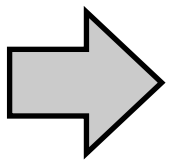
Bad Parts: global variables

- 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>
```



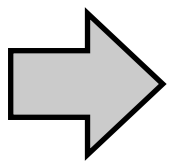
Better

```
<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
}
```

Bad Parts: implicit type coercions

- == operator coerces arguments before testing for equality

```
'' == '0'    // false
 0 == ''     // true
 0 == '0'    // true
```

- === operator does not coerce its arguments

```
'' === '0'    // false
 0 === ''     // false
 0 === '0'    // false
```

- Morale: avoid ==, always use ===

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

ECMAScript 5 Themes

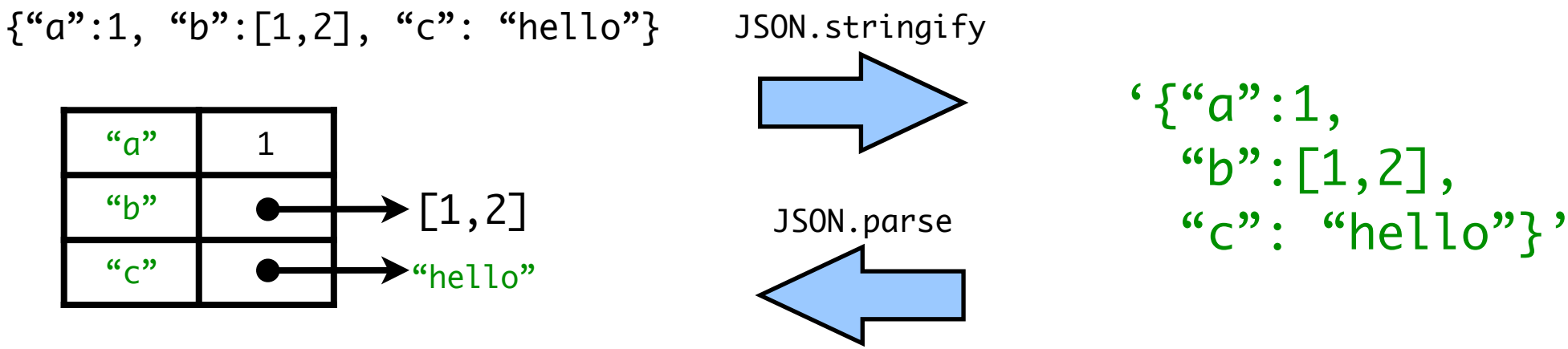
- Support for more robust programming
  - Safe JSON parsing
  - Tamper-proof objects
  - Strict mode

ECMAScript 5 Themes

- Support for more robust programming
  - **Safe JSON parsing**
  - Tamper-proof objects
  - Strict mode

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

- Support for more robust programming
  - Safe JSON parsing
  - **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 Themes

- Support for more robust programming
  - Safe JSON parsing
  - Tamper-proof objects
  - **Strict mode**

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";
  ...
}
```

