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You Don't Know JS Yet: Getting Started - 2nd Edition

NOTE:
Work in progress

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You Don't Know JS Yet - 2nd Edition

Preface

Welcome to the 2nd edition of the widely-acclaimed *You Don't Know JS* (**YDKJS**) book series: *You Don't Know JS **Yet*** (**YDKJSY**).

If you've read any of the 1st edition of the books, you can expect a refreshed approach in these new books, with plenty of new coverage of what's changed in JS over the last five years. But what I hope and believe you'll still *get* is the same committment to respecting JS and digging into what really makes it tick.

If this is your first time to read these books, I'm glad you're here. Prepare for a deep and extensive journey into all the corners of JavaScript.

The Parts

These books approach JavaScript intentionally the opposite of *The Good Parts*. No, not *the bad parts*, but rather, focused on **all the parts**.

You may have been told, or felt yourself, that JS is a deeply flawed language that was poorly designed and inconsistently implemented. Many have asserted that it's the worst most popular language in the world; that nobody writes JS because they want to, only because they have to given its place at the center of the web. That's a ridiculous, unhealthy, and wholly condescending claim.

Millions of developers write JavaScript every day, and many of them appreciate and respect the language.

Like any great language, it has its brilliant parts and it has its scars. Even the creator of JavaScript himself, Brendan Eich, laments some of those parts as mistakes. But he's wrong: they weren't mistakes at all. JS is what it is today -- the world's most ubiquitous and thus most influential programming language -- precisely because of *all those parts*.

Don't buy the lie that you should only learn and use a small collection of *good parts* while avoiding all the bad stuff. Don't buy the "X is the new Y" snake oil, that some new feature of the language instantly relegates all usage of a previous feature as obsolete and ignorant. Don't listen when someone says your code isn't "modern" because it isn't yet using a stage-0 feature that was only proposed a few weeks ago!

Every part of JS is useful. Some parts are more useful than others. Some parts require you to be more careful and intentional.

I find it absurd to try to be a truly effective JavaScript developer while only using a small sliver of what the language has to offer. Can you imagine a construction worker with a toolbox full of tools, who only uses his hammer and scoffs at the screwdriver or tape measure as inferior? That's just silly.

My unreserved claim is that you should go about learning all parts of JavaScript, and where appropriate, use them! And if I may be so bold as to suggest: it's time to discard any other JS books which tell you otherwise.

The Title?

So what's the title of the series all about?

I'm not trying to insult you with criticism about your current lack of knowledge or understanding of JavaScript. I'm not suggesting you can't or won't be able to learn JavaScript. I'm not boasting about secret advanced insider wisdom that I and only a select few possess.

Seriously, all those were real reactions to the original series title before folks even read the books. And they're baseless.

The primary point of the title "You Don't Know JS Yet" is to point out that most JS developers don't take the time to really understand how the code that they write, works. They know that it works -- that it produces a desired outcome. But they either don't understand exactly *how*, or worse, they have an inaccurate mental model for the *how* that falters on closer scrutiny.

I'm presenting a gentle but earnest challenge to you the reader, to set aside the assumptions you have about JS, and approach it with fresh eyes and an invigorated curiosity that leads you to ask *why* for every line of code you write. Why does it do what it does? Why is one way better or more appropriate than the other half dozen ways you could have accomplished it? Why do all the "popular kids" say to do X with your code, but it turns out that Y might be a better choice?

I added "Yet" to the title, not only because it's the second edition, but because ultimately I want these books to challenge you in a hopeful rather than discouraging way.

But let me be clear: I don't think it's possible to ever fully *know* JS. That's not an achievement to be obtained, but a goal to strive after. You don't finish knowing everything about JS, you just keep learning more and more as you spend more time with the language. And the deeper you go, the more you revisit what you *knew* before, and you re-learn it from that more experienced perspective.

I encourage you to adopt a mindset around JavaScript, and indeed all of software development, that you will never fully have mastered it, but that you can and should keep working to get closer to that end, a journey that will stretch for the entirety of your software development career, and beyond.

You can always know JS better than you currently do. That's what I hope these YDKJSY books represent.

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But a different, more important case still needs to be made, and these books rise to that challenge.

I've taught more than 5,000 developers from teams and companies all over the world, in more than 25 countries and six continents. And what I've seen is that far too often, what *counts* is generally just the result of the program, not how the program is written or how/why it works.

My experience not only as a developer but in teaching many other developers tells me: you will always be more effective in your development work if you more completely understand how your code works, than you are solely *just* getting it to produce a desired outcome.

In other words, *good enough to work* is not *good enough*.

All developers regularly struggle with some piece of code not working correctly, and they can't figure out why. But far too often, JS developers will blame this on the language rather than admitting it's their own understanding that is falling short. These books serve as both the question and answer: why did it do *this*, and here's how to get it to do *that* instead.

My mission with YDKJSY is to empower every single JavaScript developer to fully own the JS they write, to understand it and to write with intention and clarity.

The Path

Some of you have started reading this book with the goal of completing all six books, back-to-back.

I would like to caution you to consider changing that plan.

It is not my intention that YDKJSY be read straight through. The material in these books is dense, because JavaScript is powerful, sophisticated, and in parts rather complex. Nobody can really hope to *download* all this information to their brains in a single pass and retain any significant amount of it. That's unreasonable, and it's foolish to try.

My suggestion is you take your time going through YDKJSY. Take one chapter, read it completely through start to finish, and then go back and re-read it section by section. Stop in between each section, and practice the code or ideas from that section. For larger concepts, it probably is a good idea to expect to spend several days digesting, re-reading, practicing, then digesting some more.

You could spend a week or two on each chapter, and a month or two on each book, and a year or more on the whole series, and you would still not be squeezing every ounce of YDKJSY out.

Don't binge these books; be patient and spread out your reading. Interleave reading with lots of practice on real code in your job or on projects you participate in. Wrestle with the opinions I've presented along the way, debate with others, and most of all, disagree with me! Run a study group or book club. Teach mini-workshops at your office. Write blog posts on what you've learned. Speak about these topics at local JS meetups.

It's never my goal to convince you to agree with my opinion, but to own and be able to defend your opinions. You can't get *there* with an expedient read through of these books. That's something that takes a long while to emerge, little by little, as you study and ponder and re-visit.

These books are meant to be a field-guide on your wanderings through JavaScript, from wherever you currently are with the language, to a place of deeper understanding. And the deeper you understand JS, the more questions you will ask and the more you will have to explore! That's what I find so exciting!

I'm so glad you're embarking on this journey, and I am so honored you would consider and consult these books along the way. It's time to start *getting to know JS*.

You Don't Know JS Yet: Getting Started - 2nd Edition

Chapter 1: Getting To Know JavaScript

NOTE:
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You don't know JS, yet. Neither do I, not fully anyway. None of us do. That's the whole point of this book series!

But here's where you start that journey of getting to know the language a little better. We'll start with a few housekeeping details, then move into talking about the code part of the language in a bit.

Name

The name JavaScript is probably the most misunderstood programming language name ever.

Is this language related to Java? Is it only the script form for Java? Is it only for writing scripts and not real programs?

The truth is, the name JavaScript is an artifact of marketing shenanigans. When Brendan Eich first conceived of the language, he code named it Mocha. Internally at Netscape, the brand LiveScript was used. But when it came time to publicly name the language, "JavaScript" won the vote.

Why? Because this language was originally designed to appeal to an audience of mostly Java programmers, and because the word "script" was popular at the time to refer to lightweight programs. These lightweight "scripts" would be the first ones to embed inside of pages on this new thing called the web!

In other words, JavaScript was a marketing ploy to try to position this language as a palatable alternative to writing the heavier and more well-known Java of the day. It could just as easily have been called "WebJava", for that matter.

There are some superficial resemblances between JavaScript's code and Java code. But those are actually mostly from a common root: C (and to an extent, C++).

