JavaScript Spessore

A Thick Shot of Objects, Metaobjects, & Protocols

by Reginald "raganwald" Braithwaite

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Prefaces

[1]

Taking a page out of LiSP

Teaching Lisp by implementing Lisp is a long-standing tradition. We read book after book, lecture after lecture, blog post after blog post, all explaining how to implement Lisp in Lisp. Christian Queinnec's Lisp in Small Pieces[2] ("**LiSP**") is particularly notable, not just implementing a Lisp in Lisp, but covering a wide range of different semantics within Lisp.

LiSP's approach is to introduce a feature of Lisp, then develop an implementation. The book covers [Lisp-1 vs. Lisp-2[3], then discusses how to implement namespaces, building a simple Lisp-1 and a

[1] Group (c) 2013 J MacPherson, some rights reserved

[2] http://www.amazon.com/gp/product/B00AKE1U6O/ref=as_li_ss_tl?ie=UTF8&camp=1789&creative=390957&creativeASIN=B00AKE1U6O&linkCode=as2&tag=raganwald001-20

[3] A "Lisp-1" has a single namespace for both functions and other values. A "Lisp-2" has separate namespaces for functions and other values. To the extend that JavaScript resembles a Lisp, it resembles a Lisp-1. See The function namespace.

simple Lisp-2. Another chapter discusses scoping, and again you build interpreters for dynamic and block scoped Lisps.

Building interpreters (and eventually compilers) may seem esoteric compared to tutorials demonstrating how to build a blogging engine, but there's a method to this madness. If you implement block scoping in a "toy" language, you gain a deep understanding of how closures really work in any language. If you write a Lisp that rewrites function calls in Continuation Passing Style[4], you can't help but feel comfortable using JavaScript callbacks in Node.js[5].

Implementing a language feature teaches you a tremendous amount about how the feature works in a relatively short amount of time. And that goes double for implementing variations on the same feature–like dynamic vs block scoping or single vs multiple namespaces.

In this book, we are going to implement a number of different programming language semantics, all in JavaScript. We won't be choosing features at random; We aren't going to try to implement every possible type of programming language semantics. We won't explore dynamic vs block scoping, we won't implement call-by-name, and we will ignore the temptation to experiment with lazy evaluation.

We *are* going to implement different object semantics, implement different kinds of metaobjects, and implement different kinds of method protocols. We are going to focus on the semantics of objects, metaobjects, and protocols, because we're interested in understanding "object-oriented programming" and all of its rich possibilities.

In doing so, we'll learn about the principles of object-oriented programming in far more depth than we would if we chose to implement a "practical" example like a blogging engine.

JavaScript Allongé and allong.es

JavaScript Spessore[6] is written for the reader who has read JavaScript Allongé[7] or has equivalent experience with JavaScript, especially as it pertains to functions, closures, and prototypes. JavaScript Allongé is well-regarded amongst programmers:

> "This is a must-read for any developer who wants to know Javascript better… Reg has a way of explaining things in a way that connected the dots for me. This is probably the only programming book I've re-read cover to cover a dozen times or more."–etrinh

> "I think it's one of the best tech books I've read since Sedgewick's Algorithms in C."–Andrey Sidorov

> "Your explanation of closures in JavaScript Allongé is the best I've read."–Emehrkay

[4] https://en.wikipedia.org/wiki/Continuation-passing_style
[5] http://nodejs.org/about/
[6] https://leanpub.com/javascript-spessore
[7] https://leanpub.com/javascript-allonge

> "It's a different approach to JavaScript than you'll find in most other places and shines a light on some of the more elegant parts of JavaScript the language."–@jeremymorrell

Even if you know the material, you may want to read JavaScript Allongé to familiarize yourself its approach to functional combinators. You can read it for free online[8].

allong.es

allong.es[9] is a JavaScript library inspired by JavaScript Allongé. It contains many utility functions that are used in JavaScript Spessore's examples, such as `map`, `variadic` and `tap`. It's free, and you can even type a lot of the examples from this book into its try allong.es[10] page and see them work.

[8] https://leanpub.com/javascript-allonge/read
[9] http://allong.es
[10] http://allong.es/try/

Preamble

Dr. Alan Kay on the expression “OOP”[11]

[12]

Welcome to [JavaScript Spessore][js]. This is a book about “Thinking in Objects,” using JavaScript as the medium for discussion. The format of the book is as follows:

Caffé Lungo revisits the discussion of objects, prototypes, and delegation from the book JavaScript Allongé[13]. This gives up a grounding in what JavaScript provides “out of the box” and how people typically apply it.

The Object’s The Thing examines JavaScript’s objects and properties more closely, with an emphasis on using defined properties to control an object’s interface.

Methods expands on the notion of a method, looking at constructing composite methods, method objects, and meta-methods.

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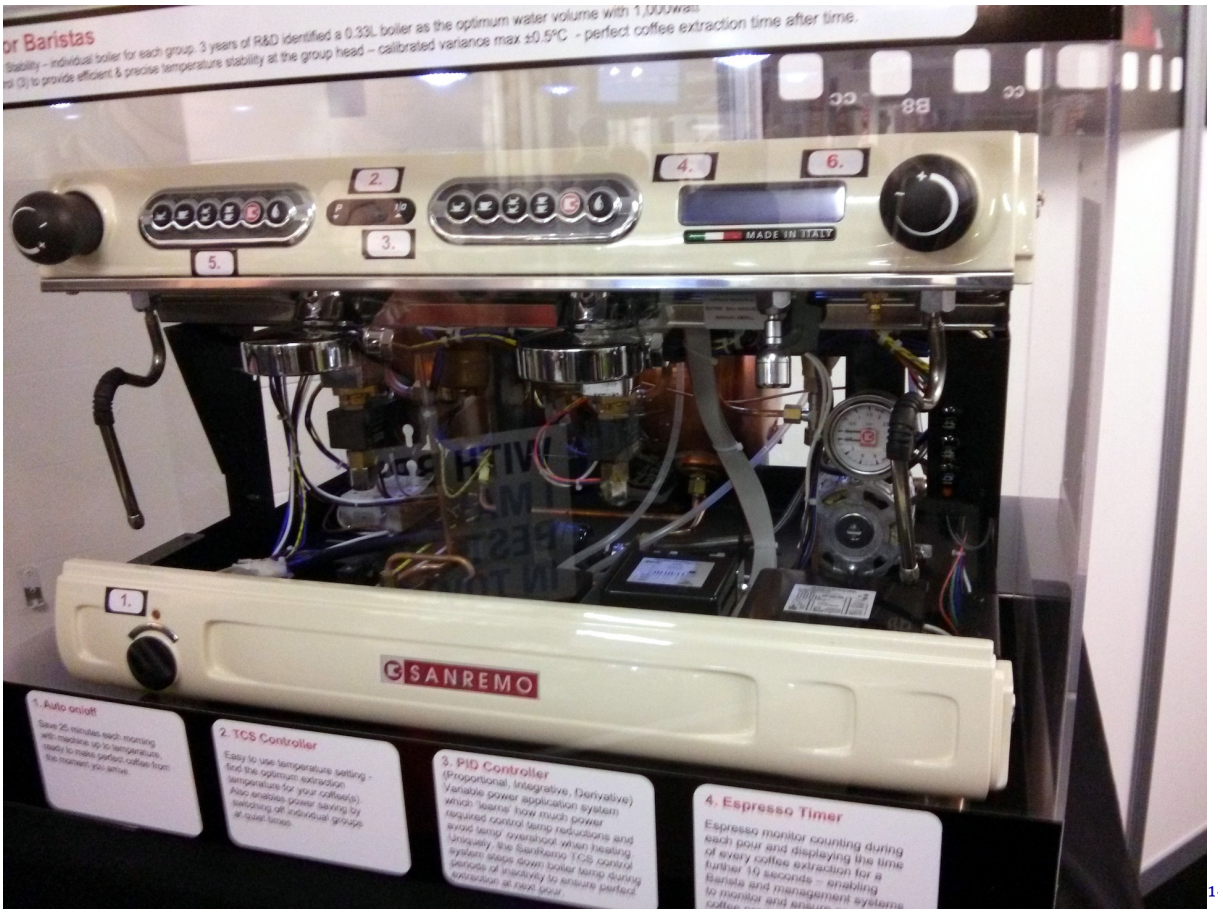
[11] images/oop.png

[12] Normalized Pump Pressure Reading (c) 2009 Nicholas Lundgaard, some rights reserved

[13] https://leanpub.com/javascript-allonge

Metaobjects dives into the notion of metaobjects, objects that define the behaviour of other objects. It then examines the distinction between prototypes and other kinds of metaobjects. It then discusses *metaobject protocols*, the design of interfaces for manipulating metaobjects.

Caffé Lungo



[14]

> **Lungo** is Italian for 'long', and refers to the coffee beverage made by using an espresso machine to make an espresso (single or double dose or shot) with much more water (generally twice as much), resulting in a *stretched* espresso, a *lungo*. In French it is called *café allongé*.–Wikipedia[15]

revisiting javascript allongé

This book is written for the reader who has read JavaScript Allongé[16] or has equivalent familiarity with functions and basic use of JavaScript's objects, functions, closures, and the prototype chain.

[14] Transparent Sanremo espresso machine, London Coffee Festival, Truman Brewery, Brick Lane, Hackney, London, UK (c) 2013 Cory Doctorow, some rights reserved

[15] https://en.wikipedia.org/wiki/Lungo

[16] https://leanpub.com/javascript-allonge

This chapter is intended as a refresher: Some of the material from JavaScript Allongé is abbreviated and reproduced.

Plain Old JavaScript Objects

In JavaScript, an object is a map from names to values. Tradition would have us call objects that don't contain any functions "POJOs," Plain Old JavaScript Objects.

The most common syntax for creating an object is called a "literal object expression:"

```
1  { year: 2012, month: 6, day: 14 }
```

Two objects created this way have differing identities:

```
1  { year: 2012, month: 6, day: 14 } === { year: 2012, month: 6, day: 14 }
2    //=> false
```

Objects use `[]` to access the values by name, using a string:

```
1  { year: 2012, month: 6, day: 14 }['day']
2    //=> 14
```

Names in literal object expressions needn't be alphanumeric strings. For anything else, enclose the label in quotes:

```
1  { 'first name': 'reginald', 'last name': 'lewis' }['first name']
2    //=> 'reginald'
```

If the name is an alphanumeric string conforming to the same rules as names of variables, there's a simplified syntax for accessing the values:

```
1  { year: 2012, month: 6, day: 14 }['day'] ===
2      { year: 2012, month: 6, day: 14 }.day
3    //=> true
```

Like all containers, objects can contain any value, including functions or other containers:

```
var Mathematics = {
  abs: function (a) {
         return a < 0 ? -a : a
       }
};

Mathematics.abs(-5)
  //=> 5
```

Funny we should mention `Mathematics`. JavaScript provides a global environment that contains some existing object that have handy functions you can use. One of them is called `Math`, and it contains functions for `abs`, `max`, `min`, and many others. Since it is always available, you can use it in any environment provided you don't shadow `Math`.

```
Math.abs(-5)
  //=> 5
```

Encapsulating State with Closures

> OOP to me means only messaging, local retention and protection and hiding of state-process, and extreme late-binding of all things.–Alan Kay[17]

We're going to look at encapsulation using JavaScript's functions and objects. We're not going to call it object-oriented programming, mind you, because that would start a long debate. This is just plain encapsulation,[18] with a dash of information-hiding.

what is hiding of state-process, and why does it matter?

> In computer science, information hiding is the principle of segregation of the design decisions in a computer program that are most likely to change, thus protecting other parts of the program from extensive modification if the design decision is changed. The protection involves providing a stable interface which protects the remainder of the program from the implementation (the details that are most likely to change).
>
> Written another way, information hiding is the ability to prevent certain aspects of a class or software component from being accessible to its clients, using either programming language features (like private variables) or an explicit exporting policy.

[17] http://userpage.fu-berlin.de/~ram/pub/pub_jf47ht81Ht/doc_kay_oop_en

[18] "A language construct that facilitates the bundling of data with the methods (or other functions) operating on that data."–Wikipedia

> –Wikipedia[19]

Consider a stack[20] data structure. There are three basic operations: Pushing a value onto the top (`push`), popping a value off the top (`pop`), and testing to see whether the stack is empty or not (`isEmpty`). These three operations are the stable interface.

Many stacks have an array for holding the contents of the stack. This is relatively stable. You could substitute a linked list, but in JavaScript, the array is highly efficient. You might need an index, you might not. You could grow and shrink the array, or you could allocate a fixed size and use an index to keep track of how much of the array is in use. The design choices for keeping track of the head of the list are often driven by performance considerations.

If you expose the implementation detail such as whether there is an index, sooner or later some programmer is going to find an advantage in using the index directly. For example, she may need to know the size of a stack. The ideal choice would be to add a `size` function that continues to hide the implementation. But she's in a hurry, so she reads the `index` directly. Now her code is coupled to the existence of an index, so if we wish to change the implementation to grow and shrink the array, we will break her code.

The way to avoid this is to hide the array and index from other code and only expose the operations we have deemed stable. If and when someone needs to know the size of the stack, we'll add a `size` function and expose it as well.

Hiding information (or "state") is the design principle that allows us to limit the coupling between components of software.

how do we hide state using javascript?

We've been introduced to JavaScript's objects, and it's fairly easy to see that objects can be used to model what other programming languages call (variously) records, structs, frames, or what-have-you. And given that their elements are mutable, they can clearly model state.

Given an object that holds our state (an array and an index[21]), we can easily implement our three operations as functions. Bundling the functions with the state does not require any special "magic" features. JavaScript objects can have elements of any type, including functions:

[19] https://en.wikipedia.org/wiki/Information_hiding

[20] https://en.wikipedia.org/wiki/Stack_

[21] Yes, there's another way to track the size of the array, but we don't need it to demonstrate encapsulation and hiding of state.

```
var stack = (function () {
  var obj = {
    array: [],
    index: -1,
    push: function (value) {
      return obj.array[obj.index += 1] = value
    },
    pop: function () {
      var value = obj.array[obj.index];
      obj.array[obj.index] = void 0;
      if (obj.index >= 0) {
        obj.index -= 1
      }
      return value
    },
    isEmpty: function () {
      return obj.index < 0
    }
  };

  return obj;
})();

stack.isEmpty()
  //=> true
stack.push('hello')
  //=> 'hello'
stack.push('JavaScript')
 //=> 'JavaScript'
stack.isEmpty()
  //=> false
stack.pop()
 //=> 'JavaScript'
stack.pop()
 //=> 'hello'
stack.isEmpty()
  //=> true
```

method-ology

In this text, we lurch from talking about “functions that belong to an object” to “methods.” Other languages may separate methods from functions very strictly, but in JavaScript every method is a function but not all functions are methods.

The view taken in this book is that a function is a method of an object if it belongs to that object and interacts with that object in some way. So the functions implementing the operations on the stack are all absolutely methods of the stack.

But these two wouldn't be methods. Although they "belong" to an object, they don't interact with it:

```
{
  min: function (x, y) {
    if (x < y) {
      return x
    }
    else {
      return y
    }
  }
  max: function (x, y) {
    if (x > y) {
      return x
    }
    else {
      return y
    }
  }
}
```

hiding state

Our stack does bundle functions with data, but it doesn't hide its state. "Foreign" code could interfere with its array or index. So how do we hide these? We already have a closure, let's use it:

```
var stack = (function () {
  var array = [],
      index = -1;

  return {
    push: function (value) {
      array[index += 1] = value
    },
    pop: function () {
      var value = array[index];
      if (index >= 0) {
```

```
        index -= 1
      }
      return value
    },
    isEmpty: function () {
      return index < 0
    }
  }
})();

stack.isEmpty()
  //=> true
stack.push('hello')
  //=> 'hello'
stack.push('JavaScript')
 //=> 'JavaScript'
stack.isEmpty()
  //=> false
stack.pop()
 //=> 'JavaScript'
stack.pop()
 //=> 'hello'
stack.isEmpty()
  //=> true
```

We don't want to repeat this code every time we want a stack, so let's make ourselves a "stack maker." The temptation is to wrap what we have above in a function:

```
var StackMaker = function () {
  return (function () {
    var array = [],
        index = -1;

    return {
      push: function (value) {
        array[index += 1] = value
      },
      pop: function () {
        var value = array[index];
        if (index >= 0) {
          index -= 1
        }
```

```
        return value
      },
      isEmpty: function () {
        return index < 0
      }
    }
  })()
}
```

But there's an easier way :-)

```
var StackMaker = function () {
  var array = [],
      index = -1;

  return {
    push: function (value) {
      array[index += 1] = value
    },
    pop: function () {
      var value = array[index];
      if (index >= 0) {
        index -= 1
      }
      return value
    },
    isEmpty: function () {
      return index < 0
    }
  }
};

stack = StackMaker()
```

Now we can make stacks freely, and we've hidden their internal data elements. We have methods and encapsulation, and we've built them out of JavaScript's fundamental functions and objects. A little further on, we'll look at JavaScript's support for class-oriented programming and some of the idioms that functions bring to the party.

is encapsulation "object-oriented?"

We've built something with hidden internal state and "methods," all without needing special `def` or `private` keywords. Mind you, we haven't included all sorts of complicated mechanisms to support inheritance, mixins, and other opportunities for debating the nature of the One True Object-Oriented Style on the Internet.

Then again, the key lesson experienced programmers repeat–although it often falls on deaf ears–is Composition instead of Inheritance[a]. So maybe we aren't missing much.

[a] http://www.c2.com/cgi/wiki?CompositionInsteadOfInheritance

Composition and Extension

composition

A deeply fundamental practice is to build components out of smaller components. The choice of how to divide a component into smaller components is called *factoring*, after the operation in number theory [22].

The simplest and easiest way to build components out of smaller components in JavaScript is also the most obvious: Each component is a value, and the components can be put together into a single object or encapsulated with a closure.

Here's an abstract "model" that supports undo and redo composed from a pair of stacks (see Encapsulating State) and a Plain Old JavaScript Object:

```
1  // helper function
2  //
3  // For production use, consider what to do about
4  // deep copies and own keys
5  var shallowCopy = function (source) {
6    var dest = {},
7        key;
8
9    for (key in source) {
10     dest[key] = source[key]
11   }
12   return dest
```

[22] And when you take an already factored component and rearrange things so that it is factored into a different set of subcomponents without altering its behaviour, you are *refactoring*.

```
};

// our model maker
var ModelMaker = function (initialAttributes) {
  var attributes = shallowCopy(initialAttributes || {}),
      undoStack = StackMaker(),
      redoStack = StackMaker(),
      obj = {
        set: function (attrsToSet) {
          var key;

          undoStack.push(shallowCopy(attributes));
          if (!redoStack.isEmpty()) {
            redoStack = StackMaker()
          }
          for (key in (attrsToSet || {})) {
            attributes[key] = attrsToSet[key]
          }
          return obj
        },
        undo: function () {
          if (!undoStack.isEmpty()) {
            redoStack.push(shallowCopy(attributes));
            attributes = undoStack.pop()
          }
          return obj
        },
        redo: function () {
          if (!redoStack.isEmpty()) {
            undoStack.push(shallowCopy(attributes));
            attributes = redoStack.pop()
          }
          return obj
        },
        get: function (key) {
          return attributes(key)
        },
        has: function (key) {
          return attributes.hasOwnProperty(key)
        },
        attributes: function {
          shallowCopy(attributes)
```

```
        }
      };
    return obj
  };
```

The techniques used for encapsulation work well with composition. In this case, we have a "model" that hides its attribute store as well as its implementation that is composed of an undo stack and redo stack.

extension

Another practice that many people consider fundamental is to *extend* an implementation. Meaning, they wish to define a new data structure in terms of adding new operations and semantics to an existing data structure.

Consider a queue[23]:

```
var QueueMaker = function () {
  var array = [],
      head = 0,
      tail = -1;
  return {
    pushTail: function (value) {
      return array[tail += 1] = value
    },
    pullHead: function () {
      var value;

      if tail >= head {
        value = array[head];
        array[head] = void 0;
        head += 1;
        return value
      }
    },
    isEmpty: function () {
      return tail < head
    }
  }
};
```

[23] http://duckduckgo.com/Queue_

Now we wish to create a deque[24] by adding `pullTail` and `pushHead` operations to our queue.[25] Unfortunately, encapsulation prevents us from adding operations that interact with the hidden data structures.

This isn't really surprising: The entire point of encapsulation is to create an opaque data structure that can only be manipulated through its public interface. The design goals of encapsulation and extension are always going to exist in tension.

Let's "de-encapsulate" our queue:

```
var QueueMaker = function () {
  var queue = {
    array: [],
    head: 0,
    tail: -1,
    pushTail: function (value) {
      return queue.array[queue.tail += 1] = value
    },
    pullHead: function () {
      var value;

      if (queue.tail >= queue.head) {
        value = queue.array[queue.head];
        queue.array[queue.head] = void 0;
        queue.head += 1;
        return value
      }
    },
    isEmpty: function () {
      return queue.tail < queue.head
    }
  };
  return queue
};
```

Now we can extend a queue into a deque:

[24] https://en.wikipedia.org/wiki/Double-ended_queue

[25] Before you start wondering whether a deque is-a queue, we said nothing about types and classes. This relationship is called was-a, or "implemented in terms of a."

```
var DequeMaker = function () {
  var deque = QueueMaker(),
      INCREMENT = 4;

  return extend(deque, {
    size: function () {
      return deque.tail - deque.head + 1
    },
    pullTail: function () {
      var value;

      if (!deque.isEmpty()) {
        value = deque.array[deque.tail];
        deque.array[deque.tail] = void 0;
        deque.tail -= 1;
        return value
      }
    },
    pushHead: function (value) {
      var i;

      if (deque.head === 0) {
        for (i = deque.tail; i <= deque.head; i++) {
          deque.array[i + INCREMENT] = deque.array[i]
        }
        deque.tail += INCREMENT
        deque.head += INCREMENT
      }
      return deque.array[deque.head -= 1] = value
    }
  })
};
```

Presto, we have reuse through extension, at the cost of encapsulation.