Ecmascript 5 Strict: no silent errors

- 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: true static scoping

- 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: 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!)
```

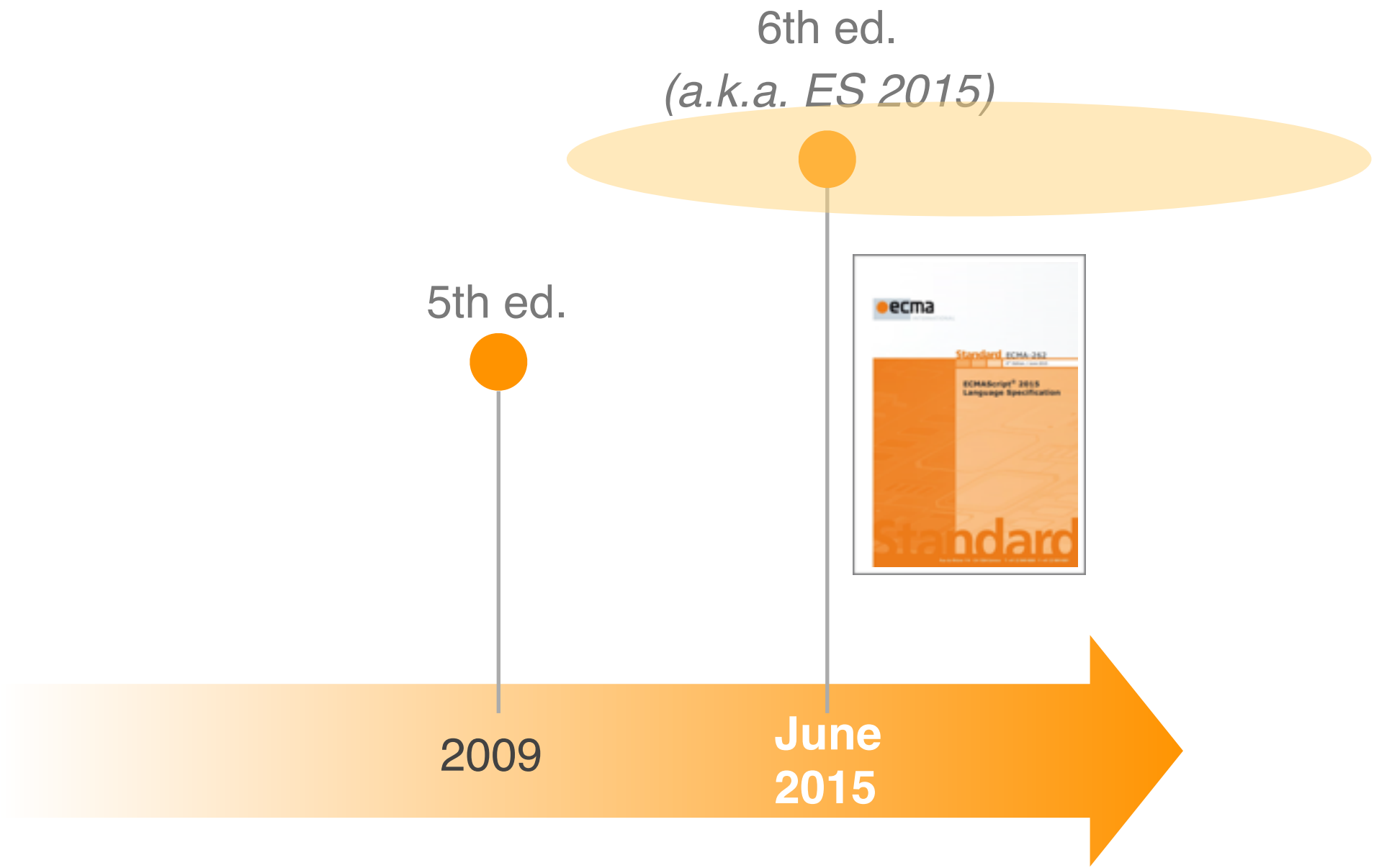
Part IV: ECMAScript 6

ECMAScript 6

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

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

ECMAScript 6: timeline

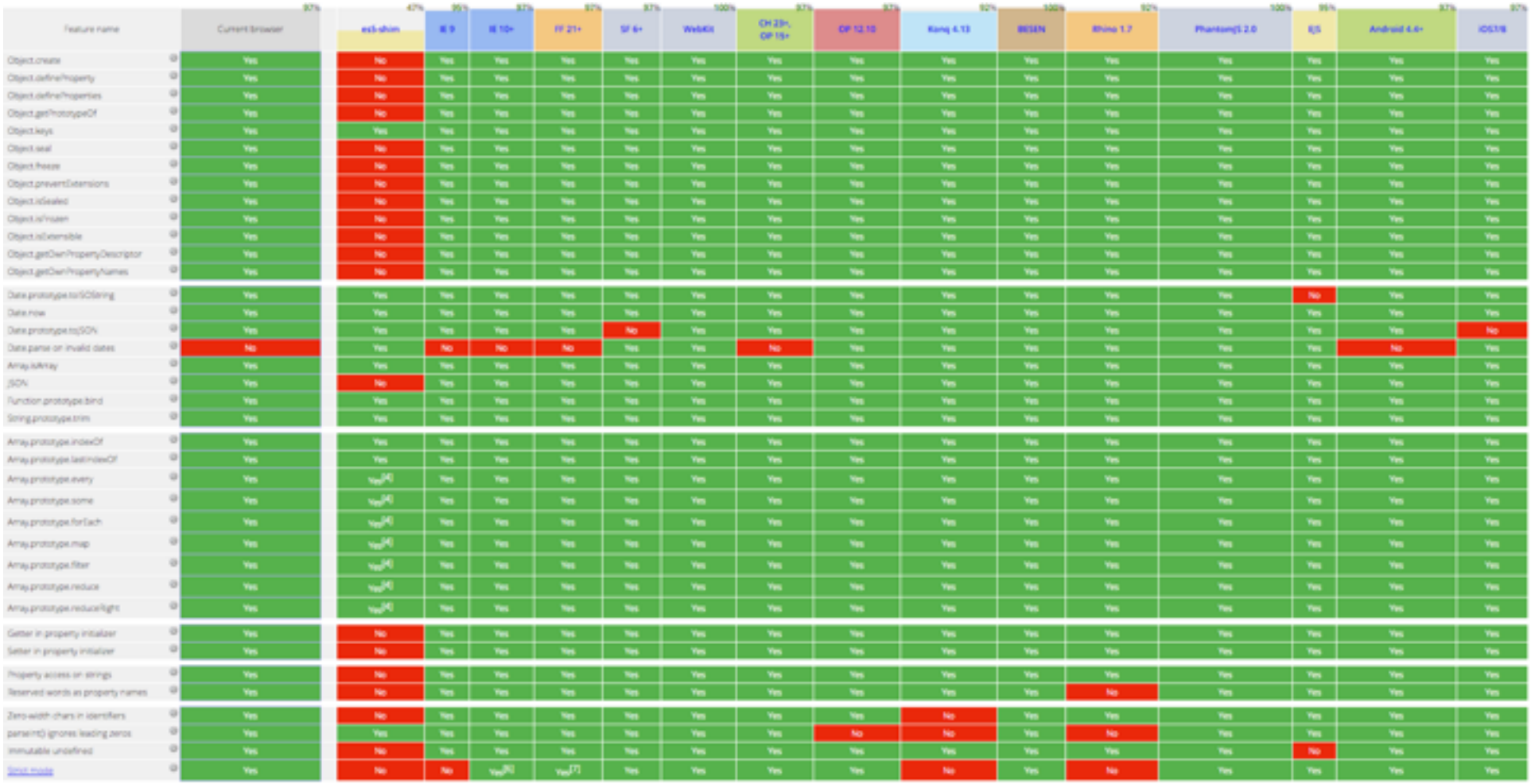


ECMAScript 6 support (february 2016)

Feature name	Current browser	Traceur	Babel + core-js[1]	Closure	TypeScript + core-js	es6-shim	IE 11	Edge 12[3]	Edge 13[3]	FF 38 ESR	FF 44	FF 45	CH 48, OP 35[2]	CH 49, OP 36[2]	CH 50, OP 37[2]	SF 6.1, SF 7	SF 7.1, SF 8	SF 9	WK	KQ 4.14[4]	PJS
Optimisation																					
proper tail calls (tail call optimisation)	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2	2/2	0/2	0/2
Syntax																					
default function parameters	6/7	4/7	4/7	4/7	4/7	0/7	0/7	0/7	0/7	3/7	4/7	4/7	0/7	7/7	7/7	0/7	0/7	0/7	7/7	0/7	0/7
rest parameters	5/5	4/5	3/5	2/5	3/5	0/5	0/5	5/5	5/5	4/5	5/5	5/5	5/5	5/5	5/5	0/5	0/5	0/5	5/5	0/5	0/5
spread (...) operator	15/15	15/15	13/15	12/15	4/15	0/15	0/15	12/15	15/15	15/15	15/15	15/15	15/15	15/15	15/15	0/15	5/15	9/15	10/15	0/15	0/15
object literal extensions	6/6	6/6	6/6	4/6	6/6	0/6	0/6	6/6	6/6	6/6	6/6	6/6	6/6	6/6	6/6	0/6	1/6	5/6	6/6	0/6	0/6
for..of loops	7/9	9/9	9/9	6/9	3/9	0/9	0/9	6/9	7/9	7/9	7/9	7/9	7/9	7/9	7/9	0/9	2/9	8/9	9/9	0/9	0/9