For example, we use the `{` to begin a block of code and the `}` to end that block of code, just like C/C++ and Java. We also use the `;` to punctuate the end of a statment.

In fact, the relationships run even deeper than the superficial. Sun, the company that still owns and runs Java, also owns the official trademark for the name "JavaScript". This trademark is almost never enforced, and likely couldn't be at this point.

Some have suggested we use JS instead of JavaScript. That's a very common shorthand, if not a good candidate for an official language name itself.

To distance JS from Sun and the trademark, the official name of the language that is specified by TC39 and formalized by ECMA standards body is: ECMAScript. And indeed, since 2016, the official language name has also included the most recent revision year; as of this writing, that's ECMAScript 2019, or otherwise abbreviated ES2019.

In other words, JavaScript (in your browser, or in Node.js) is *an* implementation of the ES2019 standard!

NOTE:
Don't use terms like "JS6" or "ES8". Some do that, and those terms only serve to perpetuate confusion. "JS" or "ES20xx" is what you should stick to.

Whether you call it JavaScript, JS, ECMAScript, or ES2019, it's most definitely not a variant of the Java language!

> "Java is to JavaScript as ham is to hamster." --Jeremey Keith, 2009

Specification

I mentioned a moment ago that TC39 -- the technical steering committee that manages JS -- votes on changes to submit to ECMA, the standards body.

The set of syntax and behavior that *is* JavaScript is the ES specification.

As of this writing, ES2019 is the most recent revision of this specification, the most recent version of the JavaScript language. This happens to be the 10th numbered revision since JavaScript's inception, so that's why you'll see that the specification's official URL as hosted by ECMA includes "10.0":

https://www.ecma-international.org/ecma-262/10.0/

The TC39 committee is comprised of anywhere from 50 to a little over 100 different people from a broad section of web-invested companies, such as browser makers (Mozilla, Google, Apple) and device makers (Samsung, etc). All members of the committee are volunteers, though many of them are employees of these companies and so some of them receive compensation in part for their duties on the committee.

TC39 meets generally about every other month, usually for about 3 days, to review work done by members since the last meeting, discuss issues, and vote on proposals. Meeting locations rotate among member companies willing to host.

All TC39 proposals progress through a five stage process -- of course, since we're programmers, it's 0-based -- Stage 0 through Stage 4. You can read more about the Stage process here: https://tc39.es/process-document/

Stage 0 means roughly, someone on TC39 thinks it's a worthy idea and plans to champion and work on it. That means lots of ideas that non-TC39 members "propose", through informal means such as social media or blog posts, are really "pre-stage 0". You have to get a TC39 member to champion a proposal for it to be considered "Stage 0" officially.

Once a proposal reaches "Stage 4" status, it is eligible to be included in the next yearly revision of the language.

All proposals are managed in the open, on TC39's Github repository: https://github.com/tc39/proposals

Anyone, whether on TC39 or not, is welcome to participate in these discussions and the processes for working on the proposals. However, only TC39 members can attend meetings and vote on these proposals. So in effect, the voice of a member of TC39 carries a lot of weight.

Contrary to some established and frustratingly perpetuated myth, there are *not* multiple versions of JavaScript. There's just **one JS**, the official standard as maintained by TC39 and ECMA.

Back in the early 2000's, when Microsoft maintained a forked and reverse-engineered (and not entirely compatible) version of JS called "JScript", there were legitimately "multiple versions" of JS. But those days are long gone. It's outdated and inaccurate to make such claims about JS today.

All major browsers and device makers have committed to keeping their JS implementations compliant with this one central specification. Of course, engines implement features at different times. But it should never be the case that the v8 engine (Chrome's JS engine) implements a specified feature differently than the SpiderMonkey engine (Mozilla's JS engine).

That means you can learn **one JS**, and rely on that same JS everywhere.

Backwards and Forwards

TODO

You Don't Know JS Yet: Scope & Closures - 2nd Edition

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You Don't Know JS Yet: Scope & Closures - 2nd Edition

Chapter 1: What is Scope?

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One of the most fundamental paradigms of nearly all programming languages is the ability to store values in variables, and later retrieve or modify those values. In fact, the ability to store values and pull values out of variables is what gives a program *state*.

Without such a concept, a program could perform some tasks, but they would be extremely limited and not terribly interesting.

But the inclusion of variables into our program begets the most interesting questions we will now address: where do those variables *live*? In other words, where are they stored? And, most importantly, how does our program find them when it needs them?

These questions speak to the need for a well-defined set of rules for storing variables in some location, and for finding those variables at a later time. We'll call that set of rules: *Scope*.

But, where and how do these *Scope* rules get set?

Compiler Theory

It may be self-evident, or it may be surprising, depending on your level of interaction with various languages, but despite the fact that JavaScript falls under the general category of "dynamic" or "interpreted" languages, it is in fact a compiled language. It is *not* compiled well in advance, as are many traditionally-compiled languages, nor are the results of compilation portable among various distributed systems.

But, nevertheless, the JavaScript engine performs many of the same steps, albeit in more sophisticated ways than we may commonly be aware, of any traditional language-compiler.

In a traditional compiled-language process, a chunk of source code, your program, will undergo typically three steps *before* it is executed, roughly called "compilation":

1. **Tokenizing/Lexing:** breaking up a string of characters into meaningful (to the language) chunks, called tokens. For instance, consider the program: `var a = 2;`. This program would likely be broken up into the following tokens: `var`, `a`, `=`, `2`, and `;`. Whitespace may or may not be persisted as a token, depending on whether it's meaningful or not.

   Note: The difference between tokenizing and lexing is subtle and academic, but it centers on whether or not these tokens are identified in a *stateless* or *stateful* way. Put simply, if the tokenizer were to invoke stateful parsing rules to figure out whether `a` should be considered a distinct token or just part of another token, *that* would be **lexing**.

2. **Parsing:** taking a stream (array) of tokens and turning it into a tree of nested elements, which collectively represent the grammatical structure of the program. This tree is called an "AST" (**A**bstract **S**yntax **T**ree).

   The tree for `var a = 2;` might start with a top-level node called `VariableDeclaration`, with a child node called `Identifier` (whose value is `a`), and another child called `AssignmentExpression` which itself has a child called `NumericLiteral` (whose value is `2`).

3. **Code-Generation:** the process of taking an AST and turning it into executable code. This part varies greatly depending on the language, the platform it's targeting, etc.

   So, rather than get mired in details, we'll just handwave and say that there's a way to take our above described AST for `var a = 2;` and turn it into a set of machine instructions to actually *create* a variable called `a` (including reserving memory, etc.), and then store a value into `a`.

   Note: The details of how the engine manages system resources are deeper than we will dig, so we'll just take it for granted that the engine is able to create and store variables as needed.

The JavaScript engine is vastly more complex than *just* those three steps, as are most other language compilers. For instance, in the process of parsing and code-generation, there are certainly steps to optimize the performance of the execution, including collapsing redundant elements, etc.

So, I'm painting only with broad strokes here. But I think you'll see shortly why *these* details we *do* cover, even at a high level, are relevant.

For one thing, JavaScript engines don't get the luxury (like other language compilers) of having plenty of time to optimize, because JavaScript compilation doesn't happen in a build step ahead of time, as with other languages.

For JavaScript, the compilation that occurs happens, in many cases, mere microseconds (or less!) before the code is executed. To ensure the fastest performance, JS engines use all kinds of tricks (like JITs, which lazy compile and even hot re-compile, etc.) which are well beyond the "scope" of our discussion here.

Let's just say, for simplicity's sake, that any snippet of JavaScript has to be compiled before (usually *right* before!) it's executed. So, the JS compiler will take the program `var a = 2;` and compile it *first*, and then be ready to execute it, usually right away.

Understanding Scope

The way we will approach learning about scope is to think of the process in terms of a conversation. But, *who* is having the conversation?