Encapsulation and Extension exist in a natural state of tension. A program with elaborate encapsulation resists breakage but can also be difficult to refactor in other ways. Be mindful of when it's best to Compose and when it's best to Extend.

This and That

Let's take another look at extensible objects. Here's a Queue:

```
var QueueMaker = function () {
  var queue = {
    array: [],
    head: 0,
    tail: -1,
    pushTail: function (value) {
      return queue.array[queue.tail += 1] = value
    },
    pullHead: function () {
      var value;

      if (queue.tail >= queue.head) {
        value = queue.array[queue.head];
        queue.array[queue.head] = void 0;
        queue.head += 1;
        return value
      }
    },
    isEmpty: function () {
      return queue.tail < queue.head
    }
  };
  return queue
};

queue = QueueMaker()
queue.pushTail('Hello')
queue.pushTail('JavaScript')
```

Let's make a copy of our queue using the `extend` recipe:

```
copyOfQueue = extend({}, queue);

queue !== copyOfQueue
  //=> true
```

Wait a second. We know that array values are references. So it probably copied a reference to the original array. Let's make a copy of the array as well:

```
copyOfQueue.array = [];
for (var i = 0; i < 2; ++i) {
  copyOfQueue.array[i] = queue.array[i]
}
```

Now let's pull the head off the original:

```
queue.pullHead()
  //=> 'Hello'
```

If we've copied everything properly, we should get the exact same result when we pull the head off the copy:

```
copyOfQueue.pullHead()
  //=> 'JavaScript'
```

What!? Even though we carefully made a copy of the array to prevent aliasing, it seems that our two queues behave like aliases of each other. The problem is that while we've carefully copied our array and other elements over, *the closures all share the same environment*, and therefore the functions in `copyOfQueue` all operate on the first queue's private data, not on the copies.

> This is a general issue with closures. Closures couple functions to environments, and that makes them very elegant in the small, and very handy for making opaque data structures. Alas, their strength in the small is their weakness in the large. When you're trying to make reusable components, this coupling is sometimes a hindrance.

Let's take an impossibly optimistic flight of fancy:

```
var AmnesiacQueueMaker = function () {
  return {
    array: [],
    head: 0,
    tail: -1,
    pushTail: function (myself, value) {
      return myself.array[myself.tail += 1] = value
    },
    pullHead: function (myself) {
      var value;
```

```
11
12        if (myself.tail >= myself.head) {
13          value = myself.array[myself.head];
14          myself.array[myself.head] = void 0;
15          myself.head += 1;
16          return value
17        }
18      },
19      isEmpty: function (myself) {
20        return myself.tail < myself.head
21      }
22    }
23  };
24
25  queueWithAmnesia = AmnesiacQueueMaker();
26  queueWithAmnesia.pushTail(queueWithAmnesia, 'Hello');
27  queueWithAmnesia.pushTail(queueWithAmnesia, 'JavaScript')
```

The `AmnesiacQueueMaker` makes queues with amnesia: They don't know who they are, so every time we invoke one of their functions, we have to tell them who they are. You can work out the implications for copying queues as a thought experiment: We don't have to worry about environments, because every function operates on the queue you pass in.

The killer drawback, of course, is making sure we are always passing the correct queue in every time we invoke a function. What to do?

what's all `this`?

Any time we must do the same repetitive thing over and over and over again, we industrial humans try to build a machine to do it for us. JavaScript is one such machine:

```
1   BanksQueueMaker = function () {
2     return {
3       array: [],
4       head: 0,
5       tail: -1,
6       pushTail: function (value) {
7         return this.array[this.tail += 1] = value
8       },
9       pullHead: function () {
10        var value;
11
```

```
12        if (this.tail >= this.head) {
13          value = this.array[this.head];
14          this.array[this.head] = void 0;
15          this.head += 1;
16          return value
17        }
18      },
19      isEmpty: function () {
20        return this.tail < this.head
21      }
22    }
23  };
24
25  banksQueue = BanksQueueMaker();
26  banksQueue.pushTail('Hello');
27  banksQueue.pushTail('JavaScript')
```

Every time you invoke a function that is a member of an object, JavaScript binds that object to the name `this` in the environment of the function just as if it was an argument.[26] Now we can easily make copies:

```
1  copyOfQueue = extend({}, banksQueue)
2  copyOfQueue.array = []
3  for (var i = 0; i < 2; ++i) {
4    copyOfQueue.array[i] = banksQueue.array[i]
5  }
6
7  banksQueue.pullHead()
8    //=> 'Hello'
9
10 copyOfQueue.pullHead()
11   //=> 'Hello'
```

Presto, we now have a way to copy arrays. By getting rid of the closure and taking advantage of `this`, we have functions that are more easily portable between objects, and the code is simpler as well.

There is more to `this` than we've discussed here. We'll explore things in more detail later, in What Context Applies When We Call a Function?.

Closures tightly couple functions to the environments where they are created limiting their flexibility. Using `this` alleviates the coupling. Copying objects is but one example of where that flexibility is needed.

[26] JavaScript also does other things with `this` as well, but this is all we care about right now.

What Context Applies When We Call a Function?

In This and That, we learned that when a function is called as an object method, the name `this` is bound in its environment to the object acting as a "receiver." For example:

```
var someObject = {
  returnMyThis: function () {
    return this;
  }
};

someObject.returnMyThis() === someObject
  //=> true
```

We've constructed a method that returns whatever value is bound to `this` when it is called. It returns the object when called, just as described.

it's all about the way the function is called

JavaScript programmers talk about functions having a "context" when being called. `this` is bound to the context.[27] The important thing to understand is that the context for a function being called is set by the way the function is called, not the function itself.

This is an important distinction. Consider closures: As we discussed in Closures and Scope, a function's free variables are resolved by looking them up in their enclosing functions' environments. You can always determine the functions that define free variables by examining the source code of a JavaScript program, which is why this scheme is known as Lexical Scope[28].

A function's context cannot be determined by examining the source code of a JavaScript program. Let's look at our example again:

```
var someObject = {
  someFunction: function () {
    return this;
  }
};

someObject.someFunction() === someObject
  //=> true
```

What is the context of the function `someObject.someFunction`? Don't say `someObject`! Watch this:

[27] Too bad the language binds the context to the name `this` instead of the name `context`!

[28] https://en.wikipedia.org/wiki/Scope_(computer_science)#Lexical_scoping

```
var someFunction = someObject.someFunction;

someFunction === someObject.someFunction
  //=> true

someFunction() === someObject
  //=> false
```

It gets weirder:

```
var anotherObject = {
  someFunction: someObject.someFunction
}

anotherObject.someFunction === someObject.someFunction
  //=> true

anotherObject.someFunction() === anotherObject
  //=> true

anotherObject.someFunction() === someObject
  //=> false
```

So it amounts to this: The exact same function can be called in two different ways, and you end up with two different contexts. If you call it using `someObject.someFunction()` syntax, the context is set to the receiver. If you call it using any other expression for resolving the function's value (such as `someFunction()`), you get something else. Let's investigate:

```
(someObject.someFunction)() == someObject
  //=> true

someObject['someFunction']() === someObject
  //=> true

var name = 'someFunction';

someObject[name]() === someObject
  //=> true
```

Interesting!

```
var baz;

(baz = someObject.someFunction)() === this
  //=> true
```

How about:

```
var arr = [ someObject.someFunction ];

arr[0]() == arr
  //=> true
```

It seems that whether you use `a.b()` or `a['b']()` or `a[n]()` or `(a.b)()`, you get context `a`.

```
var returnThis = function () { return this };

var aThirdObject = {
  someFunction: function () {
    return returnThis()
  }
}

returnThis() === this
  //=> true

aThirdObject.someFunction() === this
  //=> true
```

And if you don't use `a.b()` or `a['b']()` or `a[n]()` or `(a.b)()`, you get the global environment for a context, not the context of whatever function is doing the calling. To simplify things, when you call a function with `.` or `[]` access, you get an object as context, otherwise you get the global environment.

setting your own context

There are actually two other ways to set the context of a function. And once again, both are determined by the caller. At the very end of objects everywhere?, we'll see that everything in JavaScript behaves like an object, including functions. We'll learn that functions have methods themselves, and one of them is `call`.

Here's `call` in action:

```
returnThis() === aThirdObject
  //=> false

returnThis.call(aThirdObject) === aThirdObject
  //=> true

anotherObject.someFunction.call(someObject) === someObject
  //=> true
```

When You call a function with `call`, you set the context by passing it in as the first parameter. Other arguments are passed to the function in the normal manner. Much hilarity can result from `call` shenanigans like this:

```
var a = [1,2,3],
    b = [4,5,6];

a.concat([2,1])
  //=> [1,2,3,2,1]

a.concat.call(b,[2,1])
  //=> [4,5,6,2,1]
```

But now we thoroughly understand what `a.b()` really means: It's synonymous with `a.b.call(a)`. Whereas in a browser, `c()` is synonymous with `c.call(window)`.

apply, arguments, and contextualization

JavaScript has another automagic binding in every function's environment. `arguments` is a special object that behaves a little like an array.[29]

For example:

```
var third = function () {
  return arguments[2]
}

third(77, 76, 75, 74, 73)
  //=> 75
```

Hold that thought for a moment. JavaScript also provides a fourth way to set the context for a function. `apply` is a method implemented by every function that takes a context as its first argument, and it takes an array or array-like thing of arguments as its second argument. That's a mouthful, let's look at an example:

[29] Just enough to be frustrating, to be perfectly candid!

```
third.call(this, 1,2,3,4,5)
  //=> 3

third.apply(this, [1,2,3,4,5])
  //=> 3
```

Now let's put the two together. Here's another travesty:

```
var a = [1,2,3],
    accrete = a.concat;

accrete([4,5])
  //=> Gobbledygook!
```

We get the result of concatenating `[4,5]` onto an array containing the global environment. Not what we want! Behold:

```
var contextualize = function (fn, context) {
  return function () {
    return fn.apply(context, arguments);
  }
}

accrete = contextualize(a.concat, a);
accrete([4,5]);
  //=> [ 1, 2, 3, 4, 5 ]
```

Our `contextualize` function returns a new function that calls a function with a fixed context. It can be used to fix some of the unexpected results we had above. Consider:

```
var aFourthObject = {},
    returnThis = function () { return this; };

aFourthObject.uncontextualized = returnThis;
aFourthObject.contextualized = contextualize(returnThis, aFourthObject);

aFourthObject.uncontextualized() === aFourthObject
  //=> true
aFourthObject.contextualized() === aFourthObject
  //=> true
```

Both are `true` because we are accessing them with `aFourthObject`. Now we write:

```
var uncontextualized = aFourthObject.uncontextualized,
    contextualized = aFourthObject.contextualized;

uncontextualized() === aFourthObject;
  //=> false
contextualized() === aFourthObject
  //=> true
```

When we call these functions without using `aFourthObject.`, only the contextualized version maintains the context of `aFourthObject`.

We'll return to contextualizing methods later, in Binding. But before we dive too deeply into special handling for methods, we need to spend a little more time looking at how functions and methods work.

Extending Objects

It's very common to want to "extend" a simple object by adding properties to it:

```
var inventory = {
  apples: 12,
  oranges: 12
};

inventory.bananas = 54;
inventory.pears = 24;
```

It's also common to want to add a shallow copy[30] of the properties of one object to another:

```
  for (var fruit in shipment) {
    inventory[fruit] = shipment[fruit]
  }
```

Both needs can be met with this recipe for `extend`:

[30] https://en.wikipedia.org/wiki/Object_copy#Shallow_copy

```
var extend = variadic( function (consumer, providers) {
  var key,
      i,
      provider;

  for (i = 0; i < providers.length; ++i) {
    provider = providers[i];
    for (key in provider) {
      if (provider.hasOwnProperty(key)) {
        consumer[key] = provider[key]
      }
    }
  }
  return consumer
});
```

You can copy an object by extending an empty object:

```
extend({}, {
  apples: 12,
  oranges: 12
})
  //=> { apples: 12, oranges: 12 }
```

You can extend one object with another:

```
var inventory = {
  apples: 12,
  oranges: 12
};

var shipment = {
  bananas: 54,
  pears: 24
}

extend(inventory, shipment)
  //=> { apples: 12,
  //     oranges: 12,
  //     bananas: 54,
  //     pears: 24 }
```

And when we discuss prototypes, we will use `extend` to turn this:

```
var Queue = function () {
  this.array = [];
  this.head = 0;
  this.tail = -1
};

Queue.prototype.pushTail = function (value) {
  // ...
};
Queue.prototype.pullHead = function () {
  // ...
};
Queue.prototype.isEmpty = function () {
  // ...
}
```

Into this:

```
var Queue = function () {
  extend(this, {
    array: [],
    head: 0,
    tail: -1
  })
};

extend(Queue.prototype, {
  pushTail: function (value) {
    // ...
  },
  pullHead: function () {
    // ...
  },
  isEmpty: function () {
    // ...
  }
});
```

As we build more complex objects with more complex structures, we will revisit “extend” and improve on it.

Prototypes are Simple, it's the Explanations that are Hard To Understand

As you recall from our code for making objects extensible, we wrote a function that returned a Plain Old JavaScript Object. The colloquial term for this kind of function is a "Factory Function."

Let's strip a function down to the very bare essentials:

```
var Ur = function () {};
```

This doesn't look like a factory function: It doesn't have an expression that yields a Plain Old JavaScript Object when the function is applied. Yet, there is a way to make an object out of it. Behold the power of the `new` keyword:

```
new Ur()
  //=> {}
```

We got an object back! What can we find out about this object?

```
new Ur() === new Ur()
  //=> false
```

Every time we call `new` with a function and get an object back, we get a unique object. We could call these "Objects created with the `new` keyword," but this would be cumbersome. So we're going to call them *instances*. Instances of what? Instances of the function that creates them. So given `var i = new Ur()`, we say that `i` is an instance of `Ur`.

For reasons that will be explained after we've discussed prototypes, we also say that `Ur` is the *constructor* of `i`, and that `Ur` is a *constructor function*. Therefore, an instance is an object created by using the `new` keyword on a constructor function, and that function is the instance's constructor.

prototypes

There's more. Here's something interesting:

```
Ur.prototype
  //=> {}
```

What's this prototype? Let's run our standard test:

```
(function () {}).prototype === (function () {}).prototype
  //=> false
```

Every function is initialized with its own unique `prototype`. What does it do? Let's try something:

```
Ur.prototype.language = 'JavaScript';

var continent = new Ur();
  //=> {}
continent.language
  //=> 'JavaScript'
```

That's very interesting! Instances seem to behave as if they had the same elements as their constructor's prototype. Let's try a few things:

```
continent.language = 'CoffeeScript';
continent
  //=> {language: 'CoffeeScript'}
continent.language
  //=> 'CoffeeScript'
Ur.prototype.language
  'JavaScript'
```

You can set elements of an instance, and they "override" the constructor's prototype, but they don't actually change the constructor's prototype. Let's make another instance and try something else.

```
var another = new Ur();
  //=> {}
another.language
  //=> 'JavaScript'
```

New instances don't acquire any changes made to other instances. Makes sense. And:

```
Ur.prototype.language = 'Sumerian'
another.language
  //=> 'Sumerian'
```

Even more interesting: Changing the constructor's prototype changes the behaviour of all of its instances. This strongly implies that there is a dynamic relationship between instances and their constructors, rather than some kind of mechanism that makes objects by copying.[31]

Speaking of prototypes, here's something else that's very interesting:

[31] For many programmers, the distinction between a dynamic relationship and a copying mechanism is too fine to worry about. However, it makes many dynamic program modifications possible.

```
continent.constructor
  //=> [Function]

continent.constructor === Ur
  //=> true
```

Every instance acquires a `constructor` element that is initialized to their constructor. This is true even for objects we don't create with `new` in our own code:

```
{}.constructor
  //=> [Function: Object]
```

If that's true, what about prototypes? Do they have constructors?

```
Ur.prototype.constructor
  //=> [Function]
Ur.prototype.constructor === Ur
  //=> true
```

Very interesting! We will take another look at the `constructor` element when we discuss extending objects with delegation.

But let's get back to prototypes:

```
function C () {}

C.prototype.bodyOfWater = 'sea'
C.prototype
  //=> { bodyOfWater: 'sea' }

var c = new C();

Object.getPrototypeOf(c)
  //=> { bodyOfWater: 'sea' }

C.prototype.isPrototypeOf(c)
  //=> true
```

`getPrototypeOf` and `isPrototypeOf` are very useful. Let's see how:

```
var oldProto = C.prototype;
C.prototype = { bodyOfWater: 'ocean' };

Object.getPrototypeOf(c)
  //=> { bodyOfWater: 'sea' }

C.prototype.isPrototypeOf(c)
  //=> false

oldProto.isPrototypeOf(c)
  //=> true
```

Changing a the object bound to a function's `prototype` property doesn't change the prototype for any objects that have already been created with `new`.

create

You can create objects and assign them prototypes *without* `new`. This object doesn't have a prototype:

```
var obj = Object.create(null);
Object.getPrototypeOf(obj)
  //=> null
```

This object has the same prototype as an object we create using literal object syntax, or an object we create using `new Object()`

```
obj = Object.create(Object.prototype);
Object.getPrototypeOf(obj)
  //=> {}

Object.getPrototypeOf(obj) === Object.getPrototypeOf({})
  //=> true
Object.getPrototypeOf(obj) === Object.getPrototypeOf(new Object())
  //=> true
```

This object has a prototype of our choosing:

```
var ourPrototype = { bodyOfWater: 'ocean' };
obj = Object.create(ourPrototype);

ourPrototype.isPrototypeOf(obj)
  //=> true
```

We can create an object with any prototype we like, without writing a constructor or using `new`.

Binding Functions to Contexts

Recall that in What Context Applies When We Call a Function?, we adjourned our look at setting the context of a function with a look at a `contextualize` helper function:

```
var contextualize = function (fn, context) {
  return function () {
    return fn.apply(context, arguments)
  }
},
a = [1,2,3],
accrete = contextualize(a.concat, a);

accrete([4,5])
  //=> [ 1, 2, 3, 4, 5 ]
```

How would this help us in a practical way? Consider building an event-driven application. For example, an MVC application would bind certain views to update events when their models change. The Backbone[32] framework uses events just like this:

```
var someView = ...,
    someModel = ...;

someModel.on('change', function () {
  someView.render()
});
```

This tells `someModel` that when it invoked a `change` event, it should call the anonymous function that in turn invoked `someView`'s `.render` method. Wouldn't it be simpler to simply write:

[32] http://backbonejs.org

```
someModel.on('change', someView.render);
```

It would, except that the implementation for `.on` and similar framework methods looks something like this:

```
Model.prototype.on = function (eventName, callback) { ... callback() ... }
```

Although `someView.render()` correctly sets the method's context as `someView`, `callback()` will not. What can we do without wrapping `someView.render()` in a function call as we did above?

binding methods

Before enumerating approaches, let's describe what we're trying to do. We want to take a method call and treat it as a function. Now, methods are functions in JavaScript, but as we've learned from looking at contexts, method calls involve both invoking a function *and* setting the context of the function call to be the receiver of the method call.

When we write something like:

```
var unbound = someObject.someMethod;
```

We're binding the name `unbound` to the method's function, but we aren't doing anything with the identity of the receiver. In most programming languages, such methods are called "unbound" methods because they aren't associated with, or "bound" to the intended receiver.

So what we're really trying to do is get ahold of a *bound* method, a method that is associated with a specific receiver. We saw an obvious way to do that above, to wrap the method call in another function. Of course, we're responsible for replicating the *arity* of the method being bound. For example:

```
var boundSetter = function (value) {
  return someObject.setSomeValue(value);
};
```

Now our bound method takes one argument, just like the function it calls. We can use a bound method anywhere:

```
someDomField.on('update', boundSetter);
```

This pattern is very handy, but it requires keeping track of these bound methods. One thing we can do is bind the method "in place," using the `let` pattern like this:

```
someObject.setSomeValue = (function () {
  var unboundMethod = someObject.setSomeValue;

  return function (value) {
    return unboundMethod.call(someObject, value);
  }
})();
```

Now we know where to find it:

```
someDomField.on('update', someObject.setSomeValue);
```

This is a very popular pattern, so much so that many frameworks provide helper functions to make this easy. Underscore[33], for example, provides `_.bind` to return a bound copy of a function and `_.bindAll` to bind methods in place:

```
// bind *all* of someObject's methods in place
_.bindAll(someObject);

// bind setSomeValue and someMethod in place
_.bindAll(someObject, 'setSomeValue', 'someMethod');
```

There are two considerations to ponder. First, we may be converting an instance method into an object method. Specifically, we're creating an object method that is bound to the object.

Most of the time, the only change this makes is that it uses slightly more memory (we're creating an extra function for each bound method in each object). But if you are a little more dynamic and actually change methods in the prototype, your changes won't "override" the object methods that you created. You'd have to roll your own binding method that refers to the prototype's method dynamically or reorganize your code.

This is one of the realities of "meta-programming." Each technique looks useful and interesting in isolation, but when multiple techniques are used together, they can have unpredictable results. It's not surprising, because most popular languages consider classes and methods to be fairly global, and they handle dynamic changes through side-effects. This is roughly equivalent to programming in 1970s-era BASIC by imperatively changing global variables.

If you aren't working with old JavaScript environments in non-current browsers, you needn't use a framework or roll your own binding functions: JavaScript has a `.bind`[34] method defined for functions:

[33] http://underscorejs.org

[34] https://developer.mozilla.org/en-US/docs/JavaScript/Reference/Global_Objects/Function/bind

```
someObject.someMethod = someObject.someMethod.bind(someObject);
```

`.bind` also does some currying for you, you can bind one or more arguments in addition to the context. For example:

```
AccountModel.prototype.getBalancePromise(forceRemote) = {
  // if forceRemote is true, always goes to the remote
  // database for the most real-time value, returns
  // a promise.
};

var account = new AccountModel(...);

var boundGetRemoteBalancePromise = account.
  getBalancePromise.
  bind(account, true);
```

Very handy, and not just for binding contexts!