octal and binary literals	4/4	2/4	4/4	2/4	4/4	2/4	0/4	4/4	4/4	4/4	4/4	4/4	4/4	4/4	4/4	0/4	0/4	4/4	4/4	0/4	0/4
template strings	5/5	4/5	4/5	3/5	3/5	0/5	0/5	4/5	5/5	5/5	5/5	5/5	5/5	5/5	5/5	0/5	0/5	5/5	5/5	0/5	0/5
RegExp 'y' and 'u' flags	2/4	2/4	2/4	0/4	0/4	0/4	0/4	2/4	4/4	2/4	2/4	2/4	0/4	2/4	2/4	0/4	0/4	0/4	0/4	0/4	0/4
destructuring, declarations	21/22	20/22	21/22	18/22	14/22	0/22	0/22	0/22	0/22	19/22	19/22	19/22	0/22	21/22	21/22	0/22	9/22	19/22	22/22	0/22	0/22
destructuring, assignment	0/24	23/24	24/24	15/24	18/24	0/24	0/24	0/24	0/24	20/24	21/24	21/24	0/24	23/24	23/24	0/24	12/24	21/24	24/24	0/24	0/24
destructuring, parameters	22/23	19/23	20/23	17/23	14/23	0/23	0/23	0/23	0/23	18/23	18/23	18/23	0/23	22/23	22/23	0/23	10/23	18/23	22/23	0/23	0/23
Unicode code point escapes	2/2	1/2	1/2	1/2	1/2	0/2	0/2	2/2	2/2	0/2	1/2	1/2	2/2	2/2	2/2	0/2	0/2	2/2	2/2	0/2	0/2
new.target	2/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2	1/2	0/2	2/2	2/2	2/2	2/2	2/2	0/2	0/2	0/2	1/2	0/2	0/2
Bindings																					
const	8/8	6/8	6/8	6/8	6/8	0/8	8/8	8/8	8/8	8/8	8/8	8/8	5/8	8/8	8/8	1/8	1/8	1/8	8/8	2/8	1/8
let	10/10	8/10	8/10	8/10	7/10	0/10	8/10	8/10	8/10	0/10	8/10	8/10	5/10	10/10	10/10	0/10	0/10	0/10	10/10	0/10	0/10
block-level function declaration[12]	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	No	No	No	No	No	No
Functions																					
arrow functions	13/13	11/13	9/13	11/13	9/13	0/13	0/13	9/13	13/13	8/13	11/13	13/13	11/13	13/13	13/13	0/13	0/13	0/13	13/13	0/13	0/13