The Cast

Let's meet the cast of characters that interact to process the program `var a = 2;` , so we understand their conversations that we'll listen in on shortly:

1. *Engine*: responsible for start-to-finish compilation and execution of our JavaScript program.

2. *Compiler*: one of *Engine*'s friends; handles all the dirty work of parsing and code-generation (see previous section).

3. *Scope*: another friend of *Engine*; collects and maintains a look-up list of all the declared identifiers (variables), and enforces a strict set of rules as to how these are accessible to currently executing code.

For you to *fully understand* how JavaScript works, you need to begin to *think* like *Engine* (and friends) think, ask the questions they ask, and answer those questions the same.

Back & Forth

When you see the program `var a = 2;` , you most likely think of that as one statement. But that's not how our new friend *Engine* sees it. In fact, *Engine* sees two distinct statements, one which *Compiler* will handle during compilation, and one which *Engine* will handle during execution.

So, let's break down how *Engine* and friends will approach the program `var a = 2;` .

The first thing *Compiler* will do with this program is perform lexing to break it down into tokens, which it will then parse into a tree. But when *Compiler* gets to code-generation, it will treat this program somewhat differently than perhaps assumed.

A reasonable assumption would be that *Compiler* will produce code that could be summed up by this pseudo-code: "Allocate memory for a variable, label it `a` , then stick the value `2` into that variable." Unfortunately, that's not quite accurate.

Compiler will instead proceed as:

1. Encountering `var a` , *Compiler* asks *Scope* to see if a variable `a` already exists for that particular scope collection. If so, *Compiler* ignores this declaration and moves on. Otherwise, *Compiler* asks *Scope* to declare a new variable called `a` for that scope collection.

2. *Compiler* then produces code for *Engine* to later execute, to handle the `a = 2` assignment. The code *Engine* runs will first ask *Scope* if there is a variable called `a` accessible in the current scope collection. If so, *Engine* uses that variable. If not, *Engine* looks *elsewhere* (see nested *Scope* section below).

If *Engine* eventually finds a variable, it assigns the value `2` to it. If not, *Engine* will raise its hand and yell out an error!

To summarize: two distinct actions are taken for a variable assignment: First, *Compiler* declares a variable (if not previously declared in the current scope), and second, when executing, *Engine* looks up the variable in *Scope* and assigns to it, if found.

Compiler Speak

We need a little bit more compiler terminology to proceed further with understanding.

When *Engine* executes the code that *Compiler* produced for step (2), it has to look-up the variable `a` to see if it has been declared, and this look-up is consulting *Scope*. But the type of look-up *Engine* performs affects the outcome of the look-up.

In our case, it is said that *Engine* would be performing an "LHS" look-up for the variable `a`. The other type of look-up is called "RHS".

I bet you can guess what the "L" and "R" mean. These terms stand for "Left-hand Side" and "Right-hand Side".

Side... of what? **Of an assignment operation.**

In other words, an LHS look-up is done when a variable appears on the left-hand side of an assignment operation, and an RHS look-up is done when a variable appears on the right-hand side of an assignment operation.

Actually, let's be a little more precise. An RHS look-up is indistinguishable, for our purposes, from simply a look-up of the value of some variable, whereas the LHS look-up is trying to find the variable container itself, so that it can assign. In this way, RHS doesn't *really* mean "right-hand side of an assignment" per se, it just, more accurately, means "not left-hand side".

Being slightly glib for a moment, you could also think "RHS" instead means "retrieve his/her source (value)", implying that RHS means "go get the value of...".

Let's dig into that deeper.

When I say:

```
console.log( a );
```

The reference to `a` is an RHS reference, because nothing is being assigned to `a` here. Instead, we're looking-up to retrieve the value of `a`, so that the value can be passed to `console.log(..)`.

By contrast:

```
a = 2;
```

The reference to `a` here is an LHS reference, because we don't actually care what the current value is, we simply want to find the variable as a target for the `= 2` assignment operation.

Note: LHS and RHS meaning "left/right-hand side of an assignment" doesn't necessarily literally mean "left/right side of the `=` assignment operator". There are several other ways that assignments happen, and so it's better to conceptually think about it as: "who's the target of the assignment (LHS)" and "who's the source of the assignment (RHS)".

Consider this program, which has both LHS and RHS references:

```
function foo(a) {
	console.log( a ); // 2
}

foo( 2 );
```

The last line that invokes `foo(..)` as a function call requires an RHS reference to `foo`, meaning, "go look-up the value of `foo`, and give it to me." Moreover, `(..)` means the value of `foo` should be executed, so it'd better actually be a function!

There's a subtle but important assignment here. **Did you spot it?**

You may have missed the implied `a = 2` in this code snippet. It happens when the value `2` is passed as an argument to the `foo(..)` function, in which case the `2` value is **assigned** to the parameter `a`. To (implicitly) assign to parameter `a`, an LHS look-up is performed.

There's also an RHS reference for the value of `a`, and that resulting value is passed to `console.log(..)`. `console.log(..)` needs a reference to execute. It's an RHS look-up for the `console` object, then a property-resolution occurs to see if it has a method called `log`.

Finally, we can conceptualize that there's an LHS/RHS exchange of passing the value `2` (by way of variable `a`'s RHS look-up) into `log(..)`. Inside of the native implementation of `log(..)`, we can assume it has parameters, the first of which (perhaps called `arg1`) has an LHS reference look-up, before assigning `2` to it.

Note: You might be tempted to conceptualize the function declaration `function foo(a) {...` as a normal variable declaration and assignment, such as `var foo` and `foo = function(a){...`. In so doing, it would be tempting to think of this function declaration as involving an LHS look-up.

However, the subtle but important difference is that *Compiler* handles both the declaration and the value definition during code-generation, such that when *Engine* is executing code, there's no processing necessary to "assign" a function value to `foo`. Thus, it's not really appropriate to think of a function declaration as an LHS look-up assignment in the way we're discussing them here.

Engine/Scope Conversation

```
function foo(a) {
	console.log( a ); // 2
}

foo( 2 );
```

Let's imagine the above exchange (which processes this code snippet) as a conversation. The conversation would go a little something like this:

> ***Engine***: Hey *Scope*, I have an RHS reference for `foo`. Ever heard of it?

> ***Scope***: Why yes, I have. *Compiler* declared it just a second ago. He's a function. Here you go.

> ***Engine***: Great, thanks! OK, I'm executing `foo`.

> ***Engine***: Hey, *Scope*, I've got an LHS reference for `a`, ever heard of it?

> ***Scope***: Why yes, I have. *Compiler* declared it as a formal parameter to `foo` just recently. Here you go.

> ***Engine***: Helpful as always, *Scope*. Thanks again. Now, time to assign `2` to `a`.

> ***Engine***: Hey, *Scope*, sorry to bother you again. I need an RHS look-up for `console`. Ever heard of it?

> ***Scope***: No problem, *Engine*, this is what I do all day. Yes, I've got `console`. He's built-in. Here ya go.

> ***Engine***: Perfect. Looking up `log(..)`. OK, great, it's a function.

> ***Engine***: Yo, *Scope*. Can you help me out with an RHS reference to `a`. I think I remember it, but just want to double-check.

> ***Scope***: You're right, *Engine*. Same guy, hasn't changed. Here ya go.

> ***Engine***: Cool. Passing the value of `a`, which is `2`, into `log(..)`.

> ...

Quiz

Check your understanding so far. Make sure to play the part of *Engine* and have a "conversation" with the *Scope*:

```js
function foo(a) {
	var b = a;
	return a + b;
}

var c = foo( 2 );
```

1. Identify all the LHS look-ups (there are 3!).

2. Identify all the RHS look-ups (there are 4!).

Note: See the chapter review for the quiz answers!

Nested Scope

We said that *Scope* is a set of rules for looking up variables by their identifier name. There's usually more than one *Scope* to consider, however.