Getting the context right for methods is essential. The commonplace terminology is that we want bound methods rather than unbound methods. Current flavours of JavaScript provide a `.bind` method to help, and frameworks like Underscore also provide helpers to make binding methods easy.

Object Methods

An *instance method* is a function defined in the constructor's prototype. Every instance acquires this behaviour unless otherwise "overridden." Instance methods usually have some interaction with the instance, such as references to `this` or to other methods that interact with the instance. A *constructor method* is a function belonging to the constructor itself.

There is a third kind of method, one that any object (obviously including all instances) can have. An *object method* is a function defined in the object itself. Like instance methods, object methods usually have some interaction with the object, such as references to `this` or to other methods that interact with the object.

Object methods are really easy to create with Plain Old JavaScript Objects, because they're the only kind of method you can use. Recall from This and That:

```
QueueMaker = function () {
  return {
    array: [],
    head: 0,
    tail: -1,
    pushTail: function (value) {
      return this.array[this.tail += 1] = value
    },
    pullHead: function () {
      var value;

      if (this.tail >= this.head) {
        value = this.array[this.head];
        this.array[this.head] = void 0;
        this.head += 1;
        return value
      }
    },
    isEmpty: function () {
      return this.tail < this.head
    }
  }
};
```

`pushTail`, `pullHead`, and `isEmpty` are object methods. Also, from encapsulation:

```
var stack = (function () {
  var obj = {
    array: [],
    index: -1,
    push: function (value) {
      return obj.array[obj.index += 1] = value
    },
    pop: function () {
      var value = obj.array[obj.index];
      obj.array[obj.index] = void 0;
      if (obj.index >= 0) {
        obj.index -= 1
      }
      return value
    },
    isEmpty: function () {
```

```
      return obj.index < 0
    }
  };

  return obj;
})();
```

Although they don't refer to the object, `push`, `pop`, and `isEmpty` semantically interact with the opaque data structure represented by the object, so they are object methods too.

object methods within instances

Instances of constructors can have object methods as well. Typically, object methods are added in the constructor. Here's a gratuitous example, a widget model that has a read-only `id`:

```
var WidgetModel = function (id, attrs) {
  extend(this, attrs || {});
  this.id = function () { return id }
}

extend(WidgetModel.prototype, {
  set: function (attr, value) {
    this[attr] = value;
    return this;
  },
  get: function (attr) {
    return this[attr]
  }
});
```

`set` and `get` are instance methods, but `id` is an object method: Each object has its own `id` closure, where `id` is bound to the id of the widget by the argument `id` in the constructor. The advantage of this approach is that instances can have different object methods, or object methods with their own closures as in this case. The disadvantage is that every object has its own methods, which uses up much more memory than instance methods, which are shared amongst all instances.

Object methods are defined within the object. So if you have several different "instances" of the same object, there will be an object method for each object. Object methods can be associated with any object, not just those created with the `new` keyword. Instance methods apply to instances, objects created with the `new` keyword. Instance methods are defined in a prototype and are shared by all instances.

Extending Objects with Delegation

You recall from Composition and Extension that we extended a Plain Old JavaScript Queue to create a Plain Old JavaScript Deque. But what if we have decided to use JavaScript's prototypes and the `new` keyword instead of Plain Old JavaScript Objects? How do we extend a queue into a deque?

Here's our `Queue`:

```
var Queue = function () {
  extend(this, {
    array: [],
    head: 0,
    tail: -1
  })
};

extend(Queue.prototype, {
  pushTail: function (value) {
    return this.array[this.tail += 1] = value
  },
  pullHead: function () {
    var value;

    if (!this.isEmpty()) {
      value = this.array[this.head]
      this.array[this.head] = void 0;
      this.head += 1;
      return value
    }
  },
  isEmpty: function () {
    return this.tail < this.head
  }
});
```

And here's what our `Deque` would look like before we wire things together:

```
var Dequeue = function () {
  Queue.call(this);
};

Dequeue.INCREMENT = 4;

extend(Dequeue.prototype, {
  size: function () {
    return this.tail - this.head + 1
  },
  pullTail: function () {
    var value;

    if (!this.isEmpty()) {
      value = this.array[this.tail];
      this.array[this.tail] = void 0;
      this.tail -= 1;
      return value
    }
  },
  pushHead: function (value) {
    var i;

    if (this.head === 0) {
      for (i = this.tail; i >= this.head; --i) {
        this.array[i + INCREMENT] = this.array[i]
      }
      this.tail += this.constructor.INCREMENT;
      this.head += this.constructor.INCREMENT
    }
    this.array[this.head -= 1] = value
  }
});
```

> We obviously want to do all of a `Queue`'s initialization, thus we called `Queue.call(this)`.

So what do we want from dequeues such that we can call all of a `Queue`'s methods as well as a `Dequeue`'s? Should we copy everything from `Queue.prototype` into `Deque.prototype`, like `extend(Deque.prototype, Queue.prototype)`? That would work, except for one thing: If we later

modified `Queue`, say by mixing in some new methods into its prototype, those wouldn't be picked up by `Dequeue`.

No, there's a better idea. Prototypes are objects, right? Why must they be Plain Old JavaScript Objects? Can't a prototype be an *instance*?

Yes they can. Imagine that `Deque.prototype` was a proxy for an instance of `Queue`. It would, of course, have all of a queue's behaviour through `Queue.prototype`. We don't want it to be an *actual* instance, mind you. It probably doesn't matter with a queue, but some of the things we might work with might make things awkward if we make random instances. A database connection comes to mind, we may not want to create one just for the convenience of having access to its behaviour.

Here's such a proxy:

```
var queueProxy = new Queue();
```

And here's another:

```
var queueProxy = Object.create(Queue.prototype);
```

The key here is that the prototype of a `Dequeue` needs to be an object that has its prototype set to `Queue.prototype`. That way, we can add methods to `Dequeue`'s prototype without modifying `Queue`'s prototype. Let's double-check:

```
Queue.prototype.isPrototypeOf(queueProxy)
  //=> true
```

Let's insert `queueProxy` into our code:

```
var Dequeue = function () {
  Queue.call(this)
};

Dequeue.INCREMENT = 4;

Dequeue.prototype = queueProxy;

extend(Dequeue.prototype, {
  size: function () {
    return this.tail - this.head + 1
  },
  pullTail: function () {
    var value;
```

```
15
16      if (!this.isEmpty()) {
17        value = this.array[this.tail];
18        this.array[this.tail] = void 0;
19        this.tail -= 1;
20        return value
21      }
22    },
23    pushHead: function (value) {
24      var i;
25
26      if (this.head === 0) {
27        for (i = this.tail; i >= this.head; --i) {
28          this.array[i + INCREMENT] = this.array[i]
29        }
30        this.tail += this.constructor.INCREMENT;
31        this.head += this.constructor.INCREMENT
32      }
33      this.array[this.head -= 1] = value
34    }
35  });
```

And it seems to work:

```
d = new Dequeue()
d.pushTail('Hello')
d.pushTail('JavaScript')
d.pushTail('!')
d.pullHead()
  //=> 'Hello'
d.pullTail()
  //=> '!'
d.pullHead()
  //=> 'JavaScript'
```

Wonderful!

extracting the boilerplate

Let's turn our mechanism into a function:

```
var child = function (parent, child) {
  var proxy = Object.create(parent.prototype);
  child.prototype = proxy;
  return child;
}
```

And use it in Dequeue:

```
var Dequeue = child(Queue, function () {
  Queue.call(this)
});

Dequeue.INCREMENT = 4;

extend(Dequeue.prototype, {
  size: function () {
    return this.tail - this.head + 1
  },
  pullTail: function () {
    var value;

    if (!this.isEmpty()) {
      value = this.array[this.tail];
      this.array[this.tail] = void 0;
      this.tail -= 1;
      return value
    }
  },
  pushHead: function (value) {
    var i;

    if (this.head === 0) {
      for (i = this.tail; i >= this.head; --i) {
        this.array[i + INCREMENT] = this.array[i]
      }
      this.tail += this.constructor.INCREMENT;
      this.head += this.constructor.INCREMENT
    }
    this.array[this.head -= 1] = value
  }
});
```

future directions

Some folks just **love** to build their own mechanisms. When all goes well, they become famous as framework creators and open source thought leaders. When all goes badly they create in-house proprietary one-offs that blur the line between application and framework with abstractions everywhere.

If you're keen on learning, you can work on improving the above code to handle extending constructor properties, automatically calling the parent constructor function, and so forth. Or you can decide that doing it by hand isn't that hard so why bother putting a thin wrapper around it?

It's up to you, while JavaScript isn't the tersest language, it isn't so baroque that building inheritance ontologies requires hundreds of lines of inscrutable code.

Summary

- State can be encapsulated/hidden with closures.
- Encapsulations can be aggregated with composition.
- Encapsulation resists extension.
- The automagic binding `this` facilitates sharing of functions.
- Functions can be named and declared with a name.
- The `new` keyword turns any function into a *constructor* for creating *instances*.
- All functions have a `prototype` element.
- Instances behave as if the elements of their constructor's prototype are their elements.
- Instances can override their constructor's prototype without altering it.
- The relationship between instances and their constructor's prototype is dynamic.
- `this` works seamlessly with methods defined in prototypes.
- Everything behaves like an object.
- JavaScript can convert primitives into instances and back into primitives.
- Object methods are typically created in the constructor and are private to each object.
- Prototypes can be chained to allow extension of instances.

And most importantly:

- JavaScript has classes and methods, they just aren't formally called classes and methods in the language's syntax.

The Object's The Thing

[35]

> A Smalltalk object can do exactly three things: Hold state (references to other objects), receive a message from itself or another object, and in the course of processing a message, send messages to itself or another object.–Smalltalk on Wikipedia[36]

Objects seem simple enough: They hold state, they receive messages, they process those messages, and in the course of processing messages, they also send messages. This brief definition implies an important idea: Objects can *change state* in the course of processing messages. They do this directly by removing, changing, or adding to the references they hold.

---

[35] Londinium 1 Lever Espresso Machine (c) 2013 Alejandro Erickson, some rights reserved

[36] https://en.wikipedia.org/wiki/Smalltalk

messages and method invocations

A nine year-old messenger boy

Smalltalk speaks of "messages." The metaphor of a message is very clear. A message is composed and sent from one entity (the "sender") to one entity (the "recipient"). The sender specifies the identity of the recipient. The message may contain information for the recipient, instructions to perform some task, or a question to be answered. An immediate reply may be requested, or the sender may trust the message's recipient to act appropriately. The metaphor of the "message" emphasizes the arms-length relationship between sender and recipient.[37]

Popular languages don't usually discuss messages. Instead, they speak of "invoking methods." Invoking a method has a much more imperative implication than "sending a message." It implies that the entity doing the invoking is causing something to happen, even if the precise implementation is the receiver's responsibility. Most popular languages are synchronous: The code that invokes the method waits for a response.

methods

A method is a kind of recipe for handling a message. In JavaScript, methods are functions. In other languages, methods are a separate kind of thing than functions. In many languages, the namespace for methods is distinct from the namespace for instance variables and other internal references. In JavaScript, methods and internal state are stored together as properties by default.

If we wish to organize methods separately from internal state, we must impose our own structure.

[37]More exotic messaging protocols are possible. Instead of a message being couriered from one entity to another entity, it could be posted on a public or semi-private space where many recipients could view it and decide for themselves whether to respond. Or perhaps there is a dispatching entity that examines each message and decides who ought to respond, much as an operator might direct your call to the right person within an organization.

references and state

You can imagine sending a message to a mathematician: "What's the biggest number: one, five, or four?" You can do that is JavaScript:

```
1  Math.max(1, 5, 4)
2    //=> 5
```

Although this is a message, it is unsatisfying to think of `Math` as an object, because it doesn't have any state. Objects were invented fifty years ago[38] to model entities when building simulations. When making a simulation, an essential design technique is to make provide entity with its own independent decision-making ability.

Let's say we're modeling traffic. In real life, each car has its own characteristics like maximum speed. Each car has a driver with their own particular style of driving, and of course different cars have different destinations and perhaps different senses of urgency. Each driver independently responds to the local situation around their car. The same goes for traffic lights, roads… Everything has its own independent behavior.

The way to build a simulation is to provide each simulated entity such as the cars, roads, and traffic lights, with their own little programs. You then embed them in a simulated city with a supervisory program doling out events such as rain. Finally, you start the simulation and see what happens.

The key need is to be able to have entities be independent decision-making units that respond to events from outside of themselves. In essence, we're describing computing units. Computation has, at its heart, a program and some kind of storage representing its state. Although impractical, each entity in a simulation could be a Turing Machine with a long tape.

And thus when we think of "objects," we think of independent computing devices, each with their own storage representing their state: **An object is an entity that use handlers to respond to messages**. **It maintains internal state**, **and its handlers are responsible for querying and/or updating its state**.

Immutable Properties

Sometimes we want to share objects by reference for performance and space reasons, but we don't want them to be mutable. One motivation is when we want many objects to be able to share a common entity without worrying that one of them may inadvertently change the common entity.

JavaScript provides a way to make properties immutable:

[38] https://en.wikipedia.org/wiki/Simula "The Simula Programming Language"

```
"use strict";

var rentAmount = {};

Object.defineProperty(rentAmount, 'dollars', {
  enumerable: true,
  writable: false,
  value: 420
});

Object.defineProperty(rentAmount, 'cents', {
  enumerable: true,
  writable: false,
  value: 0
});

rentAmount.dollars
  //=> 420

rentAmount.dollars = 600;
  //=> 600

rentAmount.dollars
  //=> 420
```

`Object.defineProperty` is a general-purpose method for providing fine-grained control over the properties of any object. When we make a property `enumerable`, it shows up whenever we list the object's properties or iterate over them. When we make it writable, assignments to the property change its value. If the property isn't writable, assignments are ignored.

When we want to define multiple properties, we can also write:

```
var rentAmount = {};

Object.defineProperties(rentAmount, {
  dollars: {
    enumerable: true,
    writable: false,
    value: 420
  },
  cents: {
    enumerable: true,
    writable: false,
```

```
    value: 0
  }
});

rentAmount.dollars
  //=> 420

rentAmount.dollars = 600;
  //=> 600

rentAmount.dollars
  //=> 420
```

While we can't make the entire object immutable, we can define the properties we want to be immutable. Naturally, we can generalize this:

```
function immutable (propertiesAndValues) {
  return tap({}, function (object) {
    for (var key in propertiesAndValues) {
      if (propertiesAndValues.hasOwnProperty(key)) {
        Object.defineProperty(object, key, {
          enumerable: true,
          writable: false,
          value: propertiesAndValues[key]
        });
      }
    }
  });
}

var rentAmount = immutable({
  dollars: 420,
  cents: 0
});

rentAmount.dollars
  //=> 420

rentAmount.dollars = 600;
  //=> 600

rentAmount.dollars
  //=> 420
```

considerations

As a means for protecting our data structures from inadvertent modification, this "silent failure" isn't great, but it at least *localizes* the failure mode to the objects our code is trying to change, and not to objects that may be sharing an object we're trying to change.

But it does force us to test property assignments. Whenever you write some code like this:

```
rentCheque.amount.dollars = 600;
```

You ought to write a test case that checks to see whether the cheque's dollar figure really changed. And now that you know that immutable properties are a JavaScript feature, you really need to check assignments whether you're using them or not. Who knows what changes might be made to your code in the future? Testing assignments ensures that you will catch any regressions that might be caused in the future.

Copy On Write Semantics

Coming Soon

Accessors

The Java and Ruby folks are very comfortable with a general practice of not allowing objects to modify each other's properties. They prefer to write *getters and setters*, functions that do the getting and setting. If we followed this practice, we might write:

```
var mutableAmount = (function () {
  var _dollars = 0;
  var _cents = 0;
  return immutable({
    setDollars: function (amount) {
      return (_dollars = amount);
    },
    getDollars: function () {
      return _dollars;
    },
    setCents: function (amount) {
      return (_cents = amount);
    },
    getCents: function () {
      return _cents;
```

```
    }
  });
})();

mutableAmount.getDollars()
  //=> 0

mutableAmount.setDollars(420);

mutableAmount.getDollars()
  //=> 420
```

We've put functions in the object for getting and setting values, and we've hidden the values themselves in a *closure*, the environment of an Immediately Invoked Function Expression[39] ("IIFE").

Of course, this amount can still be mutated, but we are now mediating access with functions. We could, for example, enforce certain validity rules:

```
var mutableAmount = (function () {
  var _dollars = 0;
  var _cents = 0;
  return immutable({
    setDollars: function (amount) {
      if (amount >= 0 && amount === Math.floor(amount))
        return (_dollars = amount);
    },
    getDollars: function () {
      return _dollars;
    },
    setCents: function (amount) {
      if (amount >= 0 && amount < 100 && amount === Math.floor(amount))
        return (_cents = amount);
    },
    getCents: function () {
      return _cents;
    }
  });
})();

mutableAmount.setDollars(-5)
  //=> undefined
```

[39] https://en.wikipedia.org/wiki/Immediately-invoked_function_expression

```
24
25 mutableAmount.getDollars()
26   //=> 0
```

Immutability is easy, just leave out the "getters:"

```
1  var rentAmount = (function () {
2    var _dollars = 420;
3    var _cents = 0;
4    return immutable({
5      getDollars: function () {
6        return _dollars;
7      },
8      getCents: function () {
9        return _cents;
10     }
11   });
12 })();
13
14 mutableAmount.setDollars(-5)
15   //=> undefined
16
17 mutableAmount.getDollars()
18   //=> 0
```

using accessors for properties

Languages like Ruby allow you to write code that looks like you're doing direct access of properties but still mediate access with functions. JavaScript allows this as well. Let's revisit `Object.defineProperties`:

```
1  var mediatedAmount = (function () {
2    var _dollars = 0;
3    var _cents = 0;
4    var amount = {};
5    Object.defineProperties(amount, {
6      dollars: {
7        enumerable: true,
8        set: function (amount) {
9          if (amount >= 0 && amount === Math.floor(amount))
10           return (_dollars = amount);
11       },
```

```
      get: function () {
        return _dollars;
      }
    },
    cents: {
      enumerable: true,
      set: function (amount) {
        if (amount >= 0 && amount < 100 && amount === Math.floor(amount))
          return (_cents = amount);
      },
      get: function () {
        return _cents;
      }
    }
  });
  return amount;
})();
  //=>
    { dollars: [Getter/Setter],
      cents: [Getter/Setter] }

mediatedAmount.dollars = 600;

mediatedAmount.dollars
  //=> 600

mediatedAmount.cents = 33.5

mediatedAmount.cents
  //=> 0
```

We can leave out the setters if we wish:

```
var mediatedImmutableAmount = (function () {
  var _dollars = 420;
  var _cents = 0;
  var amount = {};
  Object.defineProperties(amount, {
    dollars: {
      enumerable: true,
      get: function () {
        return _dollars;
```

```
      }
    },
    cents: {
      enumerable: true,
      get: function () {
        return _cents;
      }
    }
  });
  return amount;
})();

mediatedImmutableAmount.dollars = 600;

mediatedImmutableAmount.dollars
  //=> 420
```

Once again, the failure is silent. Of course, we can change that:

```
var noisyAmount = (function () {
  var _dollars = 0;
  var _cents = 0;
  var amount = {};
  Object.defineProperties(amount, {
    dollars: {
      enumerable: true,
      set: function (amount) {
        if (amount !== _dollars)
          throw new Error("You can't change that!");
      },
      get: function () {
        return _dollars;
      }
    },
    cents: {
      enumerable: true,
      set: function (amount) {
        if (amount !== _cents)
          throw new Error("You can't change that!");
      },
      get: function () {
        return _cents;
```

```
      }
    }
  });
  return amount;
})();

noisyAmount.dollars = 500
  //=> Error: You can't change that!
```

Hiding Object Properties

Many "OO" programming languages have the notion of private instance variables, properties that cannot be accessed by other entities. JavaScript has no such notion, we have to use specific techniques to create the illusion of private state for objects.

enumerability

In JavaScript, there is only one kind of "privacy" for properties. But it's not what you expect. When an object has properties, you can access them with the dot notation, like this:

```
var dictionary = {
  abstraction: "an abstract or general idea or term",
  encapsulate: "to place in or as if in a capsule",
  object: "anything that is visible or tangible and is relatively stable in form"
};

dictionary.encapsulate
  //=> 'to place in or as if in a capsule'
```

You can also access properties indirectly through the use of `[]` notation and the value of an expression:

```
dictionary[abstraction]
  //=> ReferenceError: abstraction is not defined
```

Whoops, the value of an *expression*: The expression `abstraction` looks up the value associated with the variable "abstraction." Alas, such a variable hasn't been defined in this code, so that's an error. This works, because 'abstraction' is an expression that evaluates to the string we want:

```
dictionary['abstraction']
  //=> 'an abstract or general idea or term'
```

One kind of privacy concerns who has access to properties. In JavaScript, all code has access to all properties of every object. There is no way to create a property of an object such that some functions can access it and others cannot.

So what kind of privacy does JavaScript provide? In order to access a property, you have to know its name. If you don't know the names of an object's properties, you can access the names in several ways. Here's one:

```
Object.keys(dictionary)
  //=>
    [ 'abstraction',
      'encapsulate',
      'object' ]
```

This is called *enumerating* an object's properties. Not only are they "public" in the sense that any code that knows the property's names can access it, but also, any code at all can enumerate them. You can do neat things with enumerable properties, such as:

```
var descriptor = map(Object.keys(dictionary), function (key) {
  return key + ': "' + dictionary[key] + '"';
}).join('; ');

descriptor
  //=>
    'abstraction: "an abstract or general idea or term"; encapsulate: "to place i\
n or as if in a
    capsule"; object: "anything that is visible or tangible and is relatively sta\
ble in form"'
```

So, our three properties are *accessible* and also *enumerable*. Are there any properties that are accessible, but not enumerable? There sure can be. You recall that we can define properties using `Object.defineProperty`. One of the options is called, appropriately enough, `enumerable`.