class	23/23	16/23	18/23	8/23	16/23	0/23	0/23	0/23	23/23	0/23	0/23	23/23	0/23	23/23	23/23	0/23	0/23	15/23	23/23	0/23	0/23
super	8/8	7/8	4/8	4/8	7/8	0/8	0/8	0/8	8/8	0/8	0/8	8/8	0/8	8/8	8/8	0/8	0/8	6/8	8/8	0/8	0/8
generators	21/25	23/25	22/25	16/25	0/25	0/25	0/25	0/25	25/25	20/25	21/25	23/25	19/25	21/25	22/25	0/25	0/25	0/25	25/25	0/25	0/25
Built-ins																					
typed arrays	43/46	0/46	45/46	0/46	45/46	0/46	16/46	42/46	44/46	41/46	42/46	42/46	43/46	44/46	44/46	18/46	18/46	18/46	44/46	8/46	18/46
Map	16/18	13/18	18/18	0/18	18/18	14/18	7/18	15/18	17/18	14/18	16/18	17/18	16/18	16/18	16/18	0/18	10/18	17/18	18/18	0/18	0/18
Set	16/18	13/18	18/18	0/18	18/18	14/18	7/18	15/18	17/18	14/18	16/18	17/18	16/18	16/18	16/18	0/18	10/18	17/18	18/18	0/18	0/18
WeakMap	9/10	5/10	10/10	0/10	10/10	0/10	4/10	9/10	9/10	7/10	8/10	8/10	9/10	9/10	9/10	0/10	5/10	10/10	10/10	0/10	0/10

(Source: Juriy Zaytsev (kangax)
http://kangax.github.io/es5-compat-table/es6)

ECMAScript 5 support (october 2015)



(Source: Juriy Zaytsev (kangax)
http://kangax.github.io/es5-compat-table/es5)

ECMAScript 6 compilers

- Compile ECMAScript 6 to ECMAScript 5
- **Babel**: focus on producing readable (as-if hand-written) ES5 code. Supports JSX as well.

- Microsoft **TypeScript**: technically not ES6 but roughly a superset of ES6. Bonus: type inference and optional static typing.

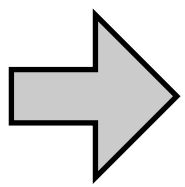
ECMAScript 6: classes

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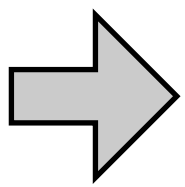
var p = new Point(1,2);
p.x;
p.toString();
```



