<!DOCTYPE html>
<html>
<body>

<h1>My First Web Page</h1>

<script>
document.write("<p>My First JavaScript</p>");
</script>

</body>
</html>
Another Example

<!DOCTYPE html>
<html>
<body>

<h1>My First Web Page</h1>

<p id="demo">My First Paragraph.</p>

<script>
document.getElementById("demo").innerHTML="My First JavaScript";
</script>

</body>
</html>
Stand-alone implementation

- Spidermonkey command-line interpreter
  - Read-eval-print loop
    - Enter declaration or statement
    - Interpreter executes
    - Displays value
    - Returns to input state

```javascript
js> function add(x, y) { return x+y; }
js> add(2,3)
5
js> add(4,5)
9
js>
```
Why talk about JavaScript?

• Very widely used, and growing
  – Web pages, AJAX, Web 2.0
  – Increasing number of web-related applications
  – Adapted as a general purpose programming language

• Illustrates core PL concepts
  – First-class functions
  – Objects, in a pure form

• Some interesting trade-offs and consequences
  – Powerful modification capabilities
    • Add new method to object, redefine prototype, access caller ...
  – Difficult to predict program properties in advance
    • Challenge for programmers, implementation, security, correctness
Keys to Good Language Design

• Motivating application
  – C: systems prog, Lisp: symbolic computation, Java: set-top box, JavaScript: web scripting

• Abstract machine
  – Underlying data structures that programs manipulate
  – JavaScript: web page -> document object model

• Theoretical considerations
  – ECMA Standard specifies semantics of JavaScript
What’s a scripting language?

• One language embedded in another
  – A scripting language is used to write programs that produce inputs to another language processor
    • Embedded JavaScript computes HTML input to the browser
    • Shell scripts compute commands executed by the shell

• Common characteristics of scripting languages
  – String processing – since commands often strings
  – Simple program structure
    • Avoid complicated declarations, to make easy to use
    • Define things “on the fly” instead of elsewhere in program
  – Flexibility preferred over efficiency, safety
    • Is lack of safety a good thing? Maybe not for the Web!

• Small programs
JavaScript History

• Developed by Brendan Eich at Netscape, 1995
  – Scripting language for Navigator 2
• Later standardized for browser compatibility
  – ECMAScript Edition 3 (aka JavaScript 1.5) -> ES5, ...
• Related to Java in name only
  – Name was part of a marketing deal
• Various implementations available
  – Spidermonkey interactive shell interface
  – Rhino: http://www.mozilla.org/rhino/
  – Browser JavaScript consoles
Motivation for JavaScript

• Netscape, 1995
  – Netscape > 90% browser market share
  – Opportunity to do “HTML scripting language”
  – Brendan Eich
    “I hacked the JS prototype in ~1 week in May
    And it showed! Mistakes were frozen early
    Rest of year spent embedding in browser” - ICFP talk, 2005

• Common uses of JavaScript have included:
  – Form validation
  – Page embellishments and special effects
  – Dynamic content manipulation
  – Web 2.0: functionality implemented on web client
    • Significant JavaScript applications: Gmail client, Google maps
Design goals

• Brendan Eich’s 2005 ICFP talk
  – 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!
JavaScript design

• Functions based on Lisp/Scheme
  – first-class inline higher-order functions
    function (x) { return x+1; }
• Objects based on Smalltalk/Self
  – var pt = {x : 10, move : function(dx){this.x += dx}}
  – Functions are also objects
• Lots of secondary issues ...
  – “In JavaScript, there is a beautiful, elegant, highly expressive language that is buried under a steaming pile of good intentions and blunders.”
    Douglas Crockford
Sample “details”

• Which declaration of g is used?

```javascript
var f = function(){
  var a = g();
  function g() { return 1;};
  function g() { return 2;};
  var g = function() { return 3;}
  return a;}
var result = f(); // what is result?
```

```javascript
var scope = "global"
function f() {
  print(scope);
  var scope = "local"
  print(scope);
}
// variable initialized here
// but defined throughout f
```
What makes a good programming language design?
Language syntax