Let's define a getter that isn't enumerable:

```
Object.defineProperty(dictionary, 'length', {
  enumerable: false,
  get: function () {
    return Object.keys(this).length
  }
});

dictionary.length
  //=> 3
```

Notice that `length` obviously isn't included in `Object.keys`, otherwise our little getter would return `4`, not `3`. And it doesn't affect our little descriptor expression, let's evaluate it again:

```
map(Object.keys(dictionary), function (key) {
  return key + ': "' + dictionary[key] + '"';
}).join('; ')
  //=>
    'abstraction: "an abstract or general idea or term"; encapsulate: "to place i\
n or as if in a
    capsule"; object: "anything that is visible or tangible and is relatively sta\
ble in form"'
```

Non-enumerable properties don't have to be getters:

```
Object.defineProperty(dictionary, 'secret', {
  enumerable: false,
  writable: true,
  value: "kept from the knowledge of any but the initiated or privileged"
});

dictionary.secret
  //=> 'kept from the knowledge of any but the initiated or privileged'

dictionary.length
  //=> 3
```

`secret` is indeed a secret. It's fully accessible if you know it's there, but it's not enumerable, so it doesn't show up in `Object.keys`.

One way to "hide" properties in JavaScript is to define them as properties with `enumerable: false`.

closures

We saw earlier that it is possible to fake private instance variables by hiding references in a closure, e.g.

```
function immutable (propertiesAndValues) {
  return tap({}, function (object) {
    for (var key in propertiesAndValues) {
      if (propertiesAndValues.hasOwnProperty(key)) {
        Object.defineProperty(object, key, {
          enumerable: true,
          writable: false,
          value: propertiesAndValues[key]
        });
      }
    }
  });
}

var rentAmount = (function () {
  var _dollars = 420;
  var _cents = 0;
  return immutable({
    dollars: function () {
      return _dollars;
    },
    cents: function () {
      return _cents;
    }
  });
})();
```

`_dollars` and `_cents` aren't properties of the `rentAmount` object at all, they're variables within the environment of an IIFE. The functions associated with `dollars` and `cents` are within its scope, so they have access to its variables.

This has some obvious space and performance implications. There's also the general problem that an environment like a closure is its own thing in JavaScript that exists outside of the language's usual features. For example, you can iterate over the enumerable properties of an object, but you can't iterate over the variables being used inside of an object's functions. Another example: you can access a property indirectly with `[expression]`. You can't access a closure's variable indirectly without some clever finagling using `eval`.

Finally, there's another very real problem: Each and every function belonging to each and every object must be a distinct entity in JavaScript's memory. Let's make another amount using the same pattern as above:

```
var rentAmount2 = (function () {
  var _dollars = 600;
  var _cents = 0;
  return immutable({
    dollars: function () {
      return _dollars;
    },
    cents: function () {
      return _cents;
    }
  });
})();
```

We now have defined four functions: Two getters for `rentAmount`, and two for `rentAmount2`. Although the two `dollars` functions have identical code, they're completely different entities to JavaScript because each has a different enclosing environment. The same thing goes for the two `cents` functions. In the end, we're going to create an enclosing environment and two new functions every time we create an amount using this pattern.

naming conventions

Let's compare this to a different approach. We'll write almost the identical code, but we'll rely on a naming convention to hide our values in plain sight:

```
function dollars () {
  return this._dollars;
}

function cents () {
  return this._cents;
}

var rentAmount = immutable({
  dollars: dollars,
  cents: cents
});
rentAmount._dollars = 420;
rentAmount._cents = 0;
```

Our convention is that other entities should not modify any property that has a name beginning with _. There's no enforcement, it's just a practice. Other entities can use getters and setters. We've

created two functions, and we're using `this` to make sure they refer to the object's environment. With this pattern, we need two functions and one object to represent an amount.

One problem with this approach, of course, is that everything we're using is enumerable:

```
Object.keys(rentAmount)
  //=>
    [ 'dollars',
      'cents',
      '_dollars',
      '_cents' ]
```

We'd better fix that:

```
Object.defineProperties(rentAmount, {
  _dollars: {
    enumerable: false,
    writable: true
  },
  _cents: {
    enumerable: false,
    writable: true
  }
});
```

Let's create another amount:

```
var raisedAmount = immutable({
  dollars: dollars,
  cents: cents
});

Object.defineProperties(raisedAmount, {
  _dollars: {
    enumerable: false,
    writable: true
  },
  _cents: {
    enumerable: false,
    writable: true
  }
});
```

```
16
17 raisedAmount._dollars = 600;
18 raisedAmount._cents = 0;
```

We create another object, but we can reuse the existing functions. Let's make sure:

```
1 rentAmount.dollars()
2   //=> 420
3
4 raisedAmount.dollars()
5   //=> 600
```

What does this accomplish? Well, it "hides" the raw properties by making them enumerable, then provides access (if any) to other objects through functions that can be shared amongst multiple objects.

As we saw earlier, this allows us to choose whether to expose setters as well as getters, it allows us to validate inputs, or even to have non-enumerable properties that are used by an object's functions to hold state.

The naming convention is useful, and of course you can use whatever convention you like. My personal preference for a very long time was to preface private names with `my`, such as `myDollars`. Underscores work just as well, and that's what we'll use in this book.

summary

JavaScript does not have a way to enforce restrictions on accessing an object's properties: Any code that knows the name of a property can access the value, setter, or getter that has been defined for the object.

Private data can be faked with closures, at a cost in memory.

javaScript does allow properties to be non-enumerable. In combination with a naming convention and/or setters and getters, a reasonable compromise can be struck between fully private instance variables and completely open access.

Object-1s and Object-2s

In the discussion of hiding properties, we saw the example of a dictionary object. Here it is with its *domain properties*, the properties that correspond to the state of the object:

```
var dictionary = {
  abstraction: "an abstract or general idea or term",
  encapsulate: "to place in or as if in a capsule",
  object: "anything that is visible or tangible and is relatively stable in form"
};
```

By default, JavaScript permits us to add "behaviour" to the dictionary by binding functions to properties. We've already seen a better solution, but let's back up for a moment and write:

```
dictionary.describe = function () {
  return map['abstraction', 'encapsulate', 'object'], function (key) {
    return key + ': "' + dictionary[key] + '"';
  }).join('; ');
};

dictionary.describe()
  //=>
    'abstraction: "an abstract or general idea or term"; encapsulate: "to place i\
n or as if in a capsule";
    object: "anything that is visible or tangible and is relatively stable in for\
m"'
```

What happens if we get the keys of our object? By now, you know the answer immediately:

```
Object.keys(dictionary)
  //=>
    [ 'abstraction',
      'encapsulate',
      'object',
      'describe' ]
```

The `describe` property is exactly the same as the `abstraction`, `encapsulate`, and `object` properties. This is not surprising once you've grasped the fact that JavaScript is sometimes described as a "Lisp-1."

What what?

lisp-1s and lisp-2s

One of the big schisms in the history of the Lisp programming languages is over namespaces. In one branch of the tree, functions live in the same namespace as every other kind of value. So a name

like `setvar` can be bound to any kind of value: A symbol, a string, a list, a function, whatever. Lisps with this namespace system are called "Lisp-1s" because they have one namespace for everything.[40]

So in a Lisp-1, `(map someList myFun)` calls the function bound to the name `map`, passing along the values bound to the symbols `someList` and `myFun`. `myFun` can (and should) be a function, and that's fine.

Other Lisps use a different system. Functions live in their own namespace. So `setvar` wouldn't be bound to a function, but it could be a symbol, list, or anything else. If you want a function named "setvar," you need special syntax to reach into the function namespace, like `#'setvar`.[41]

In a Lisp-2, `(map someList myFun)` calls the function bound to the name `map`, passing along the values bound to the symbols `someList` and `myFun`. But it's not going to work, because it's going to look up the non-function value bound to the name `myFun`. To make it work properly, we need something like `(map someList #'myFun)`, indicating that we want to go into the function namespace to look up `myFun`.

javascript is a javascript-1

In JavaScript, all values live in the same namespace. Anywhere you write a variable name like `foo`, it could be a function or it could be an "ordinary" value like an object, string, or number. When we write something like:

```
1 map(someLisp, myFun)
```

All three names (map, someLisp, and myFun) are looked up in the same namespace and can contain functions or ordinary values. This is simpler and cleaner than having special rules for how to look functions up.

javascript is also an object-1

As we've seen repeatedly, JavaScript objects have properties, and those properties can be either functions or ordinary values. If we write:

```
1 dictionary.length
```

We might be accessing a function, we might be accessing a number. The only way to know is to try it:

[40] Some people argue that Lisp-1 and Lisp-2 are examples of "opaque jargon" and are a communication anti-pattern.

[41] Why are there two different ways to handle namespaces in the Lisp family of languages? Some theorize that it goes back to some early implementation detail, perhaps it was efficient to put all the functions in one big data structure and put everything else in another. or perhaps it saved checking that something really is a function before invoking it, a rudimentary form of static type-checking.

```
var dictionary = {
  abstraction: "an abstract or general idea or term",
  encapsulate: "to place in or as if in a capsule",
  object: "anything that is visible or tangible and is relatively stable in form"
};

Object.defineProperty(dictionary, 'length', {
  enumerable: false,
  writable: false,
  value: function () {
    return Object.keys(this).length;
  }
});

dictionary.length
  //=> [Function]
```

Thus, by default, JavaScript's properties are a single namespace containing both functions and ordinary values. The functions we assign as behaviours of the object live alongside the values that belong to the domain.

Not all "OO" languages are "Object-1s." Ruby, for example, is an "Object-2." In Ruby, object methods live in a complete different namespace from their instance variables, and both of them live in a complete different namespace from the contents of containers like Hashes.

For example:

```
dictionary = Object.new

dictionary.instance_variable_set(:@abstraction, "an abstract or general idea or t\
erm")

def dictionary.abstraction
  "the act of considering something as a general quality or characteristic, " +
  "apart from concrete realities, specific objects, or actual instances."
end
```

Its methods and instance variables are assigned as if they're separate things. Let's access them from outside the object:

```
dictionary.instance_variable_get(:@abstraction)
  #=> "an abstract or general idea or term"

dictionary.abstraction
  #=> "the act of considering something as a general quality or characteristic,
       apart from concrete realities, specific objects, or actual instances.
```

And from within its own methods?

```
def dictionary.tryThis
  puts @abstraction, nil, abstraction
end

dictionary.tryThis
  #=>
    an abstract or general idea or term

    the act of considering something as a general quality or characteristic,
    apart from concrete realities, specific objects, or actual instances.
```

In Ruby, instance variables live in their own namespace separately from methods, you have to use a sigil, `@` to access them. Ruby is an Object-2.

writing javascript in object-2 style

It's a huge benefit that JavaScript is a "Lisp-1" in the sense that there is one namespace for all variables. But it can be a benefit to write JavaScript in an "Object-2" style, separating our methods from our domain properties.

One of the practices we saw earlier was to hide properties by making them non-enumerable. This is often useful for methods:

```
var dictionary = {
  abstraction: "an abstract or general idea or term",
  encapsulate: "to place in or as if in a capsule",
  object: "anything that is visible or tangible and is relatively stable in form"
};

Object.defineProperty(dictionary, 'length', {
  enumerable: false,
  writable: false,
  value: function () {
```

```
    return Object.keys(this).length;
  }
});

Object.keys(dictionary).indexOf('value') >= 0
  //=> false
```

As we see, `Object.keys` gives us the names of the enumerable properties, the ones we're using for domain state. What about the non-enumerable properties? We have a partial answer with `Object.getOwnPropertyNames`:

```
Object.getOwnPropertyNames(dictionary)
  //=>
    [ 'abstraction',
      'encapsulate',
      'object',
      'length' ]
```

Given this, we can construct:

```
function methods (object) {
  var domainProperties = Object.keys(object);

  return Object.getOwnPropertyNames(object).filter( function (name) {
    return typeof(object[name]) === 'function' && domainProperties.indexOf(name) \
=== -1;
  })
}

methods(dictionary)
  //=> ['length']
```

We will need to be strict about making all of your methods non-enumerable to use this function. We'll also have to rethink our approach to listing methods when we start working with metaobject,s the topic of the next chapter.

To Do

object composition and delegation

state machines and strategies

nouns, verbs and commands

immediate, forward, and late-binding

Methods

[42]

> In object-oriented programming, a method (or member function) is a subroutine (or procedure or function) associated with an object, and which has access to its data, its member variables.—Wikipedia[43]

What is a Method?

As an abstraction, an object is an independent entity that maintains internal state and that responds to messages by reporting its internal state and/or making changes to its internal state. In the course of handling a message, an object may send messages to other objects and receive replies from them.

A "method" is an another idea that is related to, but not the same as, handling a message. A method is a function that encapsulates an object's behaviour. Methods are invoked by a calling entity much as a function is invoked by some code.

[42] Vacuum Pots (c) 2012 Olin Viydo, some rights reserved

[43] https://en.wikipedia.org/wiki/Method_

The distinction may seem subtle, but the easiest way to grasp the distinction is to focus on the word "message." A message is an entity of its own. You can store and forward a message. You can modify it. You can copy it. You can dispatch it to multiple objects. You can put it on a "blackboard" and allow objects to decide for themselves whether they want to respond to it.

Methods, on the other hand, operate "closer to the metal." They look and behave like function calls. In JavaScript, methods *are* functions. To be a method, a function must be the property of an object. We've seen methods earlier, here's a naïve example:

```
var dictionary = {
  abstraction: "an abstract or general idea or term",
  encapsulate: "to place in or as if in a capsule",
  object: "anything that is visible or tangible and is relatively stable in form",
  descriptor: function () {
    return map['abstraction', 'encapsulate', 'object'], function (key) {
      return key + ': "' + dictionary[key] + '"';
    }).join('; ');
  }
};

dictionary.descriptor()
  //=>
    'abstraction: "an abstract or general idea or term"; encapsulate: "to place i\
n or as if in a capsule";
    object: "anything that is visible or tangible and is relatively stable in for\
m"'
```

In this example, `descriptor` is a method. As we saw earlier, this code has many problems, but let's hand-wave them for a moment. Let's be clear about our terminology. This `dictionary` object has a method called `descriptor`. The function associated with `descriptor` is called the *method handler*.

When we write `dictionary.descriptor()`, we're *invoking or calling the descriptor method*. The object is then *handling the method invocation* by evaluating the function.

In describing objects, we refer to objects as encapsulating their internal state. The ideal is that objects **never** directly access or manipulate each other's state. Instead, objects interact with each other solely through methods.

There are many things that methods can do. Two of the most obvious are to *query* an object's internal state and to *update* its state. Methods that have no purpose other than to report internal state are called queries, while methods that have no purpose other than to update an object's internal state are called updates.

The Letter and the Spirit of the Law

The 'law' that objects must only interact with each other through methods is generally accepted as an ideal, even though languages like JavaScript and Java do not enforce it. That being said, there are (roughly) two philosophies about the design of objects and their methods.

- *Literalists* believe that the important thing is the means of interaction be methods. Literalists are noted for using a profusion of getters and setters, which leads to code that is semantically identical to code where objects interact with each other's internal state, but every interaction is performed indirectly through a query or update.
- *Semanticists* believe that the important thing is that objects provide abstractions over their internal state. They avoid getters and setters, preferring to provide methods that are a level of abstraction above their internal representations.

By way of example, let's imagine that we have a `person` object. Our first cut at it involves storing a name. Here's a first cut at a literalist implementation:

```
var person = Object.create(null, {
  _firstName: {
    enumerable: false,
    writable: true
  },
  _lastName: {
    enumerable: false,
    writable: true
  },
  getFirstName: {
    enumerable: false,
    writable: true,
    value: function () {
      return _firstName;
    }
  },
  setFirstName: {
    enumerable: false,
    writable: true,
    value: function (str) {
      return _firstName = str;
    }
  },
  getLastName: {
```

```
    enumerable: false,
    writable: true,
    value: function () {
      return _lastName;
    }
  },
  setLastName: {
    enumerable: false,
    writable: true,
    value: function (str) {
      return _lastName = str;
    }
  }
});
```

This is largely pointless as it stands. Other objects now write `person.setFirstName('Bilbo')` instead of `person.firstName = 'Bilbo'`, but nothing of importance has been improved. The trouble with this approach as it stands is that it is a holdover form earlier times. Much of the trouble stems from design decisions made in languages like C++ and Java to preserve C-like semantics.

In those languages, once you have some code written as `person.firstName = 'Bilbo'`, you are forever stuck with `person` exposing a property to direct access. Without changing the semantics, you may later want to do something like make `person` observable[44], that is, we add code such that other objects can be notified when the person object's name is updated.

If `firstName` is a property being directly updated by other entities, we have no way to insert any code to handle the updating. The same argument goes for something like validating the name. Although validating names is a morass in the real world, we might have simple ideas such as that the first name will either have at least one character or be `null`, but never an empty string. If other entities directly update the property, we can't enforce this within our object.

In days of old, programmers would have needed to go through the code base changing `person.firstName = 'Bilbo'` into `person.setName('Bilbo')` (or even worse, adding all the observable code and validation code to other entities).

Thus, the literalist tradition grew of defining getters and setters as methods even if no additional functionality was needed immediately. With the code above, it is straightforward to introduce validation and observability:[45]

[44] https://en.wikipedia.org/wiki/Observer_pattern

[45] Later on, we'll see how to use method combinators to do this more elegantly.

```
var person = Object.create(null, {
  // ...
  setFirstName: {
    enumerable: false,
    writable: true,
    value: function (str) {
      // insert validation and observable boilerplate here
      return _firstName = str;
    }
  },
  setLastName: {
    enumerable: false,
    writable: true,
    value: function (str) {
      // insert validation and observable boilerplate here
      return _lastName = str;
    }
  }
});
```

That seems very nice, but balanced against this is that contemporary implementations of JavaScript allow you to write getters and setters for properties that mediate access even when other entities are using property access syntax like `person.lastName = 'Baggins'`:

```
var person = Object.create(null, {
  _firstName: {
    enumerable: false,
    writable: true
  },
  firstName: {
    get: function () {
      return _firstName;
    },
    set: function (str) {
      // insert validation and observable boilerplate here
      return _firstName = str;
    }
  },
  _lastName: {
    enumerable: false,
    writable: true
  },
```

```
  lastName: {
    get: function () {
      return _lastName;
    },
    set: function (str) {
      // insert validation and observable boilerplate here
      return _lastName = str;
    }
  }
});
```

The preponderance of evidence suggests that if you are a literalist, you are better off not bothering with making getters and setters for everything in JavaScript, as you can add them later if need be.

the semantic interpretation of object methods[46]

What about the semantic approach?

With the literalist, properties like `firstName` are decoupled from methods like `setFirstName` so that the implementation of the properties can be managed by the object. Other objects calling `person.setFirstName('Frodo')` are insulated from details such as whether other objects are to be notified when `person` is changed.

But while the implementation is hidden, there is no abstraction involved. The level of abstraction of the properties is identical to the level of abstraction of the methods.

The semanticist takes this one step further. To the semanticist, objects insulate other entities from implementation details like observables and validation, but objects also provide an abstraction to other entities.

In our `person` example, first and last name is a very low-level concern, the kind of thing you think about when you're putting things in a database and worrying about searching and sorting performance. But what would be a higher-level abstraction?

Just a name.

You ask someone their name, they tell you. You ask for a name, you get it. An object that takes and accepts names hides from us all the icky questions like:

1. How do we handle people who only have one name? (it's not just celebrities)
2. Where do we store the extra middle names like Tracy Christopher Anthony Lee?
3. How do we handle formal Spanish names like Gabriel José de la Concordia García Márquez[47]?

[46] With the greatest respect to Chongo, author of "The Homeless Interpretation of Quantum Mechanics."

[47] https://en.wikipedia.org/wiki/Gabriel_Garc%C3%ADa_Márquez

4. What do we do with maiden names[48] like Arlene Gwendolyn Lee née Barzey or Leocadia Blanco Álvarez de Pérez?

If we expose the low-level fields to other code, we demand that they know all about our object's internals and do the parsing where required. It may be simpler and easier to simply expose:

```
var person = Object.create(null, {
  _givenNames: {
    enumerable: false,
    writable: true,
    value: []
  },
  _maternalSurname: {
    enumerable: false,
    writable: true
  },
  _paternalSurname: {
    enumerable: false,
    writable: true
  },
  _premaritalName: {
    enumerable: false,
    writable: true
  },
  name: {
    get: function () {
      // ...
    },
    set: function (str) {
      // ...
    }
  }
});
```

The `person` object can then do the "icky" work itself. This centralizes responsibility for names.

Now, honestly, people have been handling names in a very US-centric way for a very long time, and few will put up a fuss if you make objects with highly literal name implementations. But the example illustrates the divide between a *literal design* where other objects operate at the same level of abstraction as the object's internals, and a *semantic design*, one that operates at a higher level of abstraction and is responsible for translating methods into queries and updates on the implementation.

[48] https://en.wikipedia.org/wiki/Married_and_maiden_names

Composite Methods

One of the primary activities in programming is to *factor* programs or algorithms, to break them into smaller parts that can be reused or recombined in different ways.

> Common industry practice is to use the words "decompose" and "factor" interchangeably to refer to any breaking of code into smaller parts. Nevertheless, we will defy industry practice and use the word "decompose" to refer to breaking code into smaller parts whether those parts are to be recombined or reused or not, and use the word "factor" to refer to the stricter case of decomposition where the intention is to recombine or reuse the parts in different ways.

Both methods and objects can and should be factored into reusable components that have a single, well-defined responsibility[49].[50]

The simplest way to decompose a method is to "extract" one or more helper methods. For example:

```
var person = Object.create(null, {

  // ...

  setFirstName: {
    enumerable: false,
    writable: true,
    value: function (str) {
      if (typeof(str) === 'string' && str != '') {
        return this._firstName = str;
      }
    }
  },
  setLastName: {
    enumerable: false,
    writable: true,
    value: function (str) {
      if (typeof(str) === 'string' && str != '') {
        return this._lastName = str;
      }
    }
  }
});
```

[49] https://en.wikipedia.org/wiki/Single_responsibility_principle

[50] Robert Martin's rule of thumb for determining whether a method has a single responsibility is to ask when and why it would ever change. If there is just one reason why you are likely to change a method, it has a single responsibility. If there is more than one reason why it might change, it should be decomposed into separate entities that each have a single responsibility.