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

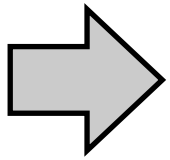
  toString() {
    return "[Point...]";
  }
}

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>
```

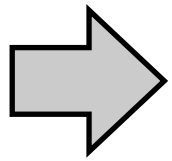
```
<script>
var res = myLib.inc();
</script>
```

```
<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() {
    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

- Dynamic module loader API (WHATWG Draft Spec *)

```
System.import("lib/math").then(function(m) {
  alert("2π = " + m.sum(m.pi, m.pi));
});
```

```
// create a sandboxed environment
var loader = new Loader({
  global: wrap(window) // replace ‘console.log’
});
loader.eval("console.log(\"hello world!\");");
```

(Source: https://babeljs.io/docs/learn-es2015/)

* See http://whatwg.github.io/loader/

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

- Proxy objects: objects whose behavior can be controlled in JavaScript itself (*virtual* objects)

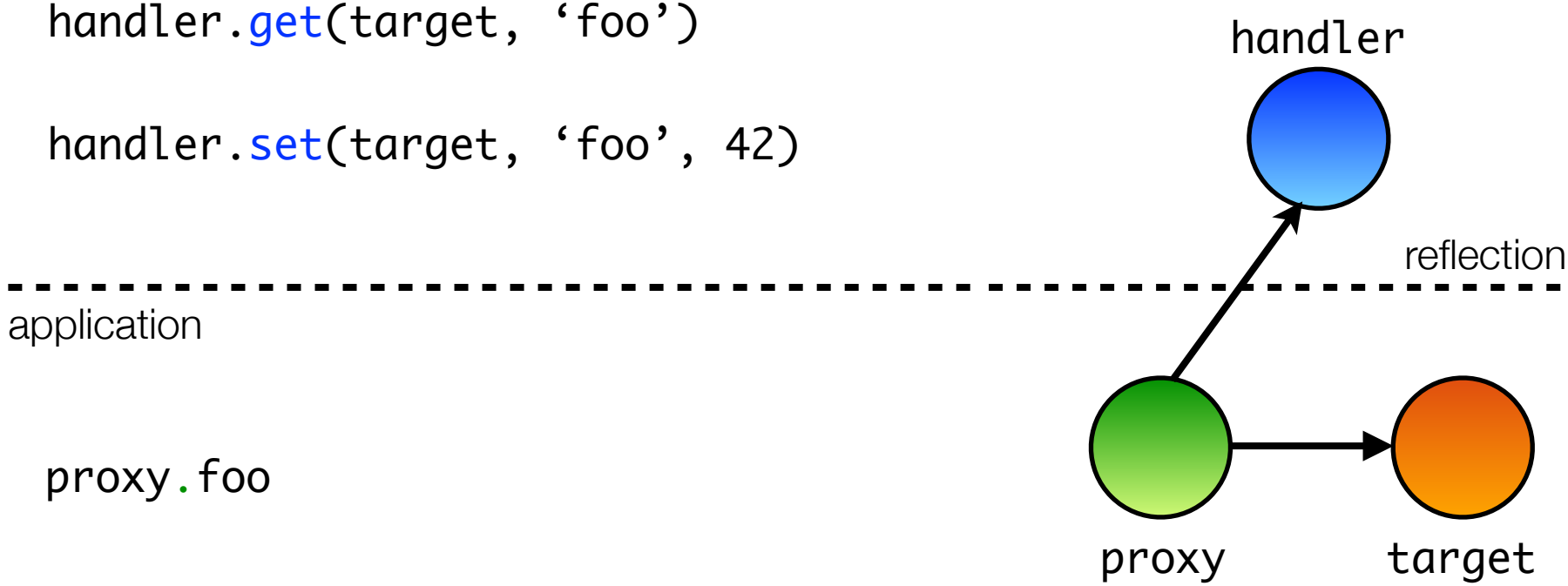
- Useful to create *generic* (i.e. type-independent) object wrappers

