



JavaScript Spessore

A Thick Shot of Objects, Metaobjects, & Protocols
by Reginald “raganwald” Braithwaite

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Reginald Braithwaite

This book is for sale at <http://leanpub.com/javascript-spessore>

This version was published on 2014-01-10



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Also By Reginald Braithwaite

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Prefaces

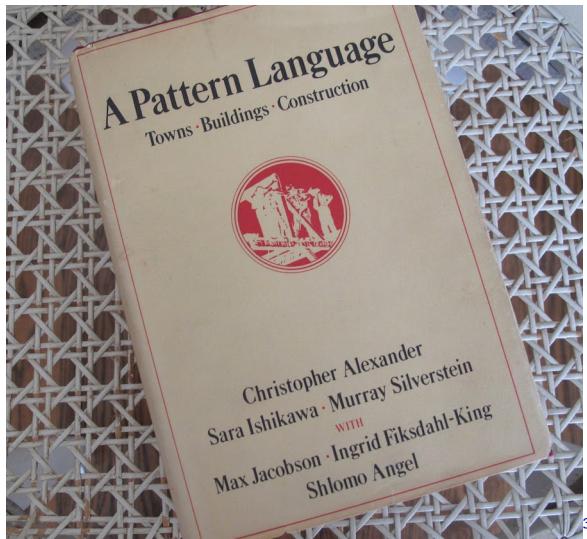


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Foreword

There are many ways to write books about Architecture. One might attempt to catalogue a broad variety of problems and their solutions, at scales ranging from designing communities down to items of furniture, as Christopher Alexander did in [A Pattern Language](#)²:



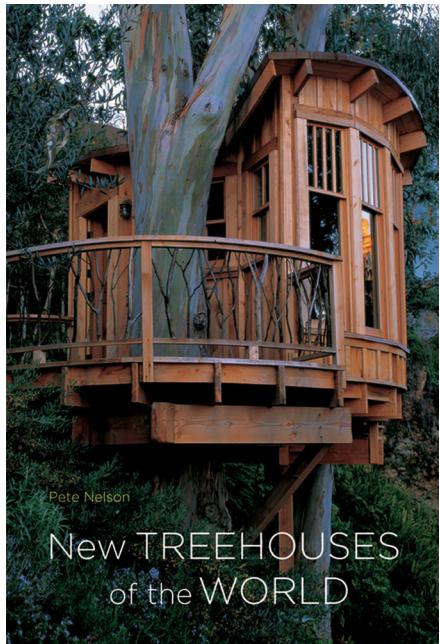
New Treehouses of the World

One might also pick a particular domain and then survey how different architects approached solving a common set of problems, highlighting the variety of possible styles. [New Treehouses of the World](#)⁴ takes this approach:

²http://www.amazon.com/gp/product/0195019199/ref=as_li_ss_tl?ie=UTF8&camp=1789&creative=390957&creativeASIN=0195019199&linkCode=as2&tag=raganwald001-20

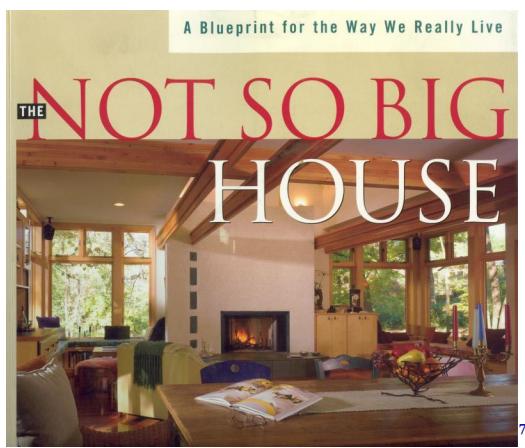
³http://www.amazon.com/gp/product/0195019199/ref=as_li_ss_tl?ie=UTF8&camp=1789&creative=390957&creativeASIN=0195019199&linkCode=as2&tag=raganwald001-20

⁴http://www.amazon.com/gp/product/0810996324/ref=as_li_ss_tl?ie=UTF8&camp=1789&creative=390957&creativeASIN=0810996324&linkCode=as2&tag=raganwald001-20



The Not So Big House

Or one might approach architecture from a single viewpoint, describing a highly specific and coherent style backed by personal experience, as Sarah Susanka did in [The Not So Big House](#)⁶:



⁵http://www.amazon.com/gp/product/0810996324/ref=as_li_ss_tl?ie=UTF8&camp=1789&creative=390957&creativeASIN=0810996324&linkCode=as2&tag=raganwald001-20

⁶http://www.amazon.com/gp/product/1600851509/ref=as_li_ss_tl?ie=UTF8&camp=1789&creative=390957&creativeASIN=1600851509&linkCode=as2&tag=raganwald001-20

⁷http://www.amazon.com/gp/product/1600851509/ref=as_li_ss_tl?ie=UTF8&camp=1789&creative=390957&creativeASIN=1600851509&linkCode=as2&tag=raganwald001-20

JavaScript Spessore

JavaScript Spessore⁸ follows this path. This book will not attempt to dictate the “one true definition” of object-oriented programming. It will not survey and catalog the many different programming languages and libraries people have used to solve software problems with objects.

Instead, JavaScript Spessore describes one way to design programs with objects as the central idea: Building software on top of a metaobject protocol. A metaobject protocol is a kind of abstraction for implementing object-oriented programming semantics. One program might be developed with pattern matching for methods, another might use state machines, a third might be heavily factored into aspects.

By implementing this metaobject protocol and semantics on top of it, we gain insight into how these semantics work and how they might be applied to solving problems we encounter as software developers.

⁸<https://leanpub.com/javascript-spessore>

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](#)⁹ ("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-2¹⁰], then discusses how to implement namespaces, building a simple Lisp-1 and a 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](#)¹¹, you can't help but feel comfortable using JavaScript callbacks in [Node.js](#)¹².

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.

⁹http://www.amazon.com/gp/product/B00AKE1U6O/ref=as_li_ss_til?ie=UTF8&camp=1789&creative=390957&creativeASIN=B00AKE1U6O&linkCode=as2&tag=raganwald001-20

¹⁰A "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](#).

¹¹https://en.wikipedia.org/wiki/Continuation-passing_style

¹²<http://nodejs.org/about/>

JavaScript Allongé and `allong.es`

JavaScript Spessore¹³ is written for the reader who has read JavaScript Allongé¹⁴ 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

“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](#)¹⁵.

`allong.es`

`allong.es`¹⁶ 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](#)¹⁷ page and see them work.

¹³<https://leanpub.com/javascript-spessore>

¹⁴<https://leanpub.com/javascript-allonge>

¹⁵<https://leanpub.com/javascript-allonge/read>

¹⁶<http://allong.es>

¹⁷<http://allong.es/try/>

Disclaimer

Writing is a journey, not a destination. This sample documents the direction we're facing as we take the next step.

This sample “document” is provided to illustrate direction [JavaScript Spessore¹⁸](#) is taking. **It is not held out to contain any of the actual book’s content.** “Purchases” are being offered to people whose primary motivation is to support the book and encourage me to get it done.

Your purchase does include the right to download any and all versions of the book, as per Leanpub’s lean publishing model. You will never be asked to pay more. You have the right to a 100% no-questions-asked refund if you are not satisfied with the progress of the book:

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That being said, writing like this cannot be rushed: progress may be slow relative to a “Learn JavaScript OO in 21 Days” type of book. If you would prefer that there be a substantial amount of work completed, please be patient and check back in a month or so.

Please also bear in mind that pricing and bundling may vary over time. The book may be offered at any price in the future or even be free to read or free to share at some point in the future.

¹⁸<https://leanpub.com/javascript-spessore>

¹⁹<https://leanpub.com/terms#returns>

Preamble



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²⁰Transparent Sanremo espresso machine, London Coffee Festival, Truman Brewery, Brick Lane, Hackney, London, UK (c) 2013 Cory Doctorow, some rights reserved

Objects and References

The material in this preamble should be familiar to the working JavaScript programmer, so feel free to skip it if you are in a hurry. However, it never hurts to review the “obvious:” Prefetching the basics into your L2 cache can improve learning performance when tackling more advanced material.