The methods `setFirstName` and `setLastName` both have a "guard clause" that will not update the object's hidden state unless the method is passed a non-empty string. The logic can be extracted into its own "helper method:"

```
var person = Object.create(null, {

  // ...

  isaValidName: {
    enumerable: false,
    writable: false,
    value: function (str) {
      return (typeof(str) === 'string' && str != '');
    }
  },
  setFirstName: {
    enumerable: false,
    writable: true,
    value: function (str) {
      if (this.isaValidName(str)) {
        return this._firstName = str;
      }
    }
  },
  setLastName: {
    enumerable: false,
    writable: true,
    value: function (str) {
      if (this.isaValidName(str)) {
        return this._lastName = str;
      }
    }
  }
});
```

The methods `setFirstName` and `setLastName` now call the helper method `isaValidName`. The usual motivation for this is known as DRY[51] or "Don't Repeat Yourself." The DRY principle is stated as "Every piece of knowledge must have a single, unambiguous, authoritative representation within a system."

In this case, presumably there is one idea, "person names must be non-empty strings," and placing the implementation for this in the `isaValidString` helper method ensures that now there is just the

[51] https://en.wikipedia.org/wiki/Don't_repeat_yourself

one authoritative source for the logic, instead of one in each name setter method.

Decomposing a method needn't always be for the purpose of DRYing up the logic. Sometimes, a method breaks down logically into a hierarchy of steps. For example:

```
var person = Object.create(null, {

  // ...

  doSomethingComplicated: {
    enumerable: false,
    writable: true,
    value: function () {
      this.setUp();
      this.doTheWork();
      this.breakdown();
      this.cleanUp();
    }
  },
  setUp: // ...
  doTheWork: // ...
  breakdown: // ...
  cleanUp: // ...
});
```

This is as true of methods as it is of functions in general. However, objects have some extra considerations. The most conspicuous is that an object is its own namespace. When you break a method down into helpers, you are adding items to the namespace, making the object as a whole more difficult to understand. What methods call `setUp`? Can `breakdown` be called independently of `cleanUp`? Everything is thrown into an object higgledy-piggledy.

decluttering with closures

JavaScript provides us with tools for reducing object clutter. The first is the Immediately Invoked Function Expression[52] ("IIFE"). If our four helpers exist only to decompose `doSomethingComplicated`, we can write:

[52] https://en.wikipedia.org/wiki/Immediately-invoked_function_expression

```
var person = Object.create(null, {

  // ...

  doSomethingComplicated: {
    enumerable: false,
    writable: true,
    value: (function () {
      return function () {
        setUp.call(this);
        doTheWork.call(this);
        breakdown.call(this);
        cleanUp.call(this);
      };
      function setUp () {
        // ...
      }
      function doTheWork () {
        // ...
      }
      function breakdown () {
        // ...
      }
      function cleanUp () {
        // ...
      }
    })()
  },
});
```

Now our four helpers exist only within the closure created by the IIFE, and thus it is impossible for any other method to call them. You could even create a `setUp` helper with a similar name for another function without clashing with this one. Note that we're not invoking these functions with `this.`, because they aren't methods any more. And to preserve the local object's context, we're calling them with `.call(this)`.

decluttering with method objects

In JavaScript, methods are represented by functions. And in JavaScript, *functions are objects*. Functions have properties, and the properties behave just like objects we create with `{}` or `Object.create`:

```
var K = function (x) {
  return function (y) {
    return x;
  };
};

Object.defineProperty(K, 'longName', {
  enumerable: true,
  writable: false,
  value: 'The K Combinator'
});

K.longName
  //=> 'The K Combinator'

Object.keys(K)
  //=> [ 'longName' ]
```

We can take advantage of this by using a function as a container for its own helper functions. There are several easy patterns for this. Of course, you could write it all out by hand:

```
function doSomethingComplicated () {
  doSomethingComplicated.setUp.call(this);
  doSomethingComplicated.doTheWork.call(this);
  doSomethingComplicated.breakdown.call(this);
  doSomethingComplicated.cleanUp.call(this);
}

doSomethingComplicated.setUp = function () {
  // ...
}

doSomethingComplicated.doTheWork = function () {
  // ...
}

doSomethingComplicated.breakdown = function () {
  // ...
}

doSomethingComplicated.cleanUp = function () {
  // ...
```

```
}

var person = Object.create(null, {

  // ...

  doSomethingComplicated: {
    enumerable: false,
    writable: true,
    value: doSomethingComplicated
  }
});
```

If we'd like to make it neat and tidy inline, `tap` is handy:

```
var person = Object.create(null, {

  // ...

  doSomethingComplicated: {
    enumerable: false,
    writable: true,
    value: tap(
      function doSomethingComplicated () {
        doSomethingComplicated.setUp.call(this);
        doSomethingComplicated.doTheWork.call(this);
        doSomethingComplicated.breakdown.call(this);
        doSomethingComplicated.cleanUp.call(this);
      }, function (its) {
        its.setUp = function () {
          // ...
        }

        its.doTheWork = function () {
          // ...
        }

        its.breakdown = function () {
          // ...
        }

        its.cleanUp = function () {
```

```
28            // ...
29          }
30        })
31    }
32  });
```

In terms of code, this is no simpler than the IIFE solution. However, placing the helper methods inside the function itself does make them available for use or modification by other methods. For example, you can now use a method decorator on any of the helpers:

```
1  var logsTheReciver = after( function (value) {
2    console.log(this);
3    return value;
4  });
5
6  person.doSomethingComplicated.doTheWork = logsTheReciver(person.doSomethingCompli\
7  cated.doTheWork);
```

This would not have been possible if `doTheWork` was hidden inside a closure.

summary

Like "ordinary" functions, methods can benefit from being decomposed or factored into smaller functions. Two of the motivations for doing so are to DRY up the code and to break a method into more easily understood and obvious parts. The parts can be represented as helper methods, functions hidden in a closure, or properties of the method itself.

Meta-Methods

function helpers

If functions are objects, and functions can have properties, then functions can have methods. We can give functions our own methods by assigning functions to their properties. We saw this previously when we decomposed an object's method into helper methods. Here's the same applied to a function:

```
function factorial (n) {
  return factorial.helper(n, 1);
}

factorial.helper = function helper (n, accumulator) {
  if (n === 0) {
    return accumulator;
  }
  else return helper(n - 1, n * accumulator);
}
```

Functions can have all sorts of properties. One of the more intriguing possibility is to maintain an array of functions:

```
function sequencer (arg) {
  var that = this;

  return sequencer._functions.reduce( function (acc, fn) {
    return fn.call(that, acc);
  }, arg);
}

Object.defineProperties(sequencer, {
  _functions: {
    enumerable: false,
    writable: false,
    value: []
  }
});
```

`sequencer` is an object-oriented way to implement the `pipeline` function from function-oriented libraries like allong.es[53]. Instead of writing something like:

```
function square (n) { return n * n; }
function increment (n) { return n + 1; }

pipeline(square, increment)(6)
  //=> 37
```

We can write:

[53] http://allong.es

```
sequencer._functions.push(square);
sequencer._functions.push(increment);

sequencer(6)
  //=> 37
```

The functions contained within the `_functions` array are helper methods. They work they same way as is we'd written something like:

```
function squarePlusOne (arg) {
  return squarePlusOne.increment(
    squarePlusOne.square(arg)
  );
}
squarePlusOne.increment = increment;
squarePlusOne.square = square;

squarePlusOne(6)
  //=> 37
```

The only difference is that they're dynamically looked up helper methods instead of statically wired in place by the body of the function. But they're still helper methods.

function methods

The obvious problem with our approach is that we aren't using our method as an object in the ideal sense. Why should other entities manipulate its internal state? If this were any other kind of object, we'd expose methods handle messages from other entities.

Let's try it:

```
Object.defineProperties(sequencer, {
  push: {
    enumerable: false,
    writable: false,
    value: function (fn) {
      return this._functions.push(fn);
    }
  }
});
```

Now we can manipulate our `sequencer` without touching its privates:

```
sequencer.push(square);
sequencer.push(increment);

sequencer(6)
  //=> 37
```

Is it a big deal to eliminate the `_functions` reference? Yes!

1. This hides the implementation: Do we have an array of functions? Or maybe we are composing the functions with a combinator? Who knows?
2. This prevents us manipulating internal state in unauthorized ways, such as calling `sequencer._functions.reverse()`

`sequencer.push` is a proper method, a function that handles messages from other entities and in the course of handling the message, queries and/or updates the function's internal state.

If we're going to treat functions like objects, we ought to give them methods.

aspect-oriented programming and meta-methods

When an object has a function as one of its properties, that's a method. And we just established that functions can have methods. So… Can a method have methods?

Most assuredly.

Here's an example that implements a simplified form of Aspect-Oriented Programming[54]

Consider a `businessObject` and a `businessObjectCollection`. Never mind what they are, that isn't important. We start with the idea that a `businessObject` can be `valid` or `invalid`, and there's a method for querying this:

```
var businessObject = Object.create(null, {
  // ...
  isValid: {
    enumerable: false,
    value: function () {
      // ...
    }
  }
});
```

Obviously, the `businessCollection` has methods for adding business objects and for finding business objects:

[54] https://en.wikipedia.org/wiki/Aspect-oriented_programming

```
var businessCollection = Object.create(null, {
  // ...
  add: {
    enumerable: false,
    value: function (bobj) {
      // ...
    }
  },
  find: {
    enumerable: false,
    value: function (fn) {
      // ...
    }
  }
});
```

Our `businessCollection` is just a collection, it doesn't actually do anything to the business objects it holds.

One day, we decide that it is an error if an invalid business object is placed in a business collection, and also an error if an invalid business object is returned when you call `businessCollection.find`. To "fail fast" in these situations, we decide that an exception should be thrown when this happens.

Should we add some checking code to `businessCollection.add` and `businessCollection.find`? Yes, but we shouldn't modify the methods themselves. Since `businessCollection`'s single responsibility is storing objects, business rules about the state of the objects being stored should be placed in some other code.

What we'd like to do is "advise" the `add` method with code that is to be run before it runs, and advise the `find` method with code that runs after it runs. If our methods had methods, we could write:

```
businessCollection.add.beforeAdvice(function (bobjProvided) {
  if (!bobjProvided.isValid())
    throw 'bad object provided to add';
});

businessCollection.find.afterAdvice(function (bobjReturned) {
  if (bobjReturned && !bobjReturned.isValid())
    throw 'bad object returned from find';
});
```

As you can see, we've invented a little protocol. `.beforeAdvice` adds a function "before" a method, and `.afterAdvice` adds a function "after" a method. We'll need a function to make method objects out of the desired method functions:

```
function advisable (methodBody) {

  function theMethod () {
    var args = [].slice.call(arguments);

    theMethod.befores.forEach( function (advice) {
      advice.apply(this, args);
    }, this);

    var returnValue = theMethod.body.apply(this, arguments);

    theMethod.afters.forEach( function (advice) {
      advice.call(this, returnValue);
    }, this);

    return returnValue;
  }

  Object.defineProperties(theMethod, {
    befores: {
      enumerable: true,
      writable: false,
      value: []
    },
    body: {
      enumerable: true,
      writable: false,
      value: body
    },
    afters: {
      enumerable: true,
      writable: false,
      value: []
    },
    beforeAdvice: {
      enumerable: false,
      writable: false,
      value: function (fn) {
        this.befores.unshift(fn);
        return this;
      }
    },
```

```
    afterAdvice: {
      enumerable: false,
      writable: false,
      value: function (fn) {
        this.afters.push(fn);
        return this;
      }
    }
  });

  return theMethod;
}
```

Let's rewrite our `businessCollection` to use our `advisable` function:

```
var businessCollection = Object.create(null, {
  // ...
  add: {
    enumerable: false,
    value: advisable(function (bobj) {
      // ...
    })
  },
  find: {
    enumerable: false,
    value: advisable(function (fn) {
      // ...
    })
  }
});
```

And now, exactly as above, we can write `businessCollection.add.beforeAdvice` and `businessCollection.find.a` separating the responsibility for error checking from the responsibility for managing a collection of business objects.

`beforeAdvice` and `afterAdvice` are methods of methods, or more simply, *meta-methods*.

Interlude: At home with the Bumblethwaites

Any discussion about programming with objects turns inevitably to programming with "classes" and to "inheritance." Some will even construct elaborate ontologies of domain objects, saying things like "ChequingAccount is-a BankAccount," and "SignatureAccount is-a ChequingAccount."

Every programming language provides its own own unique combination of features and concepts, yet there are some ideas common to all object-oriented programming that we can grasp and use as the basis for writing our own programs. Since "inheritance" is a metaphor, we'll explain these concepts using a metaphor. Specifically, we'll talk about a family.

The cast of "At Home with the Braithwaites"

The Bumblethwaite Family

Consider a programmer, Amanda Bumblethwaite.[55] Amanda has several children, one of whom is Alex Bumblethwaite. Like many families, the Bumblethwaites have their own home in the *Apiary*

[55] Amanda was born "Amanda Braithwaite," but changed surnames to "Bumblethwaite" in protest against a certain author of programming books.

Meadows, a suburban village. Although Alex is fairly independant, questions like "Can you come to a pajama party on Saturday night" are deferred to Amanda. Amanda taught each of her children how to write programs using Squeak[56] and Lego Mindstorms[57].

What can we say about the Bumblethwaites?

constructors

First, we can say that *Amanda is Alex's constructor*. Amanda provides 50% of the blueprint for making Alex, and Amanda actually carried out the work of bringing Alex into existence. (We'll hand-wave furiously about David Bumblethwaite's role.)

formal classes

Second, we can say that "Bumblethwaite" is a *formal class*. Amanda is a member of the Bumblethwaite class, and so is Alex. The formal class itself has no physical existence. Amanda has a physical existence, and there is an understanding that all of Amanda's children are necessarily Bumblethwaites, but the concept of "Bumblethwaite-ness" is abstract.

expectations

Because Amanda teaches all of her children how to program, knowing that Alex is a Bumblethwaite, we expect Alex to know how to program. Knowing that the Bumblethwaite live in Apiary Meadows, and knowing that Alex is a Bumblethwaite, we expect that Alex lives in Apiary Meadows.

delegation

Alex *delegates* a lot of behaviour to Amanda. Meaning, that there are many choices she makes by asking Amanda what to do, and Amanda makes the choice based on Alex's interests, in Alex's context.

ad hoc sets

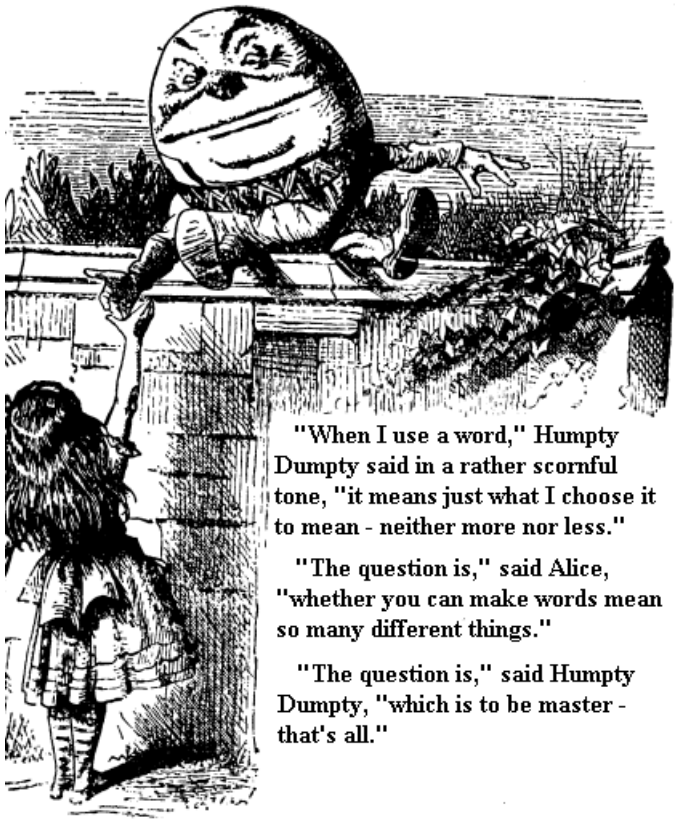
While it's true that all Bumblethwaites are programmers, the concept of "being a programmer" is different than the concept of "being a Bumblethwaite." Membership in the "set of all programmers" is determined empirically: If a person programs, they are a programmer. It is possible for someone who doesn't program to become a programmer.

Membership in "The Bumblethwaites" is a more formal affair. You must be born a Bumblethwaite, and issued a birth certificate with "Bumblethwaite" on it. Or you must marry into the Bumblethwaites, again getting a piece of paper attesting to your "Bumblethwaite-ness."

[56] http://squeak.org

[57] http://www.lego.com/en-us/mindstorms

Where “Bumblethwaite” is a formal class, “Programmer” is an ad hoc set.



humpty dumpty

These five ideas–constructors, formal classes, expectations, delegation, and ad hoc sets–characterize most ideas in object-oriented programming. Each programming language provides tools for expressing these ideas, although the languages tend to use the same words in slightly different ways.

JavaScript provides objects, functions and prototypes. The `new` keyword allows functions to be used as constructors. Prototypes are used for delegating behaviour. Just as Alex delegates behaviour to Amanda *and* Amanda constructs Alex, it is normal in JavaScript that a function is paired with a prototype to produce, through composition, an entity that handles construction and delegation of behaviour.

“Classic” JavaScript does not have the notion of a class, but JavaScript programmers often refer to such compositions as classes. JavaScript provides the `instanceof` operator to test whether an object was created by such a composite function. `instanceof` is a leaky abstraction, but it works well enough for treating constructer functions as formal classes.

Formal Classes, Expectations, and Ad Hoc Sets

The distinction between "Bumblethwaite" and "Programmer" from our example above is a fundamental idea in object-oriented programming. Formal classes are a way of organizing knowledge about the domain and establishing expectations. By organizing constructors and prototypes in a certain way, we can set the expectation that all instances of "Bumblethwaite" can program.

Let's imagine that our definition of "is a programmer" is expressed as having a function called `writeFunction`:

```
function isaProgrammer (candidate) {
  return typeof(candidate.writeFunction) === 'function';
}
```

It's easy to imagine that "amanda is a programmer:"

```
var amanda = {
  writeFunction: function (requirements) {
    var newFunction;
    // ... gimcrack code to convert formal requirements into a working function
    return newFunction;
  }
};

isaProgrammer(amanda)
  //=> true
```

We can say that "alex is a Bumblethwaite:"

```
function Bumblethwaite () {}

var alex = new Bumblethwaite();

alex instanceof Bumblethwaite
  //=> true
```

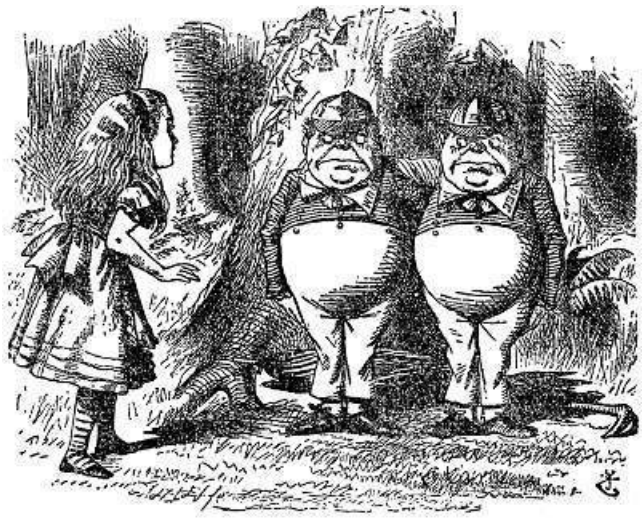
We can say that every Bumblethwaite is created as a programmer:

```
function Bumblethwaite () {
  this.writeFunction = function (requirements) {
    // ... better code to convert formal requirements into a working function
  }
}

var alex = new Bumblethwaite();

isaProgrammer(alex)
  //=> true
```

Or even that the Bumblethwaites delegate their programming to Amanda:

```
function Bumblethwaite () {}

Bumblethwaite.prototype = amanda;

alex = new Bumblethwaite();

isaProgrammer(alex)
  //=> true
```

We are setting up the *expectation* that if `alex instanceof Bumblethwaite === true`, *then* `isaProgrammer(alex) === true`. Object-oriented programming is, at its heart, around organizing knowledge such that you can form and test such expectations.



Tweedledum and Tweedledee

"duck typing"

A number of languages are built around having very high confidence in the expectations associated with classes.

Early-binding languages like OCaml carefully check programs so that if a function is expecting to work with a "Programmer" object, all other pieces of code interacting with that function pass programmer objects and nothing else.

Many (but not all) early-binding languages emphasize the use of formal-classes. Languages like Java are unable to formalize the idea that a "programmer" is any object with a `writeProgram` method, programs must formalize this notion using a class and/or interface that can then be associated with variables and/or parameters.

The compiler then checks all assignments to ensure that only values of the appropriate type are bound to each variable or parameter.

It is going to far to call such checking a "proof of program correctness," but without question such checking can reveal when a program is demonstrably *incorrect* in that it is not internally consistent.

Late-binding languages like JavaScript and Python do not provide this kind of checking, and there is no easy way to "declare" what a function or method expects. It is the programmer's responsibility to ensure that a program is internally consistent.

While many early-binding languages are built around formal classes, most late-binding languages are really built around ad hoc sets. In JavaScript, when you write `amanda.writeProgram(specification)`, all that matters is that when this is evaluated, the name `amanda` must be bound to an object that directly or indirectly implements a `writeFunction` method.

The colloquial term for this is "duck typing," as in "If it walks like a duck, and quacks like a duck, it's a duck." This phrase captures the ad hoc set way of thinking.