Just as a block or function is nested inside another block or function, scopes are nested inside other scopes. So, if a variable cannot be found in the immediate scope, *Engine* consults the next outer containing scope, continuing until found or until the outermost (aka, global) scope has been reached.

Consider:

```
function foo(a) {
	console.log( a + b );
}

var b = 2;

foo( 2 ); // 4
```

The RHS reference for `b` cannot be resolved inside the function `foo`, but it can be resolved in the *Scope* surrounding it (in this case, the global).

So, revisiting the conversations between *Engine* and *Scope*, we'd overhear:

> ***Engine***: "Hey, *Scope* of `foo`, ever heard of `b`? Got an RHS reference for it."

> ***Scope***: "Nope, never heard of it. Go fish."

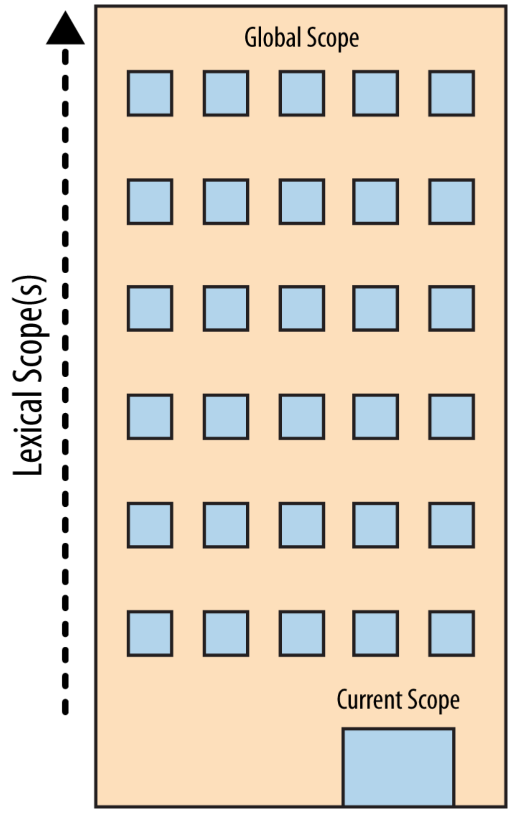
> ***Engine***: "Hey, *Scope* outside of `foo`, oh you're the global *Scope*, ok cool. Ever heard of `b`? Got an RHS reference for it."

> ***Scope***: "Yep, sure have. Here ya go."

The simple rules for traversing nested *Scope*: *Engine* starts at the currently executing *Scope*, looks for the variable there, then if not found, keeps going up one level, and so on. If the outermost global scope is reached, the search stops, whether it finds the variable or not.

Building on Metaphors

To visualize the process of nested *Scope* resolution, I want you to think of this tall building.



The building represents our program's nested *Scope* rule set. The first floor of the building represents your currently executing *Scope*, wherever you are. The top level of the building is the global *Scope*.

You resolve LHS and RHS references by looking on your current floor, and if you don't find it, taking the elevator to the next floor, looking there, then the next, and so on. Once you get to the top floor (the global *Scope*), you either find what you're looking for, or you don't. But you have to stop regardless.

Errors

Why does it matter whether we call it LHS or RHS?

Because these two types of look-ups behave differently in the circumstance where the variable has not yet been declared (is not found in any consulted *Scope*).

Consider:

```
function foo(a) {
	console.log( a + b );
	b = a;
}

foo( 2 );
```

When the RHS look-up occurs for `b` the first time, it will not be found. This is said to be an "undeclared" variable, because it is not found in the scope.

If an RHS look-up fails to ever find a variable, anywhere in the nested *Scope*s, this results in a `ReferenceError` being thrown by the *Engine*. It's important to note that the error is of the type `ReferenceError` .

By contrast, if the *Engine* is performing an LHS look-up and arrives at the top floor (global *Scope*) without finding it, and if the program is not running in "Strict Mode" [^note-strictmode], then the global *Scope* will create a new variable of that name **in the global scope**, and hand it back to *Engine*.

"*No, there wasn't one before, but I was helpful and created one for you.*"

"Strict Mode" [^note-strictmode], which was added in ES5, has a number of different behaviors from normal/relaxed/lazy mode. One such behavior is that it disallows the automatic/implicit global variable creation. In that case, there would be no global *Scope*'d variable to hand back from an LHS look-up, and *Engine* would throw a `ReferenceError` similarly to the RHS case.

Now, if a variable is found for an RHS look-up, but you try to do something with its value that is impossible, such as trying to execute-as-function a non-function value, or reference a property on a `null` or `undefined` value, then *Engine* throws a different kind of error, called a `TypeError`.

`ReferenceError` is *Scope* resolution-failure related, whereas `TypeError` implies that *Scope* resolution was successful, but that there was an illegal/impossible action attempted against the result.

Review (TL;DR)

Scope is the set of rules that determines where and how a variable (identifier) can be looked-up. This look-up may be for the purposes of assigning to the variable, which is an LHS (left-hand-side) reference, or it may be for the purposes of retrieving its value, which is an RHS (right-hand-side) reference.

LHS references result from assignment operations. *Scope*-related assignments can occur either with the `=` operator or by passing arguments to (assign to) function parameters.

The JavaScript *Engine* first compiles code before it executes, and in so doing, it splits up statements like `var a = 2;` into two separate steps:

1. First, `var a` to declare it in that *Scope*. This is performed at the beginning, before code execution.

2. Later, `a = 2` to look up the variable (LHS reference) and assign to it if found.

Both LHS and RHS reference look-ups start at the currently executing *Scope*, and if need be (that is, they don't find what they're looking for there), they work their way up the nested *Scope*, one scope (floor) at a time, looking for the identifier, until they get to the global (top floor) and stop, and either find it, or don't.

Unfulfilled RHS references result in `ReferenceError`s being thrown. Unfulfilled LHS references result in an automatic, implicitly-created global of that name (if not in "Strict Mode" [^note-strictmode]), or a `ReferenceError` (if in "Strict Mode" [^note-strictmode]).

Quiz Answers

```js
function foo(a) {
	var b = a;
	return a + b;
}

var c = foo( 2 );
```

1. Identify all the LHS look-ups (there are 3!).

   `c = ..`, `a = 2` (implicit param assignment) and `b = ..`

2. Identify all the RHS look-ups (there are 4!).

   `foo(2..`, `= a;`, `a + ..` and `.. + b`

[^note-strictmode]: MDN: Strict Mode

You Don't Know JS Yet: Scope & Closures - 2nd Edition

Chapter 2: Lexical Scope

NOTE:
Work in progress

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In Chapter 1, we defined "scope" as the set of rules that govern how the *Engine* can look up a variable by its identifier name and find it, either in the current *Scope*, or in any of the *Nested Scopes* it's contained within.

There are two predominant models for how scope works. The first of these is by far the most common, used by the vast majority of programming languages. It's called **Lexical Scope**, and we will examine it in-depth. The other model, which is still used by some languages (such as Bash scripting, some modes in Perl, etc.) is called **Dynamic Scope**.

Dynamic Scope is covered in Appendix A. I mention it here only to provide a contrast with Lexical Scope, which is the scope model that JavaScript employs.

Lex-time

As we discussed in Chapter 1, the first traditional phase of a standard language compiler is called lexing (aka, tokenizing). If you recall, the lexing process examines a string of source code characters and assigns semantic meaning to the tokens as a result of some stateful parsing.

It is this concept which provides the foundation to understand what lexical scope is and where the name comes from.