This expression evaluates to an object:

```
{}  
//=> {}
```

So does this:

```
Object.create(null)  
//=> {}
```

This one lets us define properties in a familiar way:

```
var acct = {  
    transitNumber: '129131673',  
    accountNumber: '0114584906'  
}
```

There is a syntax for accessing property contents:

```
acct.accountNumber  
//=> '0114584906'
```

We can also use it to assign properties directly:

```
var cheque = {};  
cheque.number = 1;
```

We can write a function to extend one object with the properties of another:

```
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)) {
                consumer[key] = provider[key];
            };
        };
    };
    return consumer;
};

var account = {
    transitNumber: '129131673',
    accountNumber: '0114584906'
};

extend(account, {
    type: 'chequing',
    name: 'slush fund'
});

account.name
//=> 'slush fund'
```

JavaScript properties must be named with strings, but can have any value:

```
{  
  one: 1  
}  
//=> { one: 1 }
```

If a name isn't a string, it will be converted to a string:

```
{  
  1: 'one'  
}  
//=> { '1': 'one' }
```

Since objects are values, objects can have objects as values:

```
{  
  transitNumber: {  
    federalReserveRouting: {  
      bank: '12',  
      processingCentre: '9',  
      location: '1'  
    },  
    abaInstitution: '3167',  
    checkDigit: '3'  
  },  
  accountNumber: '0114584906'  
}
```

Object values are references:

```
var reserveRouting = {  
  bank: '12',  
  processingCentre: '9',  
  location: '1'  
};  
  
var transitNumber = {  
  federalReserveRouting: reserveRouting,  
  abaInstitution: '3167',  
  checkDigit: '3'  
};
```

```

var bankAccount = {
  transitNumber: transitNumber,
  accountNumber: '0114584906'
};

var amount = {
  dollars: 2,
  cents: 56
}

var cheque = {
  bankAccount: bankAccount,
  number: '1',
  amount: amount
}

cheque
//=>
{
  bankAccount:
    {
      transitNumber:
        {
          federalReserveRouting:
            {
              bank: '12',
              processingCentre: '9',
              location: '1' },
              abaInstitution: '3167',
              checkDigit: '3' },
              accountNumber: '0114584906' },
              number: '1',
              amount: { dollars: 2, cents: 56 } }
}

```

Since they are references, mutating an object means that its value in one place mutates its value everywhere:

```

var cheque2 = {
  bankAccount: bankAccount,
  number: '2',
  amount: {
    dollars: 1,
    cents: 0
  }
}

```

```
cheque2.bankAccount.transitNumber
//=>
{ federalReserveRouting:
  { bank: '12',
    processingCentre: '9',
    location: '1' },
  abaInstitution: '3167',
  checkDigit: '3' }

extend(reserveRouting, {
  processingCentre: '1',
  location: '0'
});

cheque.bankAccount.transitNumber
//=>
{ federalReserveRouting:
  { bank: '12',
    processingCentre: '1',
    location: '0' },
  abaInstitution: '3167',
  checkDigit: '3' }

cheque2.bankAccount.transitNumber
//=>
{ federalReserveRouting:
  { bank: '12',
    processingCentre: '1',
    location: '0' },
  abaInstitution: '3167',
  checkDigit: '3' }

  month: month,
  day: 1
},
amount: extend({}, rentAmount)
}
});

rentCheques[7].amount.dollars
//=> 420
```

```
rentCheques[0].amount.dollars
//=> 420
```

The expression `extend({}, rentAmount)` copies all the properties of `rentAmount` into a new, empty object. It is evaluated every time we create a new cheque, so we get a new amount object for each cheque. Thus, when we change some of them, they are the only ones to change:

```
[4, 5, 6, 7, 8, 9, 10, 11, 12].forEach( function (month) {
  rentCheques[month - 1].amount.dollars = 600;
});

rentCheques[7].amount.dollars
//=> 600

rentCheques[0].amount.dollars
//=> 420
```

The drawback of this approach is that creating new objects takes both time and space, and it becomes very expensive. You might decide that the flaw was in assigning a new dollar amount instead of changing the entire amount:

```
[4, 5, 6, 7, 8, 9, 10, 11, 12].forEach( function (month) {
  rentCheques[month - 1].amount = {
    dollars: 600,
    cents: 0
  }
});
```

This would also have worked. If these were our only options, we would balance their respective considerations before making a choice:

1. Making separate amount objects when we crate cheques is slow and takes up space, but it is resistant to programmers making mistakes later.
2. Making new amount objects when we need to make changes is faster and tighter, but requires discipline from programmers to know when to make copies.