• JavaScript is case sensitive
  – HTML is not case sensitive; onClick, ONCLICK, ... are HTML

• Statements terminated by returns or semi-colons (;)
  – x = x+1; same as x = x+1
  – Semi-colons can be a good idea, to reduce errors

• “Blocks”
  – Group statements using { ... }
  – Not a separate scope, unlike other languages (see later slide)

• Variables
  – Define a variable using the var statement
  – Define implicitly by its first use, which must be an assignment
    • Implicit definition has global scope, even if it occurs in nested scope
Web example: page manipulation

• Some possibilities
  – createElement(elementName)
  – createTextNode(text)
  – appendChild(newChild)
  – removeChild(node)

• Example: Add a new list item:

```javascript
var list = document.getElementById('list1')
var newitem = document.createElement('li')
var newtext = document.createTextNode(text)
list.appendChild(newitem)
newitem.appendChild(newtext)
```

This example uses the browser Document Object Model (DOM)
We will focus on JavaScript as a language, not its use in the browser
Web example: browser events

```
<script type="text/JavaScript">
  function whichButton(event) {
    if (event.button==1) {
      alert("You clicked the left mouse button!")
    } else {
      alert("You clicked the right mouse button!")
    }
  }
</script>

Mouse event causes page-defined function to be called

Other events: onLoad, onMouseMove, onKeyPress, onUnLoad
JavaScript primitive datatypes

- **Boolean**
  - Two values: *true* and *false*
- **Number**
  - 64-bit floating point, similar to Java double and Double
  - No integer type
  - Special values *NaN* (not a number) and *Infinity*
- **String**
  - Sequence of zero or more Unicode characters
  - No separate character type (just strings of length 1)
  - Literal strings using ' or " characters (must match)
- **Special values**
  - *null* and *undefined*
  - `typeof(null) = object; typeof(undefined)=undefined`
Type Checking

• Static types (Algol, C, Java, OCaml)
  – The type of expressions are checked at compile-time

• Dynamic types (lisp, scheme)
  – The type of expressions are checked at runtime
  – Soft typing can be used

• Duck-Typing (Python, Ruby, Javascript)
  – If an object can walk and swim like a duck, it is treated as a duck
JavaScript blocks

• Use { } for grouping; not a separate scope

```javascript
var x = 3;
x;
{ var x = 4; x }
x;
```

• Not blocks in the sense of other languages
  – Only function calls and the with statement introduce a nested scope
JavaScript functions

• Declarations can appear in function body
  – Local variables, “inner” functions

• Parameter passing
  – Basic types passed by value, objects by reference

• Call can supply any number of arguments
  – functionname.length : # of arguments in definition
  – functionname.arguments.length : # args in call

• “Anonymous” functions (expressions for functions)
  – (function (x,y) {return x+y}) (2,3);

• Closures and Curried functions
  – function CurAdd(x){ return function(y){return x+y} };

More explanation on next slide
Function Examples

• Curried function
  
  ```javascript
  function CurriedAdd(x){ return function(y){ return x+y } }
  g = CurriedAdd(2);
  g(3)
  ```

• Variable number of arguments
  
  ```javascript
  function sumAll() {
    var total=0;
    for (var i=0; i< sumAll.arguments.length; i++)
      total+=sumAll.arguments[i];
    return(total);
  }
  sumAll(3,5,3,5,3,2,6)
  ```
Recursion

```javascript
var hanoi = function hanoi(disc, src, aux, dst) {
    if (disc > 0) {
        hanoi(disc - 1, src, dst, aux);
        document.writeln('Move disc ' + disc + ' from ' + src + ' to ' + dst);
        hanoi(disc - 1, aux, src, dst);
    }
}

var walk_the_DOM = function walk(node, func) {
    func(node);
    node = node.firstChild;
    while (node) {
        walk(node, func);
        node = node.nextSibling;
    }
}
```
Use of anonymous functions

- Simulate blocks by function definition and call

```javascript
var u = { a:1, b:2 }
var v = { a:3, b:4 }
(function (x,y) {
    var tempA = x.a; var tempB =x.b;  // local variables
    x.a=y.a; x.b=y.b;
    y.a=tempA; y.b=tempB
}) (u,v)  // "end local block"
// Side effects on u,v because objects are passed by reference
```

- Anonymous functions very useful for callbacks