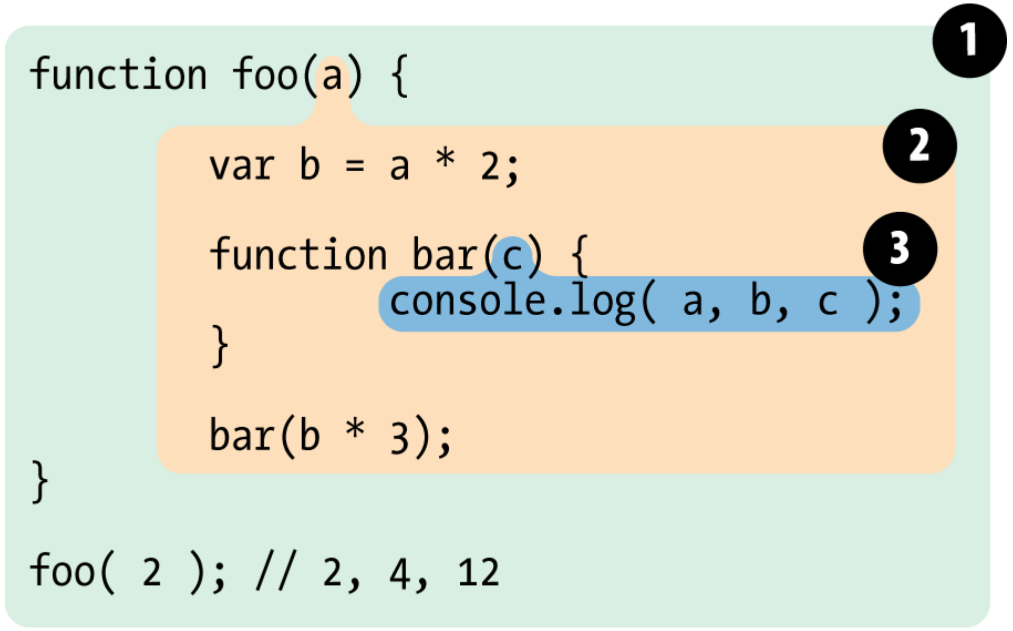
To define it somewhat circularly, lexical scope is scope that is defined at lexing time. In other words, lexical scope is based on where variables and blocks of scope are authored, by you, at write time, and thus is (mostly) set in stone by the time the lexer processes your code.

Note: We will see in a little bit there are some ways to cheat lexical scope, thereby modifying it after the lexer has passed by, but these are frowned upon. It is considered best practice to treat lexical scope as, in fact, lexical-only, and thus entirely author-time in nature.

Let's consider this block of code:

```
function foo(a) {

	var b = a * 2;

	function bar(c) {
		console.log( a, b, c );
	}

	bar(b * 3);
}

foo( 2 ); // 2 4 12
```

There are three nested scopes inherent in this code example. It may be helpful to think about these scopes as bubbles inside of each other.



```
function foo(a) {
	var b = a * 2;

	function bar(c) {
		console.log( a, b, c );
	}

	bar(b * 3);
}

foo( 2 ); // 2, 4, 12
```

Bubble 1 encompasses the global scope, and has just one identifier in it: `foo` .

Bubble 2 encompasses the scope of `foo` , which includes the three identifiers: `a` , `bar` and `b` .

Bubble 3 encompasses the scope of `bar` , and it includes just one identifier: `c` .

Scope bubbles are defined by where the blocks of scope are written, which one is nested inside the other, etc. In the next chapter, we'll discuss different units of scope, but for now, let's just assume that each function creates a new bubble of scope.

The bubble for `bar` is entirely contained within the bubble for `foo` , because (and only because) that's where we chose to define the function `bar` .

Notice that these nested bubbles are strictly nested. We're not talking about Venn diagrams where the bubbles can cross boundaries. In other words, no bubble for some function can simultaneously exist (partially) inside two other outer scope bubbles, just as no function can partially be inside each of two parent functions.

Look-ups

The structure and relative placement of these scope bubbles fully explains to the *Engine* all the places it needs to look to find an identifier.

In the above code snippet, the *Engine* executes the `console.log(..)` statement and goes looking for the three referenced variables `a`, `b`, and `c`. It first starts with the innermost scope bubble, the scope of the `bar(..)` function. It won't find `a` there, so it goes up one level, out to the next nearest scope bubble, the scope of `foo(..)`. It finds `a` there, and so it uses that `a`. Same thing for `b`. But `c`, it does find inside of `bar(..)`.

Had there been a `c` both inside of `bar(..)` and inside of `foo(..)`, the `console.log(..)` statement would have found and used the one in `bar(..)`, never getting to the one in `foo(..)`.

Scope look-up stops once it finds the first match. The same identifier name can be specified at multiple layers of nested scope, which is called "shadowing" (the inner identifier "shadows" the outer identifier). Regardless of shadowing, scope look-up always starts at the innermost scope being executed at the time, and works its way outward/upward until the first match, and stops.

Note: Global variables are also automatically properties of the global object (`window` in browsers, etc.), so it *is* possible to reference a global variable not directly by its lexical name, but instead indirectly as a property reference of the global object.

```
window.a
```

This technique gives access to a global variable which would otherwise be inaccessible due to it being shadowed. However, non-global shadowed variables cannot be accessed.

No matter *where* a function is invoked from, or even *how* it is invoked, its lexical scope is **only** defined by where the function was declared.

The lexical scope look-up process *only* applies to first-class identifiers, such as the `a`, `b`, and `c`. If you had a reference to `foo.bar.baz` in a piece of code, the lexical scope look-up would apply to finding the `foo` identifier, but once it locates that variable, object property-access rules take over to resolve the `bar` and `baz` properties, respectively.

Cheating Lexical

If lexical scope is defined only by where a function is declared, which is entirely an author-time decision, how could there possibly be a way to "modify" (aka, cheat) lexical scope at run-time?

JavaScript has two such mechanisms. Both of them are equally frowned-upon in the wider community as bad practices to use in your code. But the typical arguments against them are often missing the most important point: **cheating lexical scope leads to poorer performance.**

Before I explain the performance issue, though, let's look at how these two mechanisms work.

`eval`

The `eval(..)` function in JavaScript takes a string as an argument, and treats the contents of the string as if it had actually been authored code at that point in the program. In other words, you can programmatically generate code inside of your authored code, and run the generated code as if it had been there at author time.

Evaluating `eval(..)` (pun intended) in that light, it should be clear how `eval(..)` allows you to modify the lexical scope environment by cheating and pretending that author-time (aka, lexical) code was there all along.

On subsequent lines of code after an `eval(..)` has executed, the *Engine* will not "know" or "care" that the previous code in question was dynamically interpreted and thus modified the lexical scope environment. The *Engine* will simply perform its lexical scope look-ups as it always does.

Consider the following code:

```js
function foo(str, a) {
	eval( str ); // cheating!
	console.log( a, b );
}

var b = 2;

foo( "var b = 3;", 1 ); // 1 3
```

The string `"var b = 3;"` is treated, at the point of the `eval(..)` call, as code that was there all along. Because that code happens to declare a new variable `b`, it modifies the existing lexical scope of `foo(..)`. In fact, as mentioned above, this code actually creates variable `b` inside of `foo(..)` that shadows the `b` that was declared in the outer (global) scope.

When the `console.log(..)` call occurs, it finds both `a` and `b` in the scope of `foo(..)`, and never finds the outer `b`. Thus, we print out "1 3" instead of "1 2" as would have normally been the case.

Note: In this example, for simplicity's sake, the string of "code" we pass in was a fixed literal. But it could easily have been programmatically created by adding characters together based on your program's logic. `eval(..)` is usually used to execute dynamically created code, as dynamically evaluating essentially static code from a string literal would provide no real benefit to just authoring the code directly.

By default, if a string of code that `eval(..)` executes contains one or more declarations (either variables or functions), this action modifies the existing lexical scope in which the `eval(..)` resides. Technically, `eval(..)` can be invoked "indirectly", through various tricks (beyond our discussion here), which causes it to instead execute in the context of the global scope, thus modifying it. But in either case, `eval(..)` can at runtime modify an author-time lexical scope.