When we discuss defined properties, we will look at some techniques for making code more resistant to errors.

Summary

coming soon

What is a Metaobject Protocol?



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A metaobject protocol provides the vocabulary to access and manipulate the structure and behavior of objects. Typical functions of a metaobject protocol include: Creating and deleting new classes; Creating new methods and properties; Changing the class structure so that classes inherit from different classes; Generating or modifying the code that defines the methods for the class.—[Wikipedia](#)²²

Languages with support for object-oriented programming typically provide their own “Vocabulary to access and manipulate the structure and behavior of objects” at runtime. Ruby, for example, provides keywords like `def` and `class`, as well as imbuing objects and modules with a variety of methods for inspecting and modifying behaviour while the program is running.

²¹[Normalized Pump Pressure Reading](#) (c) 2009 Nicholas Lundgaard, some rights reserved

²²<https://en.wikipedia.org/wiki/Metaobject>

JavaScript can be said to have an extremely minimalist metaobject protocol. In this book, we'll look at building our own, richer metaobject protocols on top of JavaScript. Our metaobject protocols will be guided by the philosophy that object behaviour should be divided amongst three entities:

- Objects are responsible for the domain-specific properties of entities we're modeling.
- Metaobjects are responsible for encapsulating the behaviour of base objects.
- Protocols are façades for insulating code that defines behaviour from the implementation of metaobjects.

What is an Object?

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](#)²³

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.

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.²⁴

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

²³<https://en.wikipedia.org/wiki/Smalltalk>

²⁴More 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.

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.

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 in JavaScript:

```
Math.max(1, 5, 4)  
//=> 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 ago²⁵ to model entities when building simulations. When making a simulation, an essential design technique is to make each 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 uses handlers to respond to**

²⁵<https://en.wikipedia.org/wiki/Simula> "The Simula Programming Language"

messages. It maintains internal state, and its handlers are responsible for querying and/or updating its state.

We'll have a closer look at implementing objects in Javascript a little later in this book.

What is a Metaobject?

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.—[Wikipedia²⁶](#)

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:

```
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.

singleton metaclasses

Metaobjects solve this problem by separating the domain-specific properties of objects from their behaviour and implementation-specific properties. In classic JavaScript, we can use a prototype for the behaviour. We call this a “singleton metaobject.”

²⁶<https://en.wikipedia.org/wiki/Metaobject>

```

var singletonMetaobject = {};
var sam = Object.create(singletonMetaobject);

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

```

Notice that a prototype provides value even when we have no intention of sharing behaviour: Its value is that it separates behaviour from our model's domain properties very neatly:

```

Object.getOwnPropertyNames(sam)
//=> [ 'firstName', 'lastName' ]

```

Insulating our base objects from our metaobjects is important for hiding implementation details, a core “OO” value. When we provide a method like `fullName`, we’re hiding details of how to compute a full name from other entities, all they need to know is the name of the message to send.

hiding implementation details

But we need to hide implementation details within an object as well. Consider logging.²⁷ If we wish to write to the console every time an object is renamed, we have many choices. Here are three:

First, we can rewrite our function:

²⁷The canonical example of a cross-cutting concern. We could also consider implementing undo and transactions, they have similar characteristics.

```
singletonMetaobject.rename = function (first, last) {
  console.log(this.fullName() + " is being renamed " + first + " " + last);
  this.firstName = first;
  this.lastName = last;
  return this;
};
```

Second, we can use a [method combinator](#)²⁸:

```
var logsNameChange = before( function (first, last) {
  console.log(this.fullName() + " is being renamed " + first + " " + last);
});

singletonMetaobject.rename = logsNameChange( function (first, last) {
  this.firstName = first;
  this.lastName = last;
  return this;
});
```

Third, we could use an aspect-oriented programming library like [YouAreDaChef](#)²⁹:

```
YouAreDaChef(sam).before('rename', function (first, last) {
  console.log(this.fullName() + " is being renamed " + first + " " + last);
});
```

Never mind which choice we should exercise. The important thing is that whatever we do should be hidden from the `sam` object itself! All it “knows” is that it has a prototype. What happens inside that prototype ought to be opaque. Is the `rename` function rewritten? Is it recombined? Is there a `before_rename` property with list of functions to execute? That should be irrelevant to the `sam` object itself.