The "I" Word

When we write:

```
function Bumblethwaite () {}
Bumblethwaite.prototype.writeFunction = function (requirements) {
  // ... code to convert formal requirements into a working function
}

alex = new Bumblethwaite();
```

One thing we can say about this code is that all Bumblethwaites can program, and since Alex is-a Bumblethwaite, Alex can program. As we saw above, this is a statement about a formal class, an

expectation, delegation, and an ad hoc class. Most programmers don't bother going into all that detail: They say that "Alex is-a Braithwaite," and they say that "Alex inherits writeFunction from Bumblethwaite."

The "is-a" relationship expresses membership in a formal class and with it, a set of expectations. The exact implementation of those expectations–construction, delegation, composition, whatever–is not really part of saying "Alex is-a Bumblethwaite" or part of saying "Alex inherits writeFunction from Bumblethwaite."

Programmers often call this "interface inheritance,"[58] where the word "interface" is reasonably close to "expectation."

Sometimes people write code like this because it's a convenient way for objects to share behaviour. They aren't interested in formal classes. For example, you might write something like:

```
var WritesFunctionsUsingCombinators = {
  writeFunction: function (requirements) {
    // I a saw a combinator pyramid.
    // It was all-encompassingly unnessesary.
  }
}

var raganwald = Object.create(WritesFunctionsUsingCombinators);
```

Here the object `raganwald` is a member of the ad hoc set "programmers" because it delegates `writeProgram` to `WritesFunctionsUsingCombinators`. But it isn't an `instanceof` anything. We aren't trying to establish a formal set and some expectations for a class of objects. We could, but we're choosing to use delegation as a convenience, as an implementation technique.

This has a common name as well, it's sometimes called "implementation inheritance" when it involved some of the same mechanisms as interface inheritance. (Old-timers will also call it a "was-a" relationship.[59])

Most object-oriented languages tie interface and implementation inheritance together, but it's useful to understand and appreciate the difference between using techniques like delegation for inheriting "interfaces" or "formal classes" vs inheriting "implementations" or "membership in an ad hoc set."

[58] Java programmers sometimes say that the word "interface" applies only to the methods and signatures that are inherited, but that is far too narrow a view: An interface is a set of expectations that cover the methods and the behaviour they guarantee.

[59] Implementation inheritance "was-a" is named for historical reasons. The metaphor is of a dune buggy: A dune buggy *was* a Volkswagon Beetle, but now it's a dune buggy that uses the Volkswagon's implementation.

Metaobjects

 [60]

> In computer science, a metaobject is an object that manipulates, creates, describes, or implements other objects (including itself). The object that the metaobject is about is called the base object. Some information that a metaobject might store is the base object's type, interface, class, methods, attributes, parse tree, etc.–Wikipedia[61]

It is technically possible to write software just using objects. When we need behaviour for an object, we can give it methods by binding functions to keys in the object:

[60] Krups Machines (c) 2010 Shadow Becomes White, some rights reserved

[61] https://en.wikipedia.org/wiki/Metaobject

```
var sam = {
  firstName: 'Sam',
  lastName: 'Lowry',
  fullName: function () {
    return this.firstName + " " + this.lastName;
  },
  rename: function (first, last) {
    this.firstName = first;
    this.lastName = last;
    return this;
  }
}
```

We call this a "naïve" object. It has state and behaviour, but it lacks division of responsibility between its state and its behaviour.

This lack of separation has two drawbacks. First, it intermingles properties that are part of the model domain (such as `firstName`) with methods (and possibly other properties, although none are shown here) that are part of the implementation domain. Second, when we needed to share common behaviour, we could have objects share common functions, but does it not scale: There's no sense of organization, no clustering of objects and functions that share a common responsibility.

Metaobjects solve the lack-of-separation problem by separating the domain-specific properties of objects from their behaviour and implementation-specific properties.

The basic principle of the metaobject is that we separate the mechanics of behaviour from the domain properties of the base object. This has immediate engineering benefits, and it's also the foundation for designing programs with formal classes, expectations, and delegation.

There are many ways to implement metaobjects, and we will explore some of these as a mechanism for exploring some of the ideas in Object-Oriented Programming.

Templates and Prototypes

We've already seen `extend`:

```
var base = {
  all_your: 'base are belong to us'
};

var extended = {};

extended.all_your
  //=> undefined

extend(extended, base);

extended.all_your
  //=> 'base are belong to us'
```

`extend` *copies* the properties from one or more objects into another. This allows us to separate behaviour from domain properties in our code. The behaviour goes in a *template* object, while the domain properties go in a *concrete* object:

```
var RectangleTemplate = {
  area: function () {
    return this.length * this.width;
  }
};

var twoByThree = extend({
  length: 2,
  width: 3
}, RectangleTemplate);

twoByThree.area();
  //=> 6
```

As noted earlier, JavaScript is an object-1, so our methods are as visible as our properties when we do things like enumerate over them. Assuming that our dimensions are in meters, the following (tremendously bad) code won't work:

```
var RectangleTemplate = {
  area: function () {
    return this.length * this.width;
  },
  imperialize: function () {
    for (var dimension in this) {
      this[dimension] = this[dimension] * 3.281;
    }
    return this;
  }
};

var twoByThree = extend({
  length: 2,
  width: 3
}, RectangleTemplate);

twoByThree.imperialize().area()
  //=> TypeError: Property 'area' of object #<Object> is not a function
```

What went wrong?

```
twoByThree
  //=>
    { length: 6.562,
      width: 9.843,
      area: NaN,
      imperialize: NaN }
```

Our methods were enumerated alongside our domain properties. We learned earlier that we can use `Object.defineProperty` to make them non-enumerable. Let's rewrite `extend` to make everything in our template non-enumerable:

```
var naiveExtendWithTemplates = variadic( function (concrete, templates) {
  var key,
      i,
      template;

  for (i = 0; i < templates.length; ++i) {
    template = templates[i];
    for (key in template) {
      if (template.hasOwnProperty(key)) {
        Object.defineProperty(concrete, key, {
          writable: true,
          enumerable: false,
          value: template[key]
        });
      }
    }
  }
  return concrete;
});
```

Let's try it now:

```
var RectangleTemplate = {
  area: function () {
    return this.length * this.width;
  },
  imperialize: function () {
    for (var dimension in this) {
      this[dimension] = this[dimension] * 3.281;
    }
    return this;
  }
};

var twoByThree = naiveExtendWithTemplates({
  length: 2,
  width: 3
}, RectangleTemplate);

twoByThree.imperialize().area()
  //=> 64.589766

```

```
twoByThree
  //=> { length: 6.562, width: 9.843 }
```

this does not commute

One problem with our first cut is that you cannot use `naiveExtendWithTemplates` to make a template out of a template:

```
var SquareAwareTemplate = naiveExtendWithTemplates({
  isaSquare: function () {
    return this.length === this.width;
  }
}, RectangleTemplate);

var fourByFour = naiveExtendWithTemplates({
  length: 4,
  width: 4
}, SquareAwareTemplate);

fourByFour.area()
  //=> TypeError: Object #<Object> has no method 'area'
```

The problem arises from the fact that we iterate over properties in the template, so we are only looking at *enumerable* properties. But when we copy properties from `RectangleTemplate` into `SquareAwareTemplate`, we made the `RectangleTemplate` properties non-enumerable.

So we need to change things such that we get all the properties, including the non-enumerable ones:

```
var extendWithTemplates = variadic( function (concrete, templates) {
  var key,
      i,
      template;

  for (i = 0; i < templates.length; ++i) {
    template = templates[i];
    Object.getOwnPropertyNames(template).forEach(function (key) {
      Object.defineProperty(concrete, key, {
        writable: true,
        enumerable: false,
        value: template[key]
      });
    });
```

```
  }
  return concrete;
});
```

Let's try it again:

```
var SquareAwareTemplate = extendWithTemplates({
  isaSquare: function () {
    return this.length === this.width;
  }
}, RectangleTemplate);

var fourByFour = extendWithTemplates({
  length: 4,
  width: 4
}, SquareAwareTemplate);

fourByFour.area()
  //=> 16
```

prototypes

JavaScript does not normally use templates to separate behaviour, especially shared behaviour, from domain properties. Instead, it uses prototypes. Our example with prototypes, `Object.create` and `extend` looks like this:

```
var RectanglePrototype = extend(Object.create(null), {
  area: function () {
    return this.length * this.width;
  },
  imperialize: function () {
    for (var dimension in this) {
      this[dimension] = this[dimension] * 3.281;
    }
    return this;
  }
});

var SquareAwarePrototype = extend(Object.create(RectanglePrototype), {
  isaSquare: function () {
    return this.length === this.width;
  }
```

```
});

var fourByFour = extend(Object.create(SquareAwarePrototype), {
  length: 4,
  width: 4
});
```

In each case, we're creating a new, empty object and copying our properties into it with `extend`. Thanks to the prototype chain:

```
fourByFour.area()
  //=> 16
fourByFour.isaSquare()
  //=> true
fourByFour
  //=> { length: 4, width: 4 }
```

> We don't actually *need* `extend`, of course, we can always write things like:
>
> var SquareAwarePrototype = Object.create(RectanglePrototype); SquareAwarePrototype.isaSquare = function () { return this.length === this.width; };

templates vs prototypes

So why use templates instead of prototypes? Or rather, when would it be appropriate? This is a poignant question, especially since prototypes are the standard way to separate behaviour from domain responsibilities in JavaScript.

The decision comes down to this observation: Templates share via shallow copying, prototypes share via reference. This means that changes to a template do *not* propagate after-the-fact:

```
var RectangleTemplate = {
  area: function () {
    return this.length * this.width;
  },
  imperialize: function () {
    for (var dimension in this) {
      this[dimension] = this[dimension] * 3.281;
    }
    return this;
  }
};

var fourByFour = extendWithTemplates({
  length: 4,
  width: 4
}, RectangleTemplate);

RectangleTemplate.isaSquare = function () {
  return this.length === this.width;
};

fourByFour.isaSquare()
  //=> TypeError: Object #<Object> has no method 'isaSquare'
```

Whereas:

```
var RectanglePrototype = extend(Object.create(null), {
  area: function () {
    return this.length * this.width;
  },
  imperialize: function () {
    for (var dimension in this) {
      this[dimension] = this[dimension] * 3.281;
    }
    return this;
  }
});

var fourByFour = extend(Object.create(RectanglePrototype), {
  length: 4,
  width: 4
});
```

```
17
18 RectanglePrototype.isaSquare = function () {
19   return this.length === this.width;
20 };
21
22 fourByFour.isaSquare()
23   //=> true
```

Making changes to a prototype *after* we create objects with that prototype has the effect of changing the behaviour of those objects. Usually, that's exactly what we want: As a rule of thumb, *we prefer late-binding to early-binding.*

K> Prototypes aren't *always* superior to templates, so we should keep our minds open. JavaScript's prototypes were inspired by the language Self[62]. Self has prototypes, but they are copied like our templates rather than maintaining references. Designers David Ungar and Randall Smith had been working with large Smalltalk applications, and one of their concerns was that large hierarchies of classes became very fragile: Changes to classes would ripple through the system, making it very hard to refactor. Switching to prototypes that were copied like templates made it easier to handle changes to the code.

Prototypes have a limitation. Consider how we extend the behaviour of an object with as many templates as we like:

```
1 var RectangleTemplate...
2 var LineDrawing...
3
4 var fourByFour = extendWithTemplates(..., RectangleTemplate, LineDrawing);
```

You can extend the behaviour of an object as much as you want when you're copying functions and properties from templates. Whereas, each object can only have one prototype.

If prototypes were the only way to represent behaviour common to more than one object, this would limit our ability to express common behaviour. For example:

- Alice and Charlie both play football.
- Bob and Charlie both scuba dive.

We could easily write:

[62] https://en.wikipedia.org/wiki/Self_

```
var FootballPlayer = { ... };
var ScubaDiver = { ... };

var Alice = Object.create(FootballPlayer);
var Bob   = Object.create(ScubaDiver);
```

But what do we do with Charlie? There is no way that Charlie can delegate behaviour to *both* `FootballPlayer` *and* `ScubaDiver` using prototypes.

Using $2 words, we say that "Templates model behaviour as Directed Acyclic Graphs ("DAGs"), whereas prototypes model behaviour as Strict Trees." Every tree is a DAG, but most DAGs are not trees, thus we infer that there are things we can model with templates that we cannot model with prototypes.

Prototype Chains and Trees

As we've noted repeatedly, JavaScript's built-in metaobjects are called *prototypes*. There are several ways to create an object in JavaScript, and three of them associate the newly created object with a prototype:

1. We can use the `new` operator with a function, e.g. `new Object()`. This particular newly created object delegates its behaviour to `Object.prototype`, but any function will do, and the newly created object will delegate its behaviour to the function's `.prototype` property.
2. We can use the object literal syntax, e.g. `{ number: 6 }`. The newly created object always delegates its behaviour to `Object.prototype`.
3. We can call `Object.create(somePrototype)` and pass in any object. The newly created object will delegate its behaviour to `somePrototype`.
4. We can call `Object.create(null)`, and the newly created object won't delegate its behaviour at all.

No matter how we create an object, we can get its prototype using `Object.getPrototypeOf`:

```
function Something () {}

var object = new Something();

Object.getPrototypeOf(object) === Something.prototype
  //=> true
```

JavaScript provides several options for making sense of this arrangement at runtime. We've seen `Object.getPrototypeOf`. Another is `.hasOwnProperty`. Objects that directly or indirectly have `Object.prototype` as one of their prototypes can use this method to test whether a property is defined in the object itself. To whit:

```
var P = {
  foo: 'SNAFU'
};

var obj = Object.create(P);
obj.bar = 'Italia';

obj.hasOwnProperty('foo')
  //=> false

obj.hasOwnProperty('bar')
  //=> true
```

In earlier releases of JavaScript, this could be used to enumerate over an object's domain properties with code like this:

```
var ownProperties = [];

for (var i in obj) {
  if (obj.hasOwnProperty(i)) {
    ownProperties.push(i);
  }
}
ownProperties
  //=> [ 'bar' ]
```

What about objects that don't directly or indirectly delegate to `Object.prototype`?

```
var P2 = Object.create(null);
P2.foo = 'SNAFU'

var obj2 = Object.create(P2);
obj2.bar = 'Italia';

obj2.hasOwnProperty('foo')
  //=> TypeError: Object object has no method 'hasOwnProperty'
```

We can still use this method, we just need to do it indirectly:

```
Object.prototype.hasOwnProperty.call(obj2, 'bar')
  //=> true
```

JavaScript now gives us more elegant tools:

```
Object.defineProperty(obj2, 'hidden', {
  enumerable: false,
  value: 'secret'
});

Object.keys(obj2)
  //=> [ 'bar' ]

Object.getOwnPropertyNames(obj2)
  //=> [ 'bar', 'hidden' ]
```

`Object.keys` returns the objects own properties that are enumerable. `Object.getOwnPropertyNames` returns all of the object's own property names, enumerable or not. And the `for... in...` loop iterates over all of an object's properties, including those available through delegation to prototypes.

ontologies

It's natural for people to organize their knowledge about a domain into an *ontology*:

> Traditionally listed as a part of the major branch of philosophy known as metaphysics, ontology deals with questions concerning what entities exist or can be said to exist, and how such entities can be grouped, related within a hierarchy, and subdivided according to similarities and differences.—Wikipedia[63]

The ontology describes the behaviour we can expect of objects by assigning them to ad hoc sets. These objects are accounts, those objects are commands. Sets can have sub-sets that have refined or specialized expectation: These objects are chequing accounts, they behave like accounts and they also have these behaviours specific to chequing accounts.

There are various ways to organize such ontologies. The simplest is to arrange everything in a strict tree.

JavaScript's prototypes are very well suited for organizing the behaviour of objects into a tree-like ontology. Let us say that we are modeling DOM elements. All elements have `.name()` and `.document()` methods. We model this with a prototype:

[63] https://en.wikipedia.org/wiki/Ontology

```
var ElementPrototype = extend(Object.create(null), {
  document: function () {
    return this._document;
  },
  name: function () {
    return this._name;
  }
});
```

Now, some elements are containers that hold a list of children. We want our `Container` elements to also have all the methods and properties of an `ElementPrototype`, so we give our prototype… A prototype of its own:

```
var ContainerPrototype = extend(Object.create(ElementPrototype), {
  children: function () {
    return this._children;
  }
});
```

Now, anything that delegates to `ContainerPrototype` will behave as if it has all of `ContainerPrototype`'s methods: They delegate `.children` directly to `ContainerPrototype`, and they delegate `.document` and `.name` to `ContainerDelegate`, then `ContainerDelegate` in turn delegates them to `ElementPrototype`.

We don't have to define just methods, a prototype can hold any property or properties:

```
var ParagraphPrototype = extend(Object.create(ContainerPrototype), {
  _name: 'p';
});
```

Just as several concrete objects can share the same prototype, several prototypes can share the same prototype:

```
var TextPrototype = extend(Object.create(ElementPrototype), {
  text: function () {
    return this._text;
  }
});
```

Objects that delegate methods to `TextPrototype` also delegate methods, indirectly, to `ElementPrototype`, just as objects that delegate properties to `ParagraphPrototype` also delegate properties, indirectly, to `ContainerPrototype` and `ElementPrototype`.

In this manner, programmers can build elaborate trees of prototypes, with each prototype having a small and carefully focused responsibility. Each concrete domain object obtains behaviour from a leaf of the tree.

The drawback of this arrangement is that the various objects and prototypes are now *tightly coupled*. Changes to any one prototype ripple through the tree. The entire arrangement becomes fragile. What looked at first to be highly flexible grows over time to be highly inflexible.

the natural tension between redundancy and coupling

There is a general principle at work here. In theory, you could write a "Kompressor" program: It would read a JavaScript program and remove all duplication it finds, replacing duplication with indirection through function calls, prototypes, &c.

You could feed the output of Kompressor back into itself, removing more redundancy, until the output had reached maximum compression. From an information-theory perspective, the number of bits in the result represents the information in the original program. There is no redundancy.

However, this misses the idea that programs change over time. A written program contains bits of information about how to transform its inputs into its outputs, but it also contains bits of information designed to guide changes in the future.

A program that has been "maximally compressed" is now also maximally coupled. Changes to any one bit of information in the program may affect its behaviour in wildly unpredictable ways.

Whereas, a program that has been well-crafted deliberately decouples things that are unrelated. This increases the predictability of change, at the cost of program size. There is a natural *tension* between redundancy and coupling: A program that removes all redundancy naturally increases its coupling.

Singleton Prototypes

In classic JavaScript, we delegate object behaviour to prototypes. Typically, prototypes are used for *shared* object behaviour:

```
var RectanglePrototype = extend(Object.create(null), {
  area: function () {
    return this.length * this.width;
  },
  isaSquare: function () {
    return this.length === this.width;
  }
});

var twoByThree = extend(Object.create(RectanglePrototype), {
```

```
  length: 2,
  width: 3
});

var fourByFour = extend(Object.create(RectanglePrototype), {
  length: 4,
  width: 4
});

twoByThree.area()
  //=> 6

fourByFour.area()
  //=> 16
```

There is a problem with this approach. What happens when we want to customize the behaviour of one object?

```
fourByFour.isaJeep = function () { return false; }

fourByFour
  //=>
    { length: 4,
      width: 4,
      isaJeep: [Function] }
```

Once agin, we're mixing behaviour with domain properties. We can make `isaJeep` non-enumerable, but having embraced the idea of separating behaviour from domain properties with a prototype, why not use a prototype here? The trick is to create a unique prototype for *every* object.

Like this:

```
var fourByFour = (function () {
  var SingletonPrototype = Object.create(RectanglePrototype);

  return extend(Object.create(SingletonPrototype), {
    length: 4,
    width: 4
  });
})();
```

`SingletonPrototype` is an empty object that delegates to `RectanglePrototype`, but no object except `fourByFour` delegates to `SingletonPrototype`. We can rewrite it more simply:

```
var fourByFour = extend(
  Object.create(Object.create(RectanglePrototype)),
  {
    length: 4,
    width: 4
  }
);
```

Now when we want to bind behaviour to `fourByFour`, we can write:

```
Object.getPrototypeOf(fourByFour).isaJeep = function () { return false; }

fourByFour
  //=> { length: 4, width: 4 }

fourByFour.isaJeep()
  //=> false
```

When a prototype exists solely to manage behaviour for a single object, we call it a *singleton prototype*. It's a specific case of a *singleton metaobject*. JavaScript is agnostic about singleton metaobjects, it's up to you whether to use them.

> Other languages have support for singleton metaobjects baked in. For example, in Ruby you can define a method specific to an object:
>
> ```
> obj = Object.new
> def obj.ect
>   'Object'
> end
> ```
>
> Behind the scenes, Ruby creates a "singleton class" just for `obj` and then defines the method in the singleton class. We can see this:
>
> ```
> obj.singleton_class.instance_methods - Object.methods
>   #=> [:ect]
> ```

Metaobject-1s and Metaobject-2s

As discussed, some languages partition "ordinary" values from functions and methods. Common Lisp, for example, does so, and is called a "Lisp-2" because it has two different namespaces. Scheme,

on the other hand, is a "Lisp-1" because it treats functions just the same as all other values. To the extent that JavaScript borrows from Lisp, it borrows from the "Lisp-1" family, because it treats functions as ordinary values.

Object-oriented languages have a similar bifurcation, but it's based on their metaobjects.

A metaobject is a method that confers behaviour on another object, whether by acting as a delegate at run time, by installing behaviour through construction, or by any other mechanism. Thus, templates and prototypes are both metaobjects in JavaScript.

A "Metaobject-1" language is a language where the behaviour of a metaobject is exactly the same as the behaviour it confers on another object. In other words, metaobject-1s have one kind of behaviour.

A "Metaobject-2" language is a language where metaobjects have one kind of behaviour they confer on other objects, and another behaviour they expose for metaprogramming.

Languages like Smalltalk and Ruby are "Metaobject-2" languages out of the box: Their "classes" have a rich set of behaviours for adding, removing, and modifying behaviour that is separate from the methods they confer on instances.