Note: `eval(..)` when used in a strict-mode program operates in its own lexical scope, which means declarations made inside of the `eval()` do not actually modify the enclosing scope.

```
function foo(str) {
   "use strict";
   eval( str );
   console.log( a ); // ReferenceError: a is not defined
}

foo( "var a = 2" );
```

There are other facilities in JavaScript which amount to a very similar effect to `eval(..)`. `setTimeout(..)` and `setInterval(..)` *can* take a string for their respective first argument, the contents of which are `eval`uated as the code of a dynamically-generated function. This is old, legacy behavior and long-since deprecated. Don't do it!

The `new Function(..)` function constructor similarly takes a string of code in its **last** argument to turn into a dynamically-generated function (the first argument(s), if any, are the named parameters for the new function). This function-constructor syntax is slightly safer than `eval(..)`, but it should still be avoided in your code.

The use-cases for dynamically generating code inside your program are incredibly rare, as the performance degradations are almost never worth the capability.

`with`

The other frowned-upon (and now deprecated!) feature in JavaScript which cheats lexical scope is the `with` keyword. There are multiple valid ways that `with` can be explained, but I will choose here to explain it from the perspective of how it interacts with and affects lexical scope.

`with` is typically explained as a short-hand for making multiple property references against an object *without* repeating the object reference itself each time.

For example:

```
var obj = {
        a: 1,
        b: 2,
        c: 3
};

// more "tedious" to repeat "obj"
obj.a = 2;
obj.b = 3;
obj.c = 4;

// "easier" short-hand
with (obj) {
        a = 3;
        b = 4;
        c = 5;
}
```

However, there's much more going on here than just a convenient short-hand for object property access. Consider:

```
function foo(obj) {
        with (obj) {
                a = 2;
        }
}

var o1 = {
        a: 3
};

var o2 = {
        b: 3
};

foo( o1 );
```

```js
console.log( o1.a ); // 2

foo( o2 );
console.log( o2.a ); // undefined
console.log( a ); // 2 -- Oops, leaked global!
```

In this code example, two objects `o1` and `o2` are created. One has an `a` property, and the other does not. The `foo(..)` function takes an object reference `obj` as an argument, and calls `with (obj) { .. }` on the reference. Inside the `with` block, we make what appears to be a normal lexical reference to a variable `a`, an LHS reference in fact (see Chapter 1), to assign to it the value of `2`.

When we pass in `o1`, the `a = 2` assignment finds the property `o1.a` and assigns it the value `2`, as reflected in the subsequent `console.log(o1.a)` statement. However, when we pass in `o2`, since it does not have an `a` property, no such property is created, and `o2.a` remains `undefined`.

But then we note a peculiar side-effect, the fact that a global variable `a` was created by the `a = 2` assignment. How can this be?

The `with` statement takes an object, one which has zero or more properties, and **treats that object as if *it* is a wholly separate lexical scope**, and thus the object's properties are treated as lexically defined identifiers in that "scope".

Note: Even though a `with` block treats an object like a lexical scope, a normal `var` declaration inside that `with` block will not be scoped to that `with` block, but instead the containing function scope.

While the `eval(..)` function can modify existing lexical scope if it takes a string of code with one or more declarations in it, the `with` statement actually creates a **whole new lexical scope** out of thin air, from the object you pass to it.

Understood in this way, the "scope" declared by the `with` statement when we passed in `o1` was `o1`, and that "scope" had an "identifier" in it which corresponds to the `o1.a` property. But when we used `o2` as the "scope", it had no such `a` "identifier" in it, and so the normal rules of LHS identifier look-up (see Chapter 1) occurred.

Neither the "scope" of `o2`, nor the scope of `foo(..)`, nor the global scope even, has an `a` identifier to be found, so when `a = 2` is executed, it results in the automatic-global being created (since we're in non-strict mode).

It is a strange sort of mind-bending thought to see `with` turning, at runtime, an object and its properties into a "scope" *with* "identifiers". But that is the clearest explanation I can give for the results we see.

Note: In addition to being a bad idea to use, both `eval(..)` and `with` are affected (restricted) by Strict Mode. `with` is outright disallowed, whereas various forms of indirect or unsafe `eval(..)` are disallowed while retaining the core functionality.

Performance

Both `eval(..)` and `with` cheat the otherwise author-time defined lexical scope by modifying or creating new lexical scope at runtime.

So, what's the big deal, you ask? If they offer more sophisticated functionality and coding flexibility, aren't these *good* features? **No.**

The JavaScript *Engine* has a number of performance optimizations that it performs during the compilation phase. Some of these boil down to being able to essentially statically analyze the code as it lexes, and pre-determine where all the variable and function declarations are, so that it takes less effort to resolve identifiers during execution.

But if the *Engine* finds an `eval(..)` or `with` in the code, it essentially has to *assume* that all its awareness of identifier location may be invalid, because it cannot know at lexing time exactly what code you may pass to `eval(..)` to modify the lexical scope, or the contents of the object you may pass to `with` to create a new lexical scope to be consulted.

In other words, in the pessimistic sense, most of those optimizations it *would* make are pointless if `eval(..)` or `with` are present, so it simply doesn't perform the optimizations *at all*.

Your code will almost certainly tend to run slower simply by the fact that you include an `eval(..)` or `with` anywhere in the code. No matter how smart the *Engine* may be about trying to limit the side-effects of these pessimistic assumptions, **there's no getting around the fact that without the optimizations, code runs slower.**

Review (TL;DR)

Lexical scope means that scope is defined by author-time decisions of where functions are declared. The lexing phase of compilation is essentially able to know where and how all identifiers are declared, and thus predict how they will be looked-up during execution.

Two mechanisms in JavaScript can "cheat" lexical scope: `eval(..)` and `with`. The former can modify existing lexical scope (at runtime) by evaluating a string of "code" which has one or more declarations in it. The latter essentially creates a whole new lexical scope (again, at runtime) by treating an object reference *as* a "scope" and that object's properties as scoped identifiers.

The downside to these mechanisms is that it defeats the *Engine*'s ability to perform compile-time optimizations regarding scope look-up, because the *Engine* has to assume pessimistically that such optimizations will be invalid. Code *will* run slower as a result of using either feature. **Don't use them.**

You Don't Know JS Yet: Scope & Closures - 2nd Edition

Chapter 3: Function vs. Block Scope

NOTE:
Work in progress

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As we explored in Chapter 2, scope consists of a series of "bubbles" that each act as a container or bucket, in which identifiers (variables, functions) are declared. These bubbles nest neatly inside each other, and this nesting is defined at author-time.

But what exactly makes a new bubble? Is it only the function? Can other structures in JavaScript create bubbles of scope?

Scope From Functions

The most common answer to those questions is that JavaScript has function-based scope. That is, each function you declare creates a bubble for itself, but no other structures create their own scope bubbles. As we'll see in just a little bit, this is not quite true.

But first, let's explore function scope and its implications.

Consider this code:

```
function foo(a) {
	var b = 2;

	// some code

	function bar() {
		// ...
```

```
        }

        // more code

        var c = 3;
}
```

In this snippet, the scope bubble for `foo(..)` includes identifiers `a`, `b`, `c` and `bar`. **It doesn't matter** *where* in the scope a declaration appears, the variable or function belongs to the containing scope bubble, regardless. We'll explore how exactly *that* works in the next chapter.

`bar(..)` has its own scope bubble. So does the global scope, which has just one identifier attached to it: `foo`.

Because `a`, `b`, `c`, and `bar` all belong to the scope bubble of `foo(..)`, they are not accessible outside of `foo(..)`. That is, the following code would all result in `ReferenceError` errors, as the identifiers are not available to the global scope:

```
bar(); // fails

console.log( a, b, c ); // all 3 fail
```

However, all these identifiers (`a`, `b`, `c`, `foo`, and `bar`) are accessible *inside* of `foo(..)`, and indeed also available inside of `bar(..)` (assuming there are no shadow identifier declarations inside `bar(..)`).