The basic principle of the metaobject is that we separate the mechanics of behaviour from the domain properties of the base object. Everything else, like how inheritance is implemented, or whether a method is being logged, is hidden from the object.

²⁸<https://github.com/raganwald/method-combinators>

²⁹<https://github.com/raganwald/YouAreDaChef>

What is a Protocol?

We've seen that a metaobject separates an object's domain-specific properties from the implementation details of its behaviour. The implementation details might be simple, such as a few methods that are expressed as functions, or complex, such as an inheritance hierarchy with composite methods.

A metaobject *protocol* (or just "protocol") is an interface for managing metaobjects. While the metaobject is responsible for the object's behaviour, the protocol is responsible for creating, changing, and removing behaviour from metaobjects.

protocols and object creation

Previously, we showed how to use a prototype as a singletonMetaobject:

```
var singletonMetaobject = {};
var sam = Object.create(singletonMetaobject);

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

A protocol can hide this implementation detail behind a function:

```

function object(superprototype, propertyDescriptors) {
  if (arguments.length == 0 || typeof(superprototype) == 'undefined') {
    superprototype = Object.prototype;
  }
  var singletonMetaobject = Object.create(superprototype)
  return Object.create(singletonMetaobject, propertyDescriptors || {});
}

var sam = object();
extend(sam, {
  firstName: 'Sam',
  lastName: 'Lowry'
});

```

Adding methods to the singleton metaobject is also hidden behind a function. We'll elide the details for the moment:

```

function extendWithMethods (object, methodDescriptions) {
  for (var methodName in methodDescriptions) {
    // ...
  }
  return object;
}

extendWithMethods(sam, {
  fullName: function () {
    return this.firstName + " " + this.lastName;
  },
  rename: function (first, last) {
    this.firstName = first;
    this.lastName = last;
    return this;
  }
});

```

protocols and advice

In the previous section, we gave three different implementations for adding logging to the `rename` method. The base object is insulated from the details by its metaobject, and the code that attaches the logging should likewise be insulated from the implementation choice.

Our protocol provides the insulation for us:

```
function method (object, methodName, optionalOverride) {
  // ...
}

method(sam, 'rename').unshift( function (firstName, lastName) {
  console.log(this.fullName() + " is being renamed " + firstName + " " + lastName\
);
});

sam.rename('Samuel', 'Lowrie')
//=> Sam Lowry is being renamed Samuel Lowrie
// { firstName: 'Samuel', lastName: 'Lowrie' }
```

The metaobject hides the implementation of “advice” from the base object. However, the implementation is exposed to the code responsible for adding logging to base objects. This is where the metaobject comes in.

To be specific, we meant that a base object should be insulated from the implementation consequences of rewriting a method, applying a combinator to it, or applying “before advice” to it. But we go further: In addition to insulating the base object from the implications of this choice, we must insulate the programmer from needing to think through and possibly re-invent the implementation of any of these three choices.

Summary

Metaobject protocols are vocabularies for accessing and manipulating the structure and behavior of objects. The protocols in this book will be implemented with three main entities:

- *Objects*: Objects are responsible for domain-specific properties.
- *Metaobjects*: Metaobjects are responsible for the insulating objects from the implementation of their behaviour.
- *Protocols*: Protocols are responsible for insulating other code from the implementation of metaobject behaviour.

Objects



30

introductory remarks coming soon

³⁰Londinium 1 Lever Espresso Machine (c) 2013 Alejandro Erickson, some rights reserved

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:

```
"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:

```
var allong = require('allong.es');  
var tap = allong.es.tap;  
  
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.

Objects and Functions

Since functions are values, objects can have functions as values:

```
var allong = require('allong.es');
var variadic = allong.es.variadic;
var map = allong.es.map;

var getAll = variadic( function (object, propertyNames) {
  return map(propertyNames, function (name) { return object[name]; });
});

var federalReserve1 = {
  bank: '12',
  processingCentre: '9',
  location: '1',
  toString: function () {
    return getAll(federalReserve1, 'bank', 'processingCentre', 'location').join('\
');
  }
};

var transitNumber1 = {
  federalReserveRouting: federalReserve1,
  abaInstitution: '3167',
  checkDigit: '3',
  toString: function () {
    return getAll(transitNumber1, 'federalReserveRouting', 'abaInstitution', 'che\
ckDigit').join('');
  }
};

var account1 = {
  transitNumber: transitNumber1,
  accountNumber: '0114584906',
  toString: function () {
    return account1.transitNumber + '-' + account1.accountNumber;
  }
}
```

You can call those functions by referring to them with . , and then invoking them with ():