```javascript
setTimeout( function(){ alert("done"); }, 10000)
```
Objects

• Primitive types are immutable

• An object is a collection of named properties (mutable)
  – Simplistic view in some documentation: hash table or associative array
  – Can define by set of name:value pairs
    • objBob = {name: "Bob", grade: 'A', level: 3};
  – New properties can be added at any time
    • objBob.fullname = 'Robert';
  – A property of an object may be a function (=method)

• Functions are also objects
  – A function defines an object with method called "( )"
    function max(x,y) { if (x>y) return x; else return y;};
    max.description = “return the maximum of two arguments”;
Basic object features

• Creating and modifying objects
  function Rectangle(w, h)={this.width=w; this.height=h;}
  var r = new Rectangle(8.5, 11);
  r. area = function () { return this.width * this.height ;}
  var a = r. area;

• Better to do it in the constructor
  function Rectangle(w, h) {
    this.width = w; this.height = h ;
    this. area = function () { return this.width * this.height ;}
  }
  var r =  new Rectangle(8.5, 11);
  var a = r.area() ;
Code and data can be shared via Prototypes

• Each object linked to prototype object
• rectangle with shared area computation

```javascript
function Rectangle(w, h) {
  this.width = w; this.height = h;
}
Rectangle.prototype.area = function() {
  return this.width * this.height;
}
var r = new Rectangle(8.5, 11);
var a = r.area();
```
Inheritance

• Javascript supports Prototype-based programming
  – As opposed to Java classes
• No need for casting
• Provides a reach set of code reuse patterns
• But syntax is ugly
  – See Javascript the good parts
Changing Prototypes

• Use a function to construct an object
  
  function car(make, model, year) {
    this.make = make;
    this.model = model;
    this.year = year;
  }

• Objects have prototypes, can be changed
  
  var c = new car(“Tesla”,“S”,2014);
  car.prototype.print = function () {
    return this.year + “ “ + this.make + “ “ + this.model;
  }
  c.print();
Objects and *this*

- Property of the activation object for function call
  - In most cases, *this* points to the object which has the function as a property (or “method”)
  - Example:
    ```javascript
    var o = {x: 10, f: function(){return this.x}}
    o.f();
    10
    ```

*this* is resolved dynamically when the method is executed
JavaScript functions and *this*

```javascript
var x = 5; var y = 5;
function f() {return this.x + y;}
var o1 = {x : 10}
var o2 = {x : 20}
o1.g = f; o2.g = f;
o1.g() ⇒ 15
o2.g() ⇒ 25
var f1 = o1.g ; f1() ⇒ 10
```

Both `o1.g` and `o2.g` refer to the same function. Why are the results for `o1.g()` and `o2.g()` different?
Local variables stored in “scope object”

Special treatment for nested functions

```javascript
var x = 8
var o = { x: 10,
    f : function() {
        function g(){ return this.x } ;
        return g();
    }
};
o.f()
```

Function g gets the global object as its *this* property!
Language features

• Stack memory management
  – Parameters, local variables in activation records

• Garbage collection
  – Automatic reclamation of inaccessible memory

• Closures
  – Function together with environment (global variables)

• Exceptions
  – Jump to previously declared location, passing values

• Object features
  – Dynamic lookup, Encapsulation, Subtyping, Inheritance
Stack memory management

- Local variables in activation record of function

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

• Return a function from function call

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

• Can use this idea to define objects with “private” fields