Function scope encourages the idea that all variables belong to the function, and can be used and reused throughout the entirety of the function (and indeed, accessible even to nested scopes). This design approach can be quite useful, and certainly can make full use of the "dynamic" nature of JavaScript variables to take on values of different types as needed.

On the other hand, if you don't take careful precautions, variables existing across the entirety of a scope can lead to some unexpected pitfalls.

Hiding In Plain Scope

The traditional way of thinking about functions is that you declare a function, and then add code inside it. But the inverse thinking is equally powerful and useful: take any arbitrary section of code you've written, and wrap a function declaration around it, which in effect "hides" the code.

The practical result is to create a scope bubble around the code in question, which means that any declarations (variable or function) in that code will now be tied to the scope of the new wrapping function, rather than the previously enclosing scope. In other words, you can "hide" variables and functions by enclosing them in the scope of a function.

Why would "hiding" variables and functions be a useful technique?

There's a variety of reasons motivating this scope-based hiding. They tend to arise from the software design principle "Principle of Least Privilege" [^note-leastprivilege], also sometimes called "Least Authority" or "Least Exposure". This principle states that in the design of software, such as the API for a module/object, you should expose only what is minimally necessary, and "hide" everything else.

This principle extends to the choice of which scope to contain variables and functions. If all variables and functions were in the global scope, they would of course be accessible to any nested scope. But this would violate the "Least..." principle in that you are (likely) exposing many variables or functions which you should otherwise keep private, as proper use of the code would discourage access to those variables/functions.

For example:

```
function doSomething(a) {
	b = a + doSomethingElse( a * 2 );

	console.log( b * 3 );
}

function doSomethingElse(a) {
	return a - 1;
}

var b;
```

```
doSomething( 2 ); // 15
```

In this snippet, the `b` variable and the `doSomethingElse(..)` function are likely "private" details of how `doSomething(..)` does its job. Giving the enclosing scope "access" to `b` and `doSomethingElse(..)` is not only unnecessary but also possibly "dangerous", in that they may be used in unexpected ways, intentionally or not, and this may violate pre-condition assumptions of `doSomething(..)`.

A more "proper" design would hide these private details inside the scope of `doSomething(..)`, such as:

```
function doSomething(a) {
	function doSomethingElse(a) {
		return a - 1;
	}

	var b;

	b = a + doSomethingElse( a * 2 );

	console.log( b * 3 );
}

doSomething( 2 ); // 15
```

Now, `b` and `doSomethingElse(..)` are not accessible to any outside influence, instead controlled only by `doSomething(..)`. The functionality and end-result has not been affected, but the design keeps private details private, which is usually considered better software.

Collision Avoidance

Another benefit of "hiding" variables and functions inside a scope is to avoid unintended collision between two different identifiers with the same name but different intended usages. Collision results often in unexpected overwriting of values.

For example:

```
function foo() {
	function bar(a) {
		i = 3; // changing the `i` in the enclosing scope's for-loop
		console.log( a + i );
	}

	for (var i=0; i<10; i++) {
		bar( i * 2 ); // oops, infinite loop ahead!
	}
}

foo();
```

The `i = 3` assignment inside of `bar(..)` overwrites, unexpectedly, the `i` that was declared in `foo(..)` at the for-loop. In this case, it will result in an infinite loop, because `i` is set to a fixed value of `3` and that will forever remain `< 10`.

The assignment inside `bar(..)` needs to declare a local variable to use, regardless of what identifier name is chosen. `var i = 3;` would fix the problem (and would create the previously mentioned "shadowed variable" declaration for `i`). An *additional*, not alternate, option is to pick another identifier name entirely, such as `var j = 3;`. But your software design may naturally call for the same identifier name, so utilizing scope to "hide" your inner declaration is your best/only option in that case.

Global "Namespaces"

A particularly strong example of (likely) variable collision occurs in the global scope. Multiple libraries loaded into your program can quite easily collide with each other if they don't properly hide their internal/private functions and variables.

Such libraries typically will create a single variable declaration, often an object, with a sufficiently unique name, in the global scope. This object is then used as a "namespace" for that library, where all specific exposures of functionality are made as properties of that object (namespace), rather than as top-level lexically scoped identifiers themselves.

For example:

```
var MyReallyCoolLibrary = {
	awesome: "stuff",
	doSomething: function() {
		// ...
	},
	doAnotherThing: function() {
		// ...
	}
};
```

Module Management

Another option for collision avoidance is the more modern "module" approach, using any of various dependency managers. Using these tools, no libraries ever add any identifiers to the global scope, but are instead required to have their identifier(s) be explicitly imported into another specific scope through usage of the dependency manager's various mechanisms.

It should be observed that these tools do not possess "magic" functionality that is exempt from lexical scoping rules. They simply use the rules of scoping as explained here to enforce that no identifiers are injected into any shared scope, and are instead kept in private, non-collision-susceptible scopes, which prevents any accidental scope collisions.

As such, you can code defensively and achieve the same results as the dependency managers do without actually needing to use them, if you so choose. See the Chapter 5 for more information about the module pattern.

Functions As Scopes

We've seen that we can take any snippet of code and wrap a function around it, and that effectively "hides" any enclosed variable or function declarations from the outside scope inside that function's inner scope.

For example:

```
var a = 2;

function foo() { // <-- insert this

        var a = 3;
        console.log( a ); // 3

} // <-- and this
foo(); // <-- and this

console.log( a ); // 2
```

While this technique "works", it is not necessarily very ideal. There are a few problems it introduces. The first is that we have to declare a named-function `foo()` , which means that the identifier name `foo` itself "pollutes" the enclosing scope (global, in this case). We also have to explicitly call the function by name (`foo()`) so that the wrapped code actually executes.

It would be more ideal if the function didn't need a name (or, rather, the name didn't pollute the enclosing scope), and if the function could automatically be executed.

Fortunately, JavaScript offers a solution to both problems.

```
var a = 2;

(function foo(){ // <-- insert this

        var a = 3;
        console.log( a ); // 3

})(); // <-- and this

console.log( a ); // 2
```

Let's break down what's happening here.

First, notice that the wrapping function statement starts with `(function...` as opposed to just `function...`. While this may seem like a minor detail, it's actually a major change. Instead of treating the function as a standard declaration, the function is treated as a function-expression.

Note: The easiest way to distinguish declaration vs. expression is the position of the word "function" in the statement (not just a line, but a distinct statement). If "function" is the very first thing in the statement, then it's a function declaration. Otherwise, it's a function expression.

The key difference we can observe here between a function declaration and a function expression relates to where its name is bound as an identifier.

Compare the previous two snippets. In the first snippet, the name `foo` is bound in the enclosing scope, and we call it directly with `foo()`. In the second snippet, the name `foo` is not bound in the enclosing scope, but instead is bound only inside of its own function.

In other words, `(function foo(){ .. })` as an expression means the identifier `foo` is found *only* in the scope where the `..` indicates, not in the outer scope. Hiding the name `foo` inside itself means it does not pollute the enclosing scope unnecessarily.

Anonymous vs. Named

You are probably most familiar with function expressions as callback parameters, such as:

```
setTimeout( function(){
	console.log("I waited 1 second!");
}, 1000 );
```

This is called an "anonymous function expression", because `function()...` has no name identifier on it. Function expressions can be anonymous, but function declarations cannot omit the name -- that would be illegal JS grammar.

Anonymous function expressions are quick and easy to type, and many libraries and tools tend to encourage this idiomatic style of code. However, they have several draw-backs to consider:

1. Anonymous functions have no useful name to display in stack traces, which can make debugging more difficult.
2. Without a name, if the function needs to refer to itself, for recursion, etc., the **deprecated** `arguments.callee` reference is unfortunately required. Another example of needing to self-reference is when an event handler function wants to unbind itself after it fires.
3. Anonymous functions omit a name that is often helpful in providing more readable/understandable code. A descriptive name helps self-document the code in question.