ECMAScript 6 proxies

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

```
handler.get(target, ‘foo’)
```

```
handler.set(target, ‘foo’, 42)
```

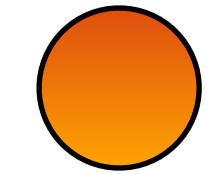



```
proxy.foo
```

```
proxy.foo = 42
```

Example: a revocable reference proxy

- revocable reference: limit the lifetime of an object reference

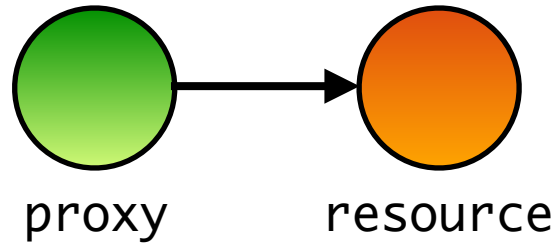


resource

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

Example: a revocable reference proxy

- revocable reference: limit the lifetime of an object reference

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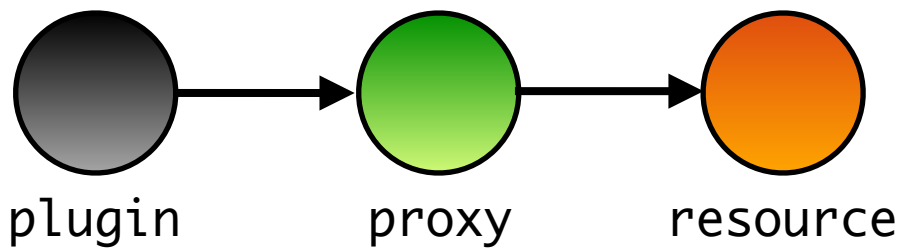
```

Example: a revocable reference proxy

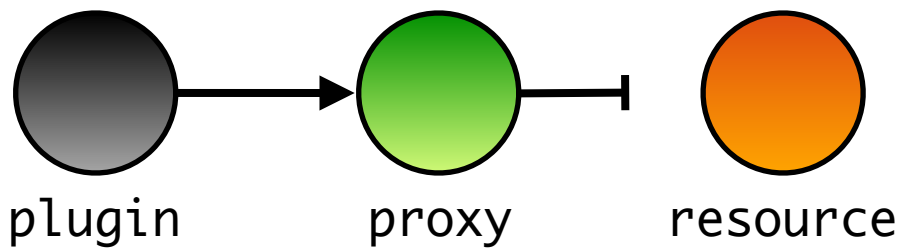
- revocable reference: limit the lifetime of an object reference




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

Example: a revocable reference proxy

- revocable reference: limit the lifetime of an object reference




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

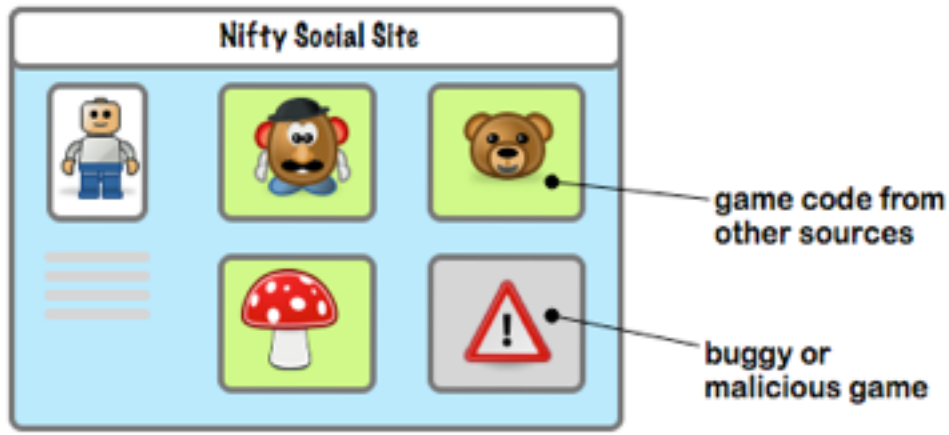
Example: a revocable reference proxy