What about JavaScript?

JavaScript's prototypes are Metaobject-1s. The only properties and behaviour a prototype has are the properties and behaviour it confers upon its delegators.

So is JavaScript a Metaobject-1 language? Yes, and no. There are a few Metaobject-2 features such as `Object.create`, `Object.isPrototypeOf` and so forth. In fact, the `Object` object is a rudimentary Metaobject-2.

`'Object` is not as rich a metaobject as you'll find in a language like Smalltalk or Ruby. For example, each Ruby class is a unique metaobject that can create new instances of itself, you can query or update the methods it confers on its instances, you can even override its creation and initialization semantics at any time.

JavaScript functions can do some of these things, but if you use them "out of the box" with the `new` keyword and with the function's body as an initializer, you will have almost none of the flexibility that metaobjects like Smalltalk classes provide.

javascript meta-object-2s

The bad news is that JavaScript is not a Metaobject-2 language. The good news is that when we want to program in a Metaobject-2 style, it provides all of the Lego blocks needed to build exactly what we want without a programming language author getting "opinionated" and forcing their particular flavour upon us.

That's nice, but what exactly do "Metaobject-2s" buy us? Why should we care?

The short answer is quite simple to grasp, although it is an abstract answer. We'll get into specific and concrete examples in upcoming chapters.

The short answer begins with the observation that we apply OOP to the problem domain to organize our program around units–objects–that encapsulate their internal state and provide a message-handling or method interface to other objects.

When we "buy into" OOP, we're "buying into" the notion that this organization is helpful for understanding and maintaining a program, that it is an advantage to have a program organized along these lines rather than having a heap of functions and procedures operating upon a heap of data structures. We buy into the idea that we can use this organization to reduce the coupling between units.

That's how objects and metaobjects help us write programs for our domain. So how can Metaobject-2s help? Well, what happens when we rise up a level? What happens when we want to program our programming paradigm? If objects responding to methods are the best way to organize our programs, why not use them to organize the way we write our programs?

Okay, *one* example:

We write methods that encapsulate the internal state of domain objects like "chequing accounts," but then when we want to program our metaobjects, we're writing things like:

```
1  var _depositFunds = ChequingAccount.prototype.depositFunds;
2  ChequingAccount.prototype.depositFunds = function (funds) {
3    if this.validAccount() && funds.validFunds() {
4      return _depositFunds.call(this, funds);
5    }
6    else return ChequingAccount.errors.InvalidOperation(this, funds);
7  }
```

There's something going on about validation, and about writing guards or before filters for methods, but are we really supposed to write things like this out all over our code? Or adopt special function combinators?

Why can't we treat our metaobjects the way we treat our objects, so that if decorating methods with validation is "a thing," we do it by calling a method and letting the metaobject encapsulate the implementation, perhaps like this, where our method has methods like `unshift` for prepending behaviour and `push` for appending behaviour:

```
ChequingAccount.depositFunds
  .unshift(function (funds) {
    if !this.validAccount() {
      return ChequingAccount.errors.InvalidOperation(this, funds);
    }
  })
  .unshift(function (funds) {
    if !funds.validFunds() {
      return ChequingAccount.errors.InvalidOperation(this, funds);
    }
  });
```

If this seems clever for the sake of cleverness, lets ask ourselves: if we decide that we're going to "subclass" `ChequingAccount` with `CryptoCurrencyAccount`, will it just work? Or do we have to carefully examine it to make sure that if we write `CryptoCurrencyAccount.prototyper.depositFunds`, that we also replicate the validation code?

If we were using a metaobject-2 that implemented `.unshift` to add some before-checking, we could see to it that it worked even when the base functionality of a method was overridden.

This is the whole point of encapsulation in OOP, you tell an object what you want done and it handles the corner cases and icky bits for you. In upcoming chapters, we'll implement this and other examples of metaobjects, in the process taking a closer look at how to think about the relationship between objects and their behaviour.

Metaobject Protocols

(insert image here)

As we discussed earlier, the idea behind metaobject-2s is to organize the way we program our objects and classes using the same tools we use to program our domain objects.

Namely, objects that manage their own internal state and respond to requests using methods. The semantics we create and the methods we expose comprise a *protocol*, and the standard phrase for developing our own programmable metaobject-2 system is to build a *metaobject protocol*.

Genesis

In this section, we're going to build a Metaobject Protocol[64]. Or in less buzzword-compatible terms, we're going to build classes that can be programmed using methods.

We can already make class-like things with functions, prototypes, and the `new` keyword, provided we directly manipulate our "classes." This makes it difficult to make changes after the fact, because all of our code is tightly coupled to the structure of our "classes."

We can decouple our code from the structure of our classes by doing all of our manipulation with methods instead of with direct manipulation of functions and prototypes. Let's start with a simple example, a quadtree[65] class.

Normally, we would start with something like this:

```
function QuadTree (nw, ne, se, sw) {
  this.nw = nw;
  this.ne = ne;
  this.se = se;
  this.sw = sw;
}
```

And we would write methods using code like this:

[64] https://en.wikipedia.org/wiki/Metaobject#Metaobject_protocol

[65] https://en.wikipedia.org/wiki/Quadtree

```
QuadTree.prototype.population = function () {
  return this.nw.population() + this.ne.population() +
         this.se.population() + this.sw.population();
}

var account = new QuadTree(...);
```

As discussed before, we are directly manipulating `QuadTree`'s internal representation. Let's abstract method definition away. We'd like to write:

```
QuadTree.defineMethod( 'population', function () {
  return this.nw.population() + this.ne.population() +
         this.se.population() + this.sw.population();
});
```

We'll see why in a moment. How do we make this work? Let's start with:

```
QuadTree.defineMethod = function (name, body) {
  this.prototype[name] = body;
  return this;
};
```

That works, and now we can introduce new semantics at will. For example, what does this do?

```
QuadTree.defineMethod = function (name, body) {
  Object.defineProperty( this.prototype, name, {
    writable: false,
    enumerable: false,
    value: body
  });
  return this;
};
```

factory factories

We can now write:

```
QuadTree.defineMethod( 'population', function () {
  return this.nw.population() + this.ne.population() +
         this.se.population() + this.sw.population();
});
```

We accomplished this by writing:

```
QuadTree.defineMethod = function (name, body) {
  this.prototype[name] = body;
  return this;
};
```

Fine. But presuming we carry on to create other classes like `Cell`, how do we give them the same `defineMethod` method?

Hmmm, it's almost like we want to have objects that delegate to a common prototype. We know how to do that:

```
var ClassMethods = {
  defineMethod: function (name, body) {
    this.prototype[name] = body;
    return this;
  }
};

var QuadTree = Object.create(ClassMethods);
```

Alas, this doesn't work for functions we use with `new`, because JavaScript functions are a special kind of object that we can't decorate with our own prototypes. We *could* fool around with mixing behaviour in, but let's abstract `new` away and use a .create‘ method to create instances.

`.create`

This is what `QuadTree` would look like with its own `.create` method. We've moved initialization into an instance method instead of being part of the factory method:

```
var QuadTree = {
  create: function () {
    var acct = Object.create(this.prototype);
    if (acct.initialize) {
      acct.initialize.apply(acct, arguments);
    }
    return acct;
  },
  defineMethod: function (name, body) {
    this.prototype[name] = body;
    return this;
  },
  prototype: {
    initialize: function (nw, ne, se, sw) {
      this.nw = nw;
      this.ne = ne;
      this.se = se;
      this.sw = sw;
    }
  }
};
```

Let's extract a few things. Step one:

```
function Class () {
  return {
    create: function () {
      var instance = Object.create(this.prototype);
      Object.defineProperty(instance, 'constructor', {
        value: this
      });
      if (instance.initialize) {
        instance.initialize.apply(instance, arguments);
      }
      return instance;
    },
    defineMethod: function (name, body) {
      this.prototype[name] = body;
      return this;
    },
    prototype: {}
  };
```

```
}

var QuadTree = Class();

QuadTree.defineMethod(
  'initialize', function (nw, ne, se, sw) {
    this.nw = nw;
    this.ne = ne;
    this.se = se;
    this.sw = sw;
  }
).defineMethod(
  'population', function () {
    return this.nw.population() + this.ne.population() +
           this.se.population() + this.sw.population();
  }
);
```

Step two:

```
var BasicObjectClass = {
  prototype: {}
}

function Class (superclass) {
  return {
    create: function () {
      var instance = Object.create(this.prototype);
      Object.defineProperty(instance, 'constructor', {
        value: this
      });
      if (instance.initialize) {
        instance.initialize.apply(instance, arguments);
      }
      return instance;
    },
    defineMethod: function (name, body) {
      this.prototype[name] = body;
      return this;
    },
    prototype: Object.create(superclass.prototype)
  };
```

```
}

var QuadTree = Class(BasicObjectClass);
```

Step three:

```
var BasicObjectClass = {
  prototype: {}
}

var MetaMetaObjectPrototype = {
  create: function () {
    var instance = Object.create(this.prototype);
    Object.defineProperty(instance, 'constructor', {
      value: this
    });
    if (instance.initialize) {
      instance.initialize.apply(instance, arguments);
    }
    return instance;
  },
  defineMethod: function (name, body) {
    this.prototype[name] = body;
    return this;
  }
}

function Class (superclass) {
  return Object.create(MetaMetaObjectPrototype, {
    prototype: {
      value: Object.create(superclass.prototype)
    }
  })
}

var QuadTree = Class(BasicObjectClass);

// QuadTree.defineMethod...
```

Step four, now we change the shape:

```
var Class = {
  create: function (superclass) {
    return Object.create(MetaMetaObjectPrototype, {
      prototype: {
        value: Object.create(superclass.prototype)
      }
    });
  }
}

var QuadTree = Class.create(BasicObjectClass);

// QuadTree.defineMethod...
```

Step five:

```
var MetaObjectPrototype = Object.create(MetaMetaObjectPrototype, {
  initialize: {
    value: function (superclass) {
      this.prototype = Object.create(superclass.prototype)
    }
  }
});

var Class = {
  create: function (superclass) {
    var klass = Object.create(this.prototype);
    Object.defineProperty(klass, 'constructor', {
      value: this
    });
    if (klass.initialize) {
      klass.initialize.apply(klass, arguments);
    }
    return klass;
  },
  prototype: MetaObjectPrototype
};

var QuadTree = Class.create(BasicObjectClass);

// QuadTree.defineMethod...
```

ouroboros

Now we are in an interesting place. Let's consolidate and rename things:

```
var MetaObjectPrototype = {
  create: function () {
    var instance = Object.create(this.prototype);
    Object.defineProperty(instance, 'constructor', {
      value: this
    });
    if (instance.initialize) {
      instance.initialize.apply(instance, arguments);
    }
    return instance;
  },
  defineMethod: function (name, body) {
    this.prototype[name] = body;
    return this;
  },
  initialize: function (superclass) {
    if (superclass != null && superclass.prototype != null) {
      this.prototype = Object.create(superclass.prototype);
    }
    else this.prototype = Object.create(null);
  }
};

var MetaClass = {
  create: function () {
    var klass = Object.create(this.prototype);
    Object.defineProperty(klass, 'constructor', {
      value: this
    });
    if (klass.initialize) {
      klass.initialize.apply(klass, arguments);
    }
    return klass;
  },
  prototype: MetaObjectPrototype
};
```

And now we do something interesting, we use `MetaClass` to make `Class`:

```
var Class = MetaClass.create(MetaClass);

Class.constructor === MetaClass
  //=> true
```

And we use `Class` to make `QuadTree`:

```
var BasicObjectClass = Class.create(null);

var QuadTree = Class.create(BasicObjectClass);

QuadTree.constructor === Class
  //=> true

QuadTree.defineMethod(
  'initialize', function (nw, ne, se, sw) {
    this.nw = nw;
    this.ne = ne;
    this.se = se;
    this.sw = sw;
  }
).defineMethod(
  'population', function () {
    return this.nw.population() + this.ne.population() +
           this.se.population() + this.sw.population();
  }
);
```

As well as `Cell`:

```
var Cell = Class.create(BasicObjectClass);

Cell.defineMethod( 'initialize', function (population) {
  this._population = population;
}).defineMethod( 'population', function () {
  return this._population;
});
```

What have we achieved? Well, `QuadTree` and `Cell` are both classes, and they're also *instances* of class `Class`. How does this help us? We now have the ability to modify every aspect of the creation of classes and instances by modifying methods and classes. For example, if all classes need a new method, we can call `Class.defineMethod`.

Let's try creating a new method on all classes:

```
Class.defineMethod( 'instanceMethods', function () {
  var prototype = this.prototype;
  return Object.getOwnPropertyNames(prototype).filter( function (propertyName) {
    return typeof(prototype[propertyName]) === 'function';
  })
});

Cell.instanceMethods()
 //=> [ 'initialize', 'population' ]
```

It works!

The Class Class

In The "I" Word, we discussed how the word "inheritance" is used, loosely, to refer to either or both of membership in a formal class ("is-a"), and delegation of implementation and expectations ("was-a"). Given our code for initializing metaobjects:

```
initialize: function (superclass) {
  if (superclass != null && superclass.prototype != null) {
    this.prototype = Object.create(superclass.prototype);
  }
  else this.prototype = Object.create(null);
}
```

This sets up the prototype chain for instances. For example, a special subclass of `QuadTree` for trees of trees that supports interpolating `n`, `e`, `s`, `w`, and `c`:

```
var TreeOfTrees = Class.create(QuadTree);

TreeOfTrees.defineMethod('n', function () {
  return this.ne.constructor.create(this.nw.ne, this.ne.nw, this.ne.sw, this.nw.s\
e);
}).defineMethod('e', function () {
  return this.ne.constructor.create(this.ne.sw, this.ne.se, this.se.ne, this.se.n\
w);
})
// ...
```

Instances of `TreeOfTrees` inherit the methods defined in `TreeOfTrees` as well as those in `QuadTree`. Although this technique can be overused, it is a useful option for sharing behaviour.

Obviously, implementation inheritance allows two classes to share a common superclass, and thus share behaviour between them. What about classes themselves? As described, they are all instances of `Class`, but that is not a hard and fast requirement.

fluent interfaces

Consider fluent interfaces[66]. In software engineering, a fluent interface (as first coined by Eric Evans and Martin Fowler) is an implementation of an object oriented API that aims to provide for more readable code.

Object and instance methods can be bifurcated into two classes: Those that query something, and those that update something. Most design philosophies arrange things such that update methods return the value being updated. However, the fluent[67] style presumes that most of the time when you perform an update, you are more interested in doing other things with the receiver then the values being passed as argument(s), so the rule is to return the receiver unless the method is a query.

So, given:

```
var MutableQuadTree = Class.create(BasicObjectClass);
```

We might write:

```
MutableQuadTree
  .defineMethod( 'setNW', function (value) {
    this.nw = value;
    return this;
  })
  .defineMethod( 'setNE', function (value) {
    this.ne = value;
    return this;
  })
  .defineMethod( 'setSE', function (value) {
    this.se = value;
    return this;
  })
  .defineMethod( 'setSW', function (value) {
    this.sw = value;
    return this;
  });
```

This would be a fluent interface, allowing us to write things like:

[66] https://en.wikipedia.org/wiki/Fluent_interface
[67] https://en.wikipedia.org/wiki/Fluent_interface

```
var tree = MutableQuadTree
            .create()
              .setNW(Cell.create(1))
              .setNE(Cell.create(0))
              .setSE(Cell.create(0))
              .setSW(Cell.create(01);
```

However, what work it is! Another possibility would be to subclass `Class`, and override `defineMethod`, like so:

```
var allong = require('allong.es');
var unvariadic = allong.es.unvariadic;

var FluentClass = Class.create(Class);

FluentClass.defineMethod( 'defineMethod', function (name, body) {
  this.prototype[name] = unvariadic(body.length, function () {
    var returnValue = body.apply(this, arguments);
    if (typeof(returnValue) === 'undefined') {
      return this;
    }
    else return returnValue;
  });
  return this;
});
```

A normal method semantics are that if it doesn't explicitly return a value, it returns `undefined`. A `FluentClass` method's semantics are that if it doesn't explicitly return a value, it returns the receiver. So now, we can write:

```
var MutableQuadTree = FluentClass.create(BasicObjectClass);

MutableQuadTree
  .defineMethod( 'setNW', function (value) {
    this.nw = value;
  })
  .defineMethod( 'setNE', function (value) {
    this.ne = value;
  })
  .defineMethod( 'setSE', function (value) {
    this.se = value;
  })
```

```
13    .defineMethod( 'setSW', function (value) {
14      this.sw = value;
15    });
16
17  var tree = MutableQuadTree
18    .create()
19      .setNW(Cell.create(1))
20      .setNE(Cell.create(0))
21      .setSE(Cell.create(0))
22      .setSW(Cell.create(01);
```

And our trees are *fluent by default*: Any method that doesn't explicitly return a value with the `return` keyword will return the receiver.

By creating classes that share their own implementation of `defineMethod`, we now have a way to create collections of objects that have their own special semantics. There are many ways to do this, of course, but the key idea here is that we're using polymorphism: Fluent classes look just like regular classes, so there is no need to write any special code when defining a fluent method or creating an object with fluent semantics.

We're using the exact same techniques for programming with metaclasses that we use for programming with domain objects.

Class Mixins

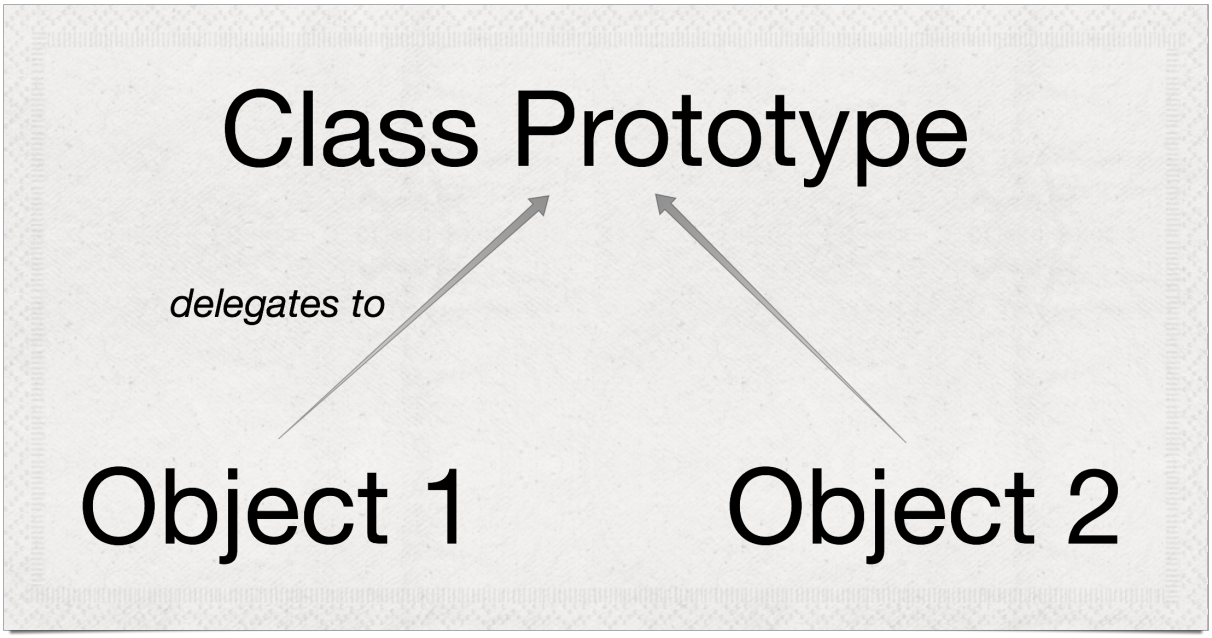
In The Class Class, we saw how we could use implementation inheritance to create `FluentClass`, a class where methods are fluent by default.

Implementation inheritance is not the only way to customize class behaviour, and it's rarely the best choice. Long experience with hierarchies of domain objects has shown that excessive reliance on implementation inheritance leads to fragile software that ends up being excessively coupled.

Contemporary thought suggests that traits or mixins are a better choice when there isn't a strong need to model an "is-a" relationship. Considering that JavaScript is a language that emphasizes ad hoc sets rather than formal classes, it makes sense to look at other ways to create classes with custom semantics.