```
account1.toString()  
//=> '129131673-0114584906'
```

Functions that are associated with properties are values, we can do whatever we want with them:

```
var accountStringifier = account1.toString;  
  
accountStringifier  
//=> [function]  
  
accountStringifier()  
//=> '129131673-0114584906'
```

You have to be careful when you share a single function amongst multiple objects. Watch the ‘copypasta’ error:

```
var amount = {  
    dollars: 2,  
    cents: 56,  
    toString: function () {  
        return '$' + amount.dollars + '.' + (amount.cents < 10 ? ('0' + amount.cents)\  
        : amount.cents)  
    }  
}  
  
var amount2 = {  
    dollars: 1,  
    cents: 0,  
    toString: function () {  
        return '$' + amount.dollars + '.' + (amount.cents < 10 ? ('0' + amount.cents)\  
        : amount.cents)  
    }  
}  
  
amount.toString()  
//=> '$2.56'  
  
amount2.toString()  
//=> '$2.56'
```

Some simple factoring will help.

```
function inDollarsAndCents (amount) {
  return '$' + amount.dollars + '.' + (amount.cents < 10 ? ('0' + amount.cents) : \
  amount.cents);
};

var amount = {
  dollars: 2,
  cents: 56,
  toString: function () {
    return inDollarsAndCents(amount);
  }
}

var amount2 = {
  dollars: 1,
  cents: 0,
  toString: function () {
    return inDollarsAndCents(amount2);
  }
}

amount.toString()
//=> '$2.56'

amount2.toString()
//=> '$1.00'
```

This is a general principle: *functions that belong to objects really need a reference to the current object to be useful.*

this

JavaScript provideth:

```

function inDollarsAndCents () {
  "use strict";
  return '$' + this.dollars + '.' + (this.cents < 10 ? ('0' + this.cents) : this.\cents);
}

var amount = {
  dollars: 2,
  cents: 56,
  toString: inDollarsAndCents
}

var amount2 = {
  dollars: 1,
  cents: 0,
  toString: inDollarsAndCents
}

amount.toString()
//=> '$2.56'

amount2.toString()
//=> '$1.00'

```

Within a function that is invoked as a property of an object, the environment contains a magic variable, `this`, that refers to the object.

`this` does not refer to the object if we invoke the function in another way. Recall that functions are values we can extract from an object without calling them:

```

var stringifier = amount.toString;

stringifier
//=> [Function: inDollarsAndCents]

```

However, invoking a function without a property reference means that we have lost the context provided by `this:[^global]`

```

stringifier()
//=>
TypeError: Cannot read property 'dollars' of undefined

```

[^global] If we run without “strict” mode, we get a very unhelpful “global” context that often delays or obfuscates the source of bugs.

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 Expression³¹](#) ("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:

³¹https://en.wikipedia.org/wiki/Immediately-invoked_function_expression

```
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

mutableAmount.getDollars()
//=> 0
```

Immutability is easy, just leave out the “getters:”

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

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

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

```
var mediatedAmount = (function () {
  var _dollars = 0;
  var _cents = 0;
  var amount = {};
  Object.defineProperties(amount, {
    dollars: {
      enumerable: true,
      set: function (amount) {
        if (amount >= 0 && amount === Math.floor(amount))
          return (_dollars = amount);
      },
      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 allong = require('allong.es');
map = allong.es.map;

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.

```

var allong = require('allong.es');
var tap = allong.es.tap;

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
  }
});
```

```
raisedAmount._dollars = 600;  
raisedAmount._cents = 0;
```

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

```
rentAmount.dollars()  
//=> 420  
  
raisedAmount.dollars()  
//=> 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.³²

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`.³³

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:

```
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:

³²Some people argue that Lisp-1 and Lisp-2 are examples of “opaque jargon” and are a communication anti-pattern.

³³Why 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.

```
dictionary.length
```

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

```
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 term")  
  
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 metaobjects, the topic of the next chapter.