```
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; };
  }
}
```

Part V: 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:



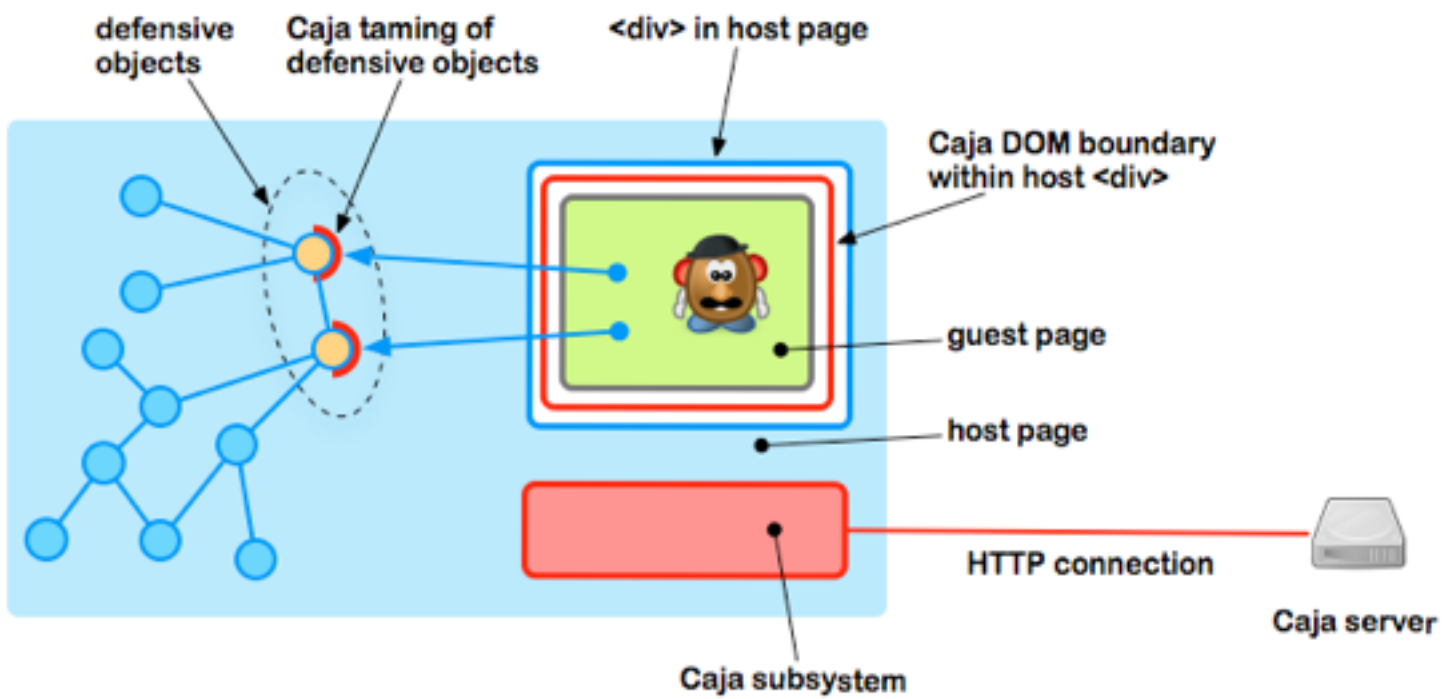
https://developers.google.com/caja/docs/about/

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

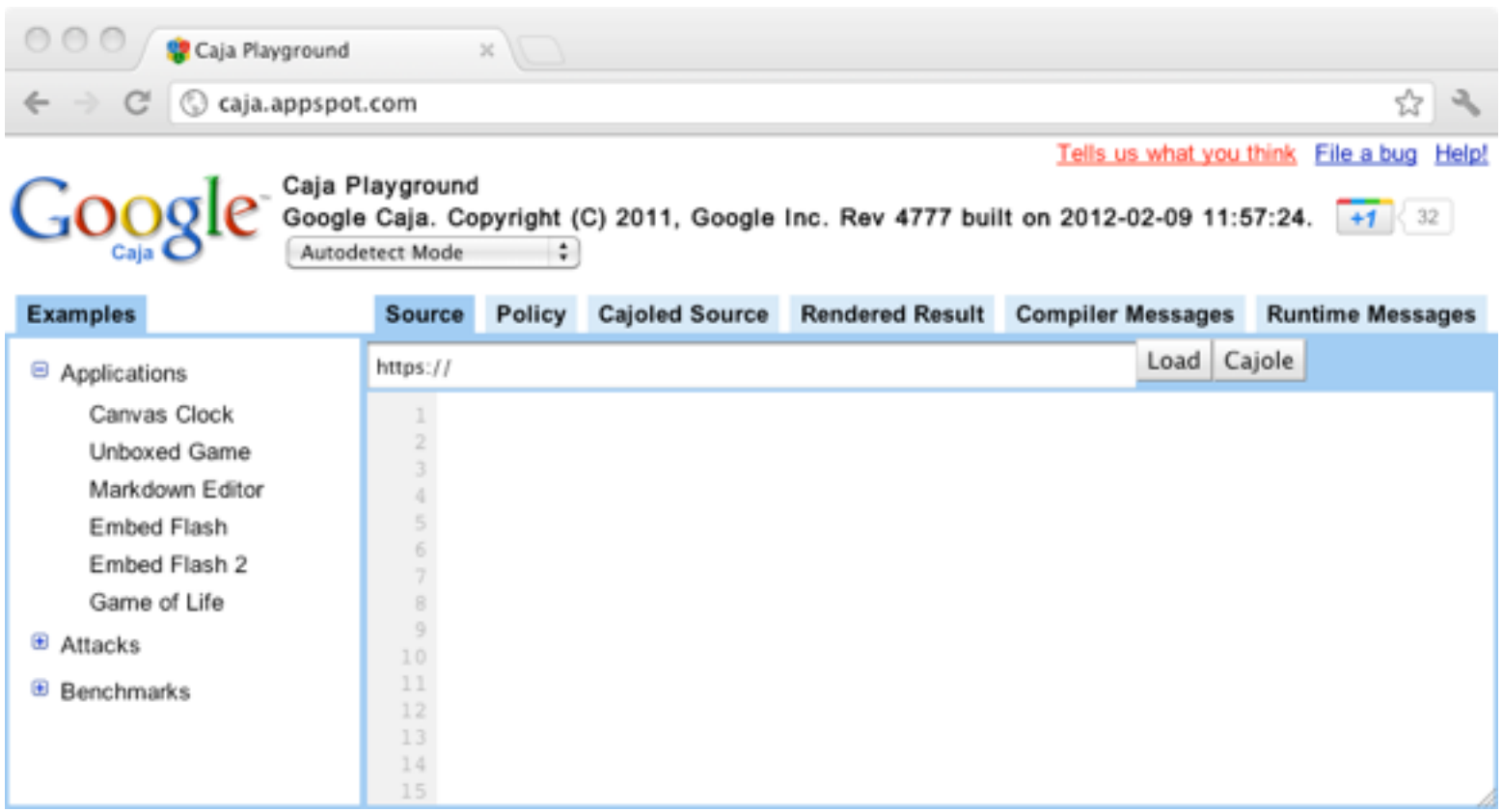
- Caja proxies the DOM. Untrusted content interacts with a virtual DOM, never with the real DOM.



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

Caja

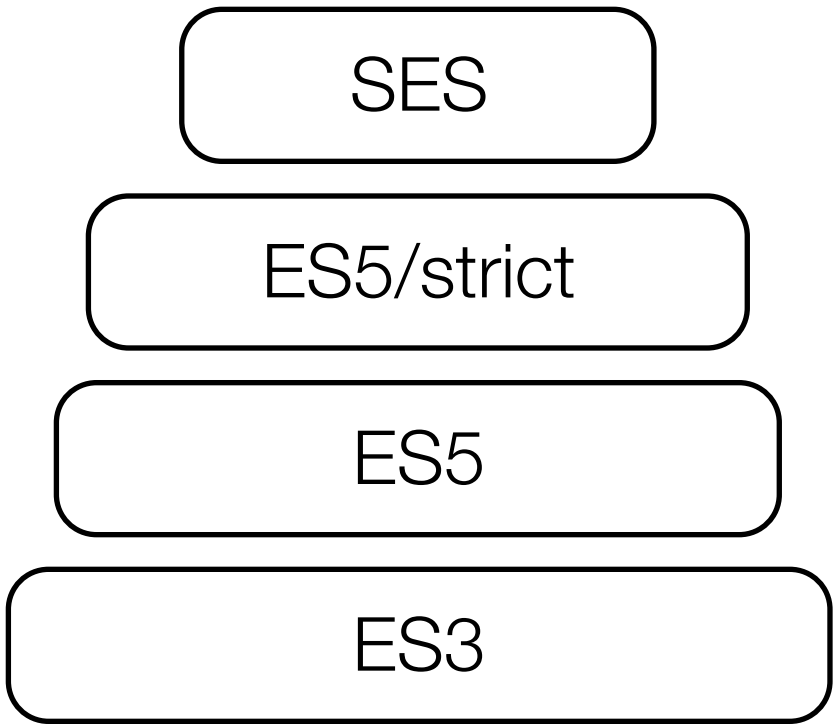
- Example: Caja Playground
- http://caja.appspot.com



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>
```