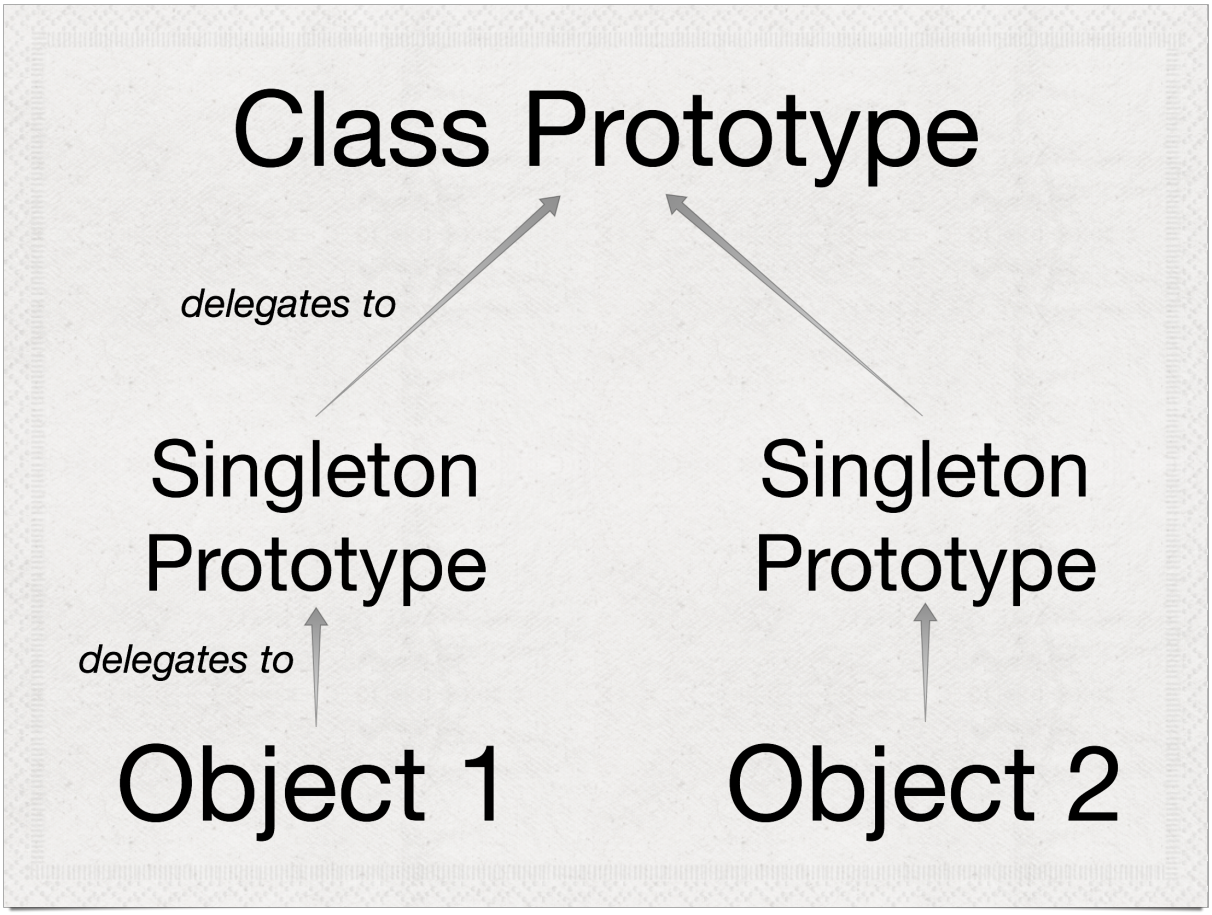
singleton prototypes

The typical arrangement for "classes" is that objects of the same class share a common prototype associated with the class:



Standard class prototype delegation

This is true whether we are using functions as our "classes" or objects that are themselves instances of `Class`. In Singleton Prototypes, we looked at how we can associate a singleton prototype with each object:



Singleton prototype delegation

Each object delegates its behaviour to its own singleton prototype, and *that* prototype delegates in turn to the class prototype. As discussed earlier, the motivation for this arrangement is so that methods can be added to individual objects while preserving a separation of domain attributes from methods. For example, you can add a method to an object's singleton prototype and still use `.hasOwnProperty()` to distinguish attributes from methods.

To create objects with singleton prototypes, we could use classes that have their own `.create` method:

```
var SingletonPrototypicalClass = Class.create(Class);

SingletonPrototypicalClass.defineMethod('create', function () {
  var singletonPrototype = Object.create(this.prototype);
  var instance = Object.create(singletonPrototype);
  Object.defineProperty(instance, 'constructor', {
    value: this
  });
  if (instance.initialize) {
    instance.initialize.apply(instance, arguments);
  }
  return instance;
});
```

This "injects" the singleton prototype in between the newly created instance and the class's prototype. So if we create a new class:

```
var SingletonPrototypeCell = SingletonPrototypicalClass.create();
var SingletonPrototypeQuadTree = SingletonPrototypicalClass.create();
```

We know that every instance of `SingletonPrototypeCell` and `SingletonPrototypeQuadTree` will have its own singleton prototype.

mixins

This seems very nice, but what do we do if we want a class that has both fluent interface semantics *and* singleton prototype semantics, like our `MutableQuadTree` example?

Do we decide that all classes should encompass both behaviours by adding the functionality to `Class`? That works, but it leads to a very heavyweight class system. This is the philosophy of languages like Ruby, where all classes have a lot of functionality. That is consistent with their approach to basic objects as well: The default `Object` class also has a lot of functionality that every object inherits by default.

Do we make `SingletonPrototypicalClass` a subclass of `FluentClass`? That makes it impossible to have a class with singleton prototype semantics that doesn't also have fluent semantics, and there's the little matter that fluency and prototype semantics really aren't related in any kind of "is-a" semantic sense. Making `FluentClass` a subclass of `SingletonPrototypicalClass` has the same problems.

Forty years of experience modeling domain entities has led OO thinking to the place where representing independent semantics with inheritance is now considered an anti-pattern. Instead, we look for ways to select traits, behaviours, or semantics on an a'la carte basis using template inheritance, also called *mixing in behaviour*.

Mixing behaviour in is as simple as extending the class object:

```
var MutableQuadTree = Class.create();

extend(MutableQuadTree, {
  defineMethod: function (name, body) {
    this.prototype[name] = unvariadic(body.length, function () {
      var returnValue = body.apply(this, arguments);
      if (typeof(returnValue) === 'undefined') {
        return this;
      }
      else return returnValue;
    });
    return this;
  }
});

extend(MutableQuadTree, {
  create: function () {
    var singletonPrototype = Object.create(this.prototype);
    var instance = Object.create(singletonPrototype);
    Object.defineProperty(instance, 'constructor', {
      value: this
    });
    if (instance.initialize) {
      instance.initialize.apply(instance, arguments);
    }
    return instance;
  }
});
```

We eschew monkeying around explicitly with internals, so let's create some functions we can call:

```
function Fluentize (klass) {
  extend(klass, {
    defineMethod: function (name, body) {
      this.prototype[name] = unvariadic(body.length, function () {
        var returnValue = body.apply(this, arguments);
        if (typeof(returnValue) === 'undefined') {
          return this;
        }
        else return returnValue;
      });
      return this;
```

```
    }
  });
}

function Singletonize (klass) {
  extend(klass, {
    create: function () {
      var singletonPrototype = Object.create(this.prototype);
      var instance = Object.create(singletonPrototype);
      Object.defineProperty(instance, 'constructor', {
        value: this
      });
      if (instance.initialize) {
        instance.initialize.apply(instance, arguments);
      }
      return instance;
    }
  });
}
```

Now we can write:

```
MutableQuadTree = Class.create();
Fluentize(MutableQuadTree);
Singletonize(MutableQuadTree);
```

This cleanly separates the notion of subclassing classes from the notion of some classes having traits or behaviours they share with other classes.

Note that although the mixin pattern is completely different from the subclassing `Class` pattern, both are made possible by using objects as classes rather than using functions, the `new` keyword, and directly manipulating prototypes to define methods.

Well, Actually...

Both inheritance and mixins have their place for both our domain classes and the metaobjects that define them. However, if not designed with care, object-oriented code bases evolve over time to become brittle and coupled whether they're built with inheritance or mixins. Let's take another look at class mixins and see why.

In Class Mixins, we saw how we could build two mixins, `Fluentize` and `Singletonize`. Implementing these two semantics as mixins allows us to create classes that have neither semantic, fluent

semantics, singleton prototype semantics, or both. This is far less brittle than trying to do the same thing by cramming both sets of functionality into every class (the "heavyweight base" approach) or trying to set up an artificial inheritance hierarchy.

This sounds great for classes of classes and for our domains as well: Build classes for domain objects, and write mixins for various bits of shared functionality. Close the book, we're done!

Alas, we're not done. The flexibility of mixins is an illusion, and by examining the hidden problem, we'll gain a deeper understanding of how to design object-oriented software.

selfbindingization

In our next example, `Fluentize` overrides the `defineMethod` method, such that fluent classes use its implementation and not the implementation built into `MetaClass`. Likewise, `Singletonize` overrides the `create` method, such that singleton prototype classes use its implementation and not the implementation built into `MetaClass`.

These two mixins affect completely different methods, and furthermore the changes they make do not affect each other in any way. But this isn't always the case, consider this counter:

```
var Counter = Class.create();

Counter
  .defineMethod('initialize', function () { this._count = 0; })
  .defineMethod('increment', function () { ++this._count; })
  .defineMethod('count', function () { return this.count; });

var c = Counter.create();
```

And we have some function written in continuation-passing-style:

```
function log (message, callback) {
  console.log(message);
  return callback();
}
```

Alas, we can't use our counter:

```
log("doesn't work", c.increment);
```

The trouble is that the expression `c.increment` returns the body of the method, but when it is invoked using `callback()`, the original context of `c` has been lost. The usual solution is to write:

```
log("works", c.increment.bind(c));
```

The `.bind` method binds the context permanently. Another solution is to write (or use a function[68] to write):

```
c.increment = c.increment.bind(c);
```

Then you can write:

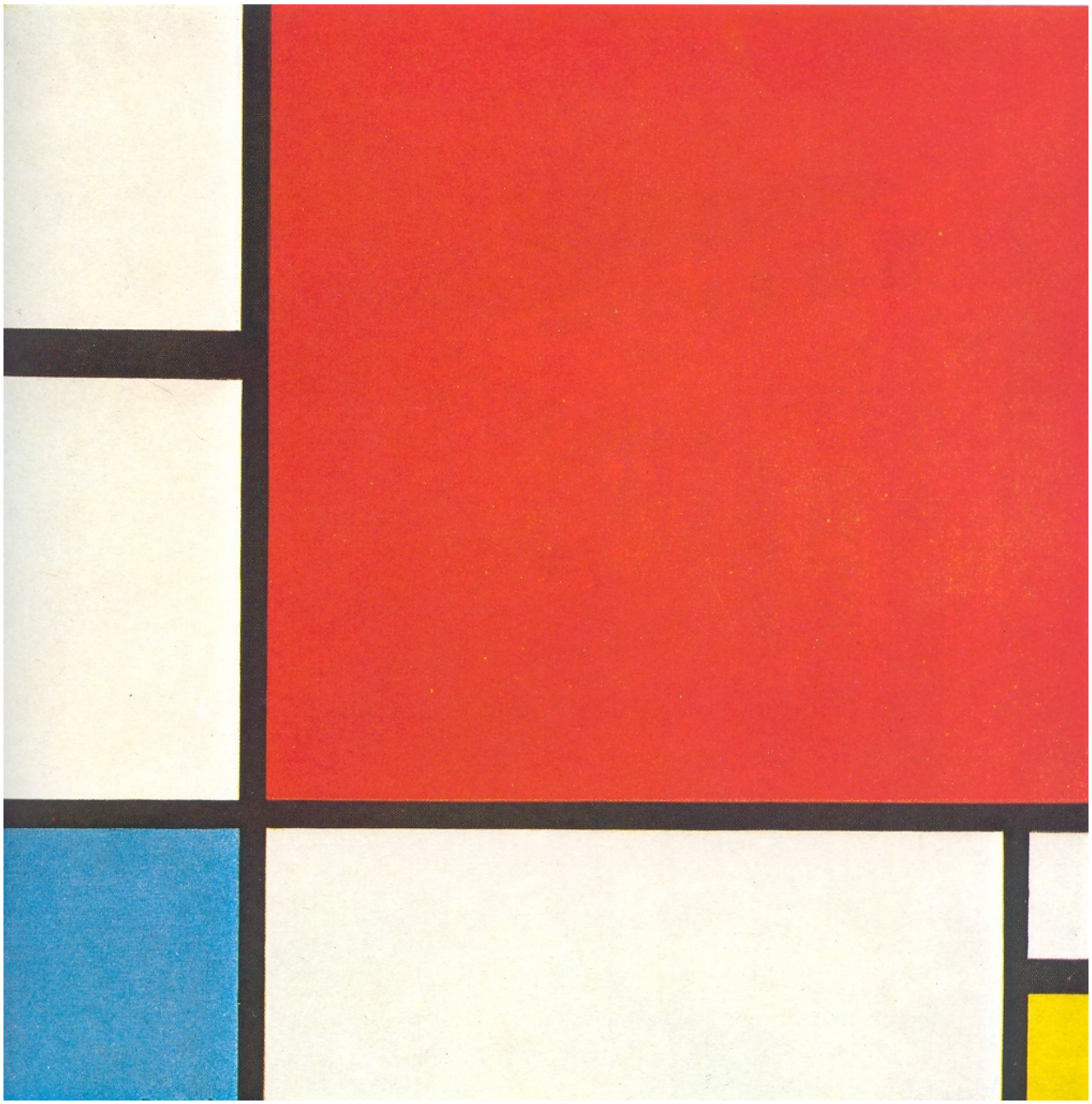
```
log("works without thinking about it", c.increment);
```

It seems like a lot of trouble to be writing this out everywhere, *especially* when the desired behaviour is nearly always that methods be bound. Let's write another mixin:

```
function SelfBindingize (klass) {
  klass.defineMethod = function (name, body) {
    Object.defineProperty(this.prototype, name, {
      get: function () {
        return body.bind(this);
      }
    });
    return this;
  }
}

var SelfBindingCounter = Class.create();
SelfBindingize(SelfBindingCounter);

SelfBindingCounter.defineMethod('initialize', function () { this._count = 0; })
SelfBindingCounter.defineMethod('increment', function () { return ++this._count; \
})
SelfBindingCounter.defineMethod('count', function () { return this.count; });

var cc = SelfBindingCounter.create();

function log (message, callback) {
  console.log(message);
  return callback();
}

log("works without thinking about it", cc.increment);
```

[68] http://underscorejs.org/#bind

Classes that mix `SelfBindingize` in are self-binding. We've encapsulated the internal representation and implementation, and hidden it behind a method that we mix into the class.



Composition with Red, Blue and Yellow–Piet Mondrian (1930)

composition

As we might expect, `SelfBindingize` plays nicely with `Singletonize`, just as `Fluentize` did. But speaking of `Fluentize`, `Singletonize` does **not** play nicely with `Fluentize`. They both create new versions of `defineMethod`, and if you try to use both, only the last one executed will take effect.

The problem is that `SelfBindingize` and `Fluentize` don't *compose*. We can make up lots more similar examples too. In fact, metaprogramming tools generally *don't* compose when you write them individually. And this lesson is not restricted to "advanced" ideas like writing class mixins: Mixins in the problem domain have the same problem, they tend *not* to compose by default, and that makes using them a finicky and fragile process.

The naïve way to solve this problem is to write our mixins, and then when conflicts are discovered, rewrite them to play well together. This is not a bad strategy, in fact it might be considered the "optimistic" strategy. As long as we are aware of the possibility of conflicts and know to look for them when the code does not do what we expect, it is not unreasonable to try to avoid conflicts rather than investing in another layer of abstraction up front.

On the other hand, if we expect to be doing a lot of mixing in, it is a good investment to design around composition up front rather than deal with the uncertainty of not knowing when what appears to be a small change might lead to a lot of rewriting later on.

When dealing with semantics "in the large," such as when writing class mixins, there generally aren't a lot of "custom" semantics needed in one software application, and they generally come up early in the design and development process. Thus, many developers take the optimistic approach: They build classes and incorporate custom semantics as they go, resolving any conflicts where needed.

However, in the real of the problem domain, there are many more requirements for mixing functionality in, and requirements change more often. Thus, experienced programmers will sometimes build (or "borrow" from a library) infrastructure to make it easy to compose mixed-in functionality for domain objects.

For example, in the Ruby on Rails[69] framework, there is extensive support for binding behaviour to controller methods and to model object lifecycles, and the library is carefully written so that you can bind more than one quantum of behaviour, and the bindings compose neatly without overwriting each others' effects.

This support is implemented with metaprogramming of the semantics of controller and model base classes. If we accept the notion that we are more likely to need to compose model behaviour than metaobject behaviour, one way forward is to use our tools for metaobject programming to implement a protocol for composing model behaviour.

method decorators

When looking at writing classes with classes, we used the example of making methods fluent by default. Fluent APIs are a wide-ranging, cross-cutting concern the can be applied to many designs. But for every wide-ranging design technique, there are thousands of application-specific domain concerns that can be applied to method semantics.

Depending on the problem domain, programmers might be concerned about things like:

[69] https://github.com/gititboards/RubyOnRails

- Checking for permissions before executing a method
- Logging the invocation and/or result of a method
- Checking entities for validity before persisting them to storage.

Each domain concern can be written as a mixin of sorts. In javaScript Allongé[70], we looked at techniques for using combinators to apply special semantics to methods. For example, here is a simple combinator that "validates" the arguments to a method:

```
function validates (methodBody) {
  return function () {
    var i;

    for (i = 0; i < arguments.length; ++i) {
      if (typeof(arguments[i].validate) === 'function' && !arguments[i].validate(\
)) throw "validation failure";
    }
    return fn.apply(this, arguments);
  }
}
```

Amongst other improvements, a more robust implementation would mimic the method body's arity. But this is close enough for discussion: Applied to a function, it returns a function that first checks all of its arguments. If any of them implement a `.validate` method, that method is called and an error thrown if it doesn't return `true`.

And here's a combinator that implements "always fluent" method semantics (this differs slightly from the "fluent-by-default" that we saw earlier):

```
function fluent (methodBody) {
  return function () {
    methodBody.apply(this, arguments);
    return this
  }
}
```

These two combinators compose nicely if you write something like this:

[70] https://leanpub.com/javascript-allonge

```
function Account () {
  // ...
}

Account.prototype.validate = function () {
  // ...
};

function AccountList () {
  this.accounts = [];
}

AccountList.prototype.add = fluent( validates( function (account) {
  this.accounts.push(account);
}));
```

You can even explicitly compose the combinators:

```
var compose = require('allong').es.compose;

var fluentlyValidates = compose(fluent, validates);
```

Or apply them after assigning the method:

```
AccountList.prototype.add = function (account) {
  this.accounts.push(account);
};

// ...

AccountList.prototype.add = fluent( validates( AccountList.prototype.add ) );
```

Everything seems wonderful with this approach! But this has limitations as well. The limitation is that combinators operate on functions. The hidden assumption is that when we apply the combinator, we already have a function we want to decorate. This won't work, for example:

```
function AccountList () {
  this.accounts = [];
}

AccountList.prototype.add = fluent( validates( AccountList.prototype.add ) );

// ...

AccountList.prototype.add = function (account) {
  this.accounts.push(account);
};
```

You can't decorate the method's function before you assign it! Here's another variation of the same problem:

```
function AccountList () {
  this.accounts = [];
}

AccountList.prototype.add = fluent( validates( function (account) {
  this.accounts.push(account);
}));

// ...
```

So far so good, but:

```
function IndexedAccountList () {
  this.accounts = {};
}

IndexedAccountList.prototype = Object.create(AccountList.prototype);

IndexedAccountList.prototype.add = function (account) {
  this.accounts[account.id] = account;
}

IndexedAccountList.prototype.at = function (id) {
  return this.accounts[id];
}
```

Our `IndexedAccountList.prototype.add` overrides `AccountList.prototype.add`... And in the process, overrides the modifications made by `fluent` and `validates`. This makes perfect sense if you are using prototypical inheritance purely as a convenience for sharing some behaviour. But if you are actually trying to model a formal class, then perhaps you always want the `.add` method to validate its arguments and fluently return the receiver. Perhaps you only want to override how the method adds things internally without modifying the "contract" you are expressing with the outside world?

Regardless of your exact interpretation of the semantics of overriding a method that you've decorated, the larger issue remains that there is some brittleness involved in using functions to decorate methods in classes. They don't *always* compose neatly and cleanly.

As discussed, if we need to do this on a regular basis, we can invest up front in some infrastructure to make decorating methods easy and composable, without worrying about making them play well together or about what order we apply them.

In our next section, we'll look at how to do that with metamethods.

Composing Method Behaviour

coming soon

To Do

immediate, forward, and late-binding of metaobjects

degenerate protocols

contracts and liskov equivalence

simple delegation

resolution: merge, override, and final

method guards and contracts

early and late method composition

multiple dispatch and generic functions

pattern matching protocols

Appendices

Utility Functions

Throughout this book, we have used utility functions in our code snippets and examples. Here is a list of functions we've borrowed from other sources. Most are from underscore[71] or allong.es[72].

```
var allong = require('allong.es');
var _ = require('underscore');
```

extend

`extend` can be found in the underscore[73] library:

```
var extend = _.extend;
```

Or you can use this formulation:

```
var __slice = [].slice;

function extend () {
  var consumer = arguments[0],
      providers = __slice.call(arguments, 1),
      key,
      i,
      provider,
      except;

  for (i = 0; i < providers.length; ++i) {
    provider = providers[i];
    except = provider['except'] || [];
    except.push('except');
    for (key in provider) {
      if (except.indexOf(key) < 0 && provider.hasOwnProperty(key)) {
```

[71] http://underscorejs.org
[72] http://allong.es
[73] http://underscorejs.org

```
        consumer[key] = provider[key];
      };
    };
  };
  return consumer;
};
```

pipeline

`pipeline` composes functions in the order they are applied:

```
var pipeline = allong.es.pipeline;

function square (n) { return n * n; }
function increment (n) { return n + 1; }

pipeline(square, increment)(6)
  //=> 37
```

tap

`tap` passes a value to a function, discards the result, and returns the original value:

```
var tap = allong.es.tap;

tap(6, function (n) {
  console.log("Hello there, " + n);
});
  //=>
    Hello there, 6
    6
```

map

`map` applies function to an array, returning an array of the results:

```
var map = allong.es.map;

map([1, 2, 3], function (n) {
  return n * n;
});
  //=> [1, 4, 9]
```

variadic

`variadic` takes a function and returns a "variadic" function, one that collects arguments in an array and passes them to the last parameter:

```
var variadic = allong.es.variadic;

var a = variadic(function (args) {
  return { args: args };
});

a(1, 2, 3, 4, 5)
  //=> { args: [1, 2, 3, 4, 5] }

var b = variadic(function (first, second, rest) {
  return { first: first, second: second, rest: rest };
});

b(1, 2, 3, 4, 5)
  //=> { first: 1, second: 2, rest: [3, 4, 5] }
```

unvariadic

`unvariadic` takes a variadic function and turns it into a function with a fixed arity:

```
var unvariadic = allong.es.unvariadic;

function ensuresArgumentsAreNumbers (fn) {
  return unvariadic(fn.length, function () {
    for (var i in arguments) {
      if (typeof(arguments[i]) !== 'number') {
        throw "Ow! NaN!!"
      }
    }
```

```
    return fn.apply(this, arguments);
  });
}

function myAdd (a, b) {
  return a + b;
}

var myCheckedAdd = ensuresArgumentsAreNumbers(myAdd);

myCheckedAdd.length
  //=> 2
```