```javascript
uniqeId function () {
  if (!arguments.callee.id) arguments.callee.id=0;
  return arguments.callee.id++;
}
```

– Can implement breakpoints
Implementing Closures

function f(x) {
  function g(y) { return x + y; };
  return g ;
}
var h = f(3);
var j = f(4);
var z = h(5);
var w = j(7);
Implementing Closures(1)

function f(x) {
    function g(y) { return x + y; };
    return g ;
}

var h = f(3);
var j = f(4);
var z = h(5);
var w = j(7);
Implementing Closures(2)

function f(x) {
    function g(y) { return x + y; };
    return g ;
}

var h = f(3);
var j = f(4);
var z = h(5);
var w = j(7);

![Diagram showing the implementation of closures]
function f(x) {
  function g(y) { return x + y; };
  return g ;
}
var h = f(3);
var j = f(4);
var z = h(5);
var w = j(7);
function f(x) {
    function g(y) { return x + y; };
    return g ;
}
var h = f(3);
var j = f(4);
var z = h(5);
var w = j(7);
h= null;
Garbage collection

- Automatic reclamation of unused memory
  - Navigator 2: per page memory management
    - Reclaim memory when browser changes page
  - Navigator 3: reference counting
    - Each memory region has associated count
    - Count modified when pointers are changed
    - Reclaim memory when count reaches zero
  - Navigator 4: mark-and-sweep, or equivalent
    - Garbage collector marks reachable memory
    - Sweep and reclaim unreachable memory

Reference http://www.unix.org.ua/orelly/web/jscript/ch11_07.html
Discuss garbage collection in connection with memory management
Exceptions

• Throw an expression of any type
  ```javascript
  throw "Error2";
  throw 42;
  throw {toString: function() { return "I'm an object!"; }};
  ```

• Catch
  ```javascript
  try { ... 
  } catch (e if e == "FirstException") { // do something 
  } catch (e if e == "SecondException") { // do something else 
  } catch (e){ // executed if no match above 
  }
  ```

Object features

• Dynamic lookup
  – Method depends on run-time value of object

• Encapsulation
  – Object contains private data, public operations

• Subtyping
  – Object of one type can be used in place of another

• Inheritance
  – Use implementation of one kind of object to implement another kind of object
Concurrence

• JavaScript itself is single-threaded
  – How can we tell if a language provides concurrency?
• AJAX provides a form of concurrency
  – Create XMLHttpRequest object, set callback function
  – Call request method, which continues asynchronously
  – Reply from remote site executes callback function
    • Event waits in event queue...
    – Closures important for proper execution of callbacks
• Another form of concurrency
  – use setTimeout to do cooperative multi-tasking
    • Maybe we will explore this in homework ...
Unusual features of JavaScript

• Some built-in functions
  – Eval (next slide), Run-time type checking functions, ...

• Regular expressions
  – Useful support of pattern matching

• Add, delete methods of an object dynamically
  – Seen examples adding methods. Do you like this? Disadvantages?
    – myobj.a = 5; myobj.b = 12; delete myobj.a;

• Redefine native functions and objects (incl undefined)

• Iterate over methods of an object
  – for (variable in object) { statements }

• With statement (“considered harmful” – why??)
  – with (object) { statements }
JavaScript eval

• Evaluate string as code
  – The eval function evaluates a string of JavaScript code, in scope of the calling code

• Examples
  var code = "var a = 1";
  eval(code); // a is now '1'
  var obj = new Object();
  obj.eval(code); // obj.a is now 1

• Most common use
  – Efficiently deserialized a large, complicated JavaScript data structures received over network via XMLHttpRequest

• What does it cost to have eval in the language?
  – Can you do this in C? What would it take to implement?
Other code/string conversions

- String computation of property names

```javascript
var m = "toS";
var n = "tring";
Object.prototype[m + n] = function(){return undefined};
```

- In addition
  - for (p in o){....}
  - o[p]
  - eval(...)

  allow strings to be used as code and vice versa
Sample Javascript delights

• return
  {
    status: true
  };

• var length = 3;
  console.log(length);

• What does “a + b” mean

• Falsy values: 0, Nan, ”, false, null, undefined
Lessons Learned

• Few constructs make a powerful language
• Simplifies the interpreter
• But the interaction can be hard to understand for programmers
  – JSLint
• Hard for compilation
  – JIT compilers
    • Spider Monkey, Mozilla, Safari, Chrome
• Some efforts to create safe Javascript sub-languages (Adsafe, Google Dart...)

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• Tutorial
  – http://www.w3schools.com/js/
• JavaScript 1.5 Guide
• Douglas Crockford
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– David Flanagan