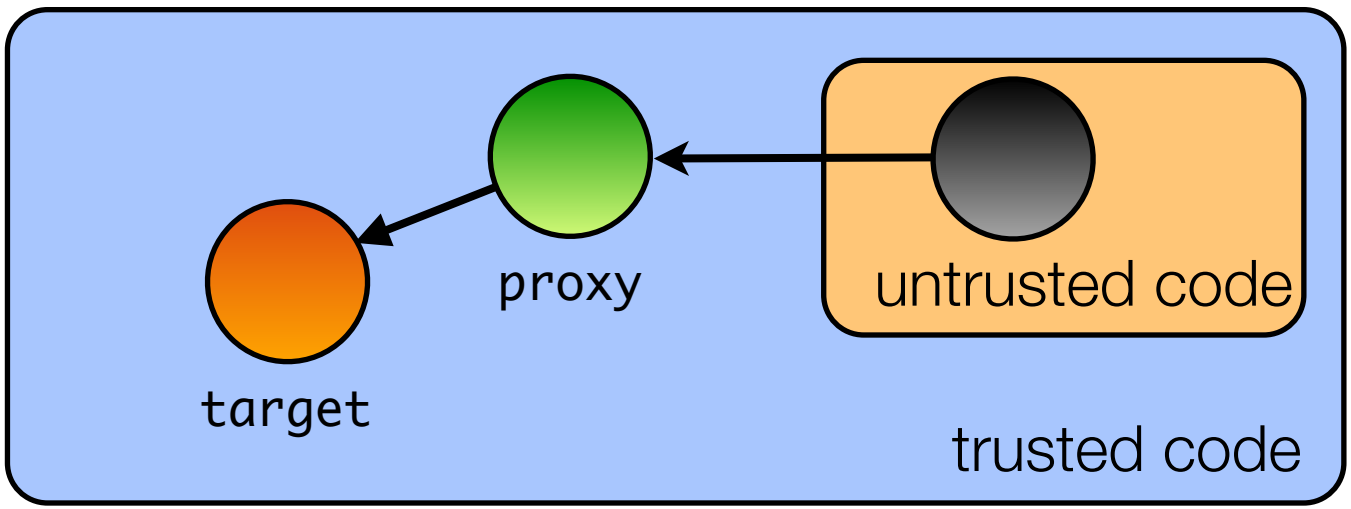
Secure ECMAScript

```
<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 powerful objects with restrictive proxies (“taming”)
  - E.g. revocable reference: limit the lifetime of an object reference



Wrap-up

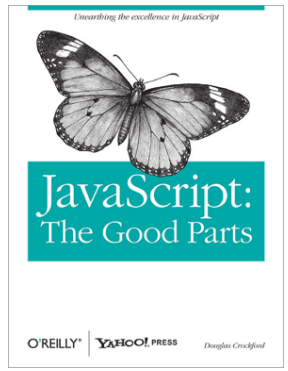
Wrap-up

ES3

ES5

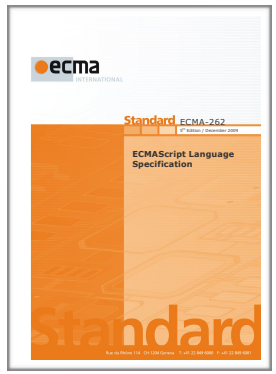
ES5/strict

SES



JavaScript:

the Good,
the Bad,



the Strict,

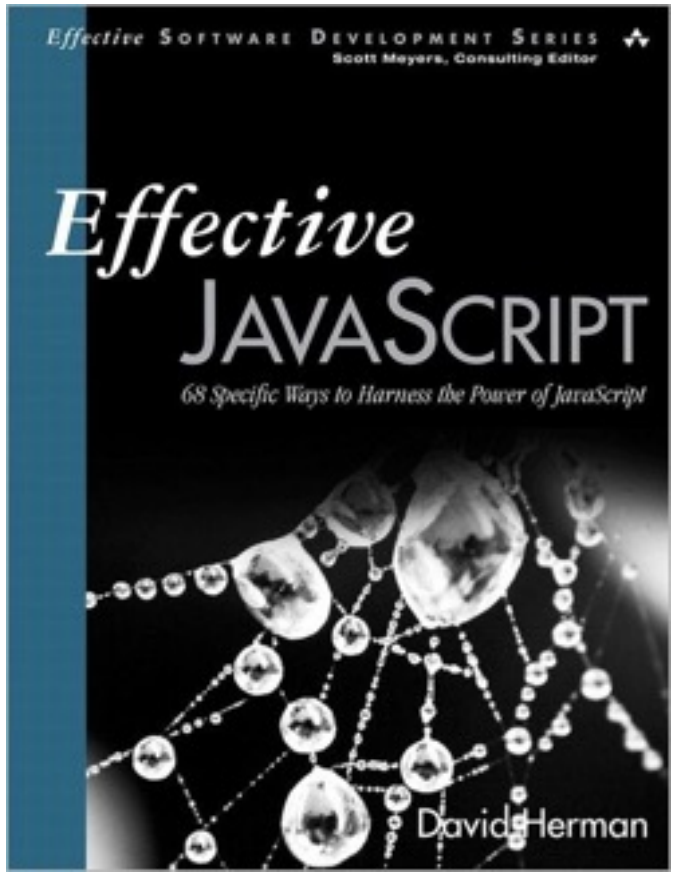
and
the Secure parts.

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: https://github.com/google/caja/wiki/SES
- HTML templating with template strings: http://www.2ality.com/2015/01/template-strings-html.html
- ES6 latest developments: https://github.com/tc39 and the es-discuss@mozilla.org mailing list.
  ES6 Modules: http://www.2ality.com/2014/09/es6-modules-final.html https://github.com/ModuleLoader/es6-module-loader and http://jsmodules.io/
  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 client-side code using Modern JavaScript

or

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

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