Inline function expressions are powerful and useful -- the question of anonymous vs. named doesn't detract from that. Providing a name for your function expression quite effectively addresses all these draw-backs, but has no tangible downsides. The best practice is to always name your function expressions:

```
setTimeout( function timeoutHandler(){ // <-- Look, I have a name!
	console.log( "I waited 1 second!" );
}, 1000 );
```

Invoking Function Expressions Immediately

```
var a = 2;

(function foo(){

	var a = 3;
	console.log( a ); // 3

})();

console.log( a ); // 2
```

Now that we have a function as an expression by virtue of wrapping it in a `( )` pair, we can execute that function by adding another `()` on the end, like `(function foo(){ .. })()`. The first enclosing `( )` pair makes the function an expression, and the second `()` executes the function.

This pattern is so common, a few years ago the community agreed on a term for it: **IIFE**, which stands for **I**mmediately **I**nvoked **F**unction **E**xpression.

Of course, IIFE's don't need names, necessarily -- the most common form of IIFE is to use an anonymous function expression. While certainly less common, naming an IIFE has all the aforementioned benefits over anonymous function expressions, so it's a good practice to adopt.

```
var a = 2;

(function IIFE(){

	var a = 3;
	console.log( a ); // 3

})();

console.log( a ); // 2
```

There's a slight variation on the traditional IIFE form, which some prefer: `(function(){ .. }())`. Look closely to see the difference. In the first form, the function expression is wrapped in `( )`, and then the invoking `()` pair is on the outside right after it. In the second form, the invoking `()` pair is moved to the inside of the outer `( )` wrapping pair.

These two forms are identical in functionality. **It's purely a stylistic choice which you prefer.**

Another variation on IIFE's which is quite common is to use the fact that they are, in fact, just function calls, and pass in argument(s).

For instance:

```
var a = 2;

(function IIFE( global ){

	var a = 3;
	console.log( a ); // 3
	console.log( global.a ); // 2

})( window );

console.log( a ); // 2
```

We pass in the `window` object reference, but we name the parameter `global`, so that we have a clear stylistic delineation for global vs. non-global references. Of course, you can pass in anything from an enclosing scope you want, and you can name the parameter(s) anything that suits you. This is mostly just stylistic choice.

Another application of this pattern addresses the (minor niche) concern that the default `undefined` identifier might have its value incorrectly overwritten, causing unexpected results. By naming a parameter `undefined`, but not passing any value for that argument, we can guarantee that the `undefined` identifier is in fact the undefined value in a block of code:

```
undefined = true; // setting a land-mine for other code! avoid!

(function IIFE( undefined ){

	var a;
	if (a === undefined) {
		console.log( "Undefined is safe here!" );
	}

})();
```

Still another variation of the IIFE inverts the order of things, where the function to execute is given second, *after* the invocation and parameters to pass to it. This pattern is used in the UMD (Universal Module Definition) project. Some people find it a little cleaner to understand, though it is slightly more verbose.

```
var a = 2;

(function IIFE( def ){
	def( window );
})(function def( global ){

	var a = 3;
	console.log( a ); // 3
	console.log( global.a ); // 2

});
```

The `def` function expression is defined in the second-half of the snippet, and then passed as a parameter (also called `def`) to the `IIFE` function defined in the first half of the snippet. Finally, the parameter `def` (the function) is invoked, passing `window` in as the `global` parameter.

Blocks As Scopes

While functions are the most common unit of scope, and certainly the most wide-spread of the design approaches in the majority of JS in circulation, other units of scope are possible, and the usage of these other scope units can lead to even better, cleaner to maintain code.

Many languages other than JavaScript support Block Scope, and so developers from those languages are accustomed to the mindset, whereas those who've primarily only worked in JavaScript may find the concept slightly foreign.

But even if you've never written a single line of code in block-scoped fashion, you are still probably familiar with this extremely common idiom in JavaScript:

```js
for (var i=0; i<10; i++) {
	console.log( i );
}
```

We declare the variable `i` directly inside the for-loop head, most likely because our *intent* is to use `i` only within the context of that for-loop, and essentially ignore the fact that the variable actually scopes itself to the enclosing scope (function or global).

That's what block-scoping is all about. Declaring variables as close as possible, as local as possible, to where they will be used. Another example:

```js
var foo = true;

if (foo) {
	var bar = foo * 2;
	bar = something( bar );
	console.log( bar );
}
```

We are using a `bar` variable only in the context of the if-statement, so it makes a kind of sense that we would declare it inside the if-block. However, where we declare variables is not relevant when using `var`, because they will always belong to the enclosing scope. This snippet is essentially "fake" block-scoping, for stylistic reasons, and relying on self-enforcement not to accidentally use `bar` in another place in that scope.

Block scope is a tool to extend the earlier "Principle of Least ~~Privilege~~ Exposure" [^note-leastprivilege] from hiding information in functions to hiding information in blocks of our code.

Consider the for-loop example again:

```js
for (var i=0; i<10; i++) {
	console.log( i );
}
```

Why pollute the entire scope of a function with the `i` variable that is only going to be (or only *should be*, at least) used for the for-loop?

But more importantly, developers may prefer to *check* themselves against accidentally (re)using variables outside of their intended purpose, such as being issued an error about an unknown variable if you try to use it in the wrong place. Block-scoping (if it were possible) for the `i` variable would make `i` available only for the for-loop, causing an error if `i` is accessed elsewhere in the function. This helps ensure variables are not re-used in confusing or hard-to-maintain ways.

But, the sad reality is that, on the surface, JavaScript has no facility for block scope.

That is, until you dig a little further.

`with`

We learned about `with` in Chapter 2. While it is a frowned upon construct, it *is* an example of (a form of) block scope, in that the scope that is created from the object only exists for the lifetime of that `with` statement, and not in the enclosing scope.

`try/catch`

It's a *very* little known fact that JavaScript in ES3 specified the variable declaration in the `catch` clause of a `try/catch` to be block-scoped to the `catch` block.

For instance:

```
try {
	undefined(); // illegal operation to force an exception!
}
catch (err) {
	console.log( err ); // works!
}
```

```
console.log( err ); // ReferenceError: `err` not found
```

As you can see, `err` exists only in the `catch` clause, and throws an error when you try to reference it elsewhere.

Note: While this behavior has been specified and true of practically all standard JS environments (except perhaps old IE), many linters seem to still complain if you have two or more `catch` clauses in the same scope which each declare their error variable with the same identifier name. This is not actually a re-definition, since the variables are safely block-scoped, but the linters still seem to, annoyingly, complain about this fact.

To avoid these unnecessary warnings, some devs will name their `catch` variables `err1`, `err2`, etc. Other devs will simply turn off the linting check for duplicate variable names.

The block-scoping nature of `catch` may seem like a useless academic fact, but see Appendix B for more information on just how useful it might be.

`let`

Thus far, we've seen that JavaScript only has some strange niche behaviors which expose block scope functionality. If that were all we had, and *it was* for many, many years, then block scoping would not be terribly useful to the JavaScript developer.

Fortunately, ES6 changes that, and introduces a new keyword `let` which sits alongside `var` as another way to declare variables.

The `let` keyword attaches the variable declaration to the scope of whatever block (commonly a `{ .. }` pair) it's contained in. In other words, `let` implicitly hijacks any block's scope for its variable declaration.

```
var foo = true;

if (foo) {
	let bar = foo * 2;
```

```
		bar = something( bar );
		console.log( bar );
}

console.log( bar ); // ReferenceError
```

Using `let` to attach a variable to an existing block is somewhat implicit. It can confuse you if you're not paying close attention to which blocks have variables scoped to them, and are in the habit of moving blocks around, wrapping them in other blocks, etc., as you develop and evolve code.

Creating explicit blocks for block-scoping can address some of these concerns, making it more obvious where variables are attached and not. Usually, explicit code is preferable over implicit or subtle code. This explicit block-scoping style is easy to achieve, and fits more naturally with how block-scoping works in other languages:

```
var foo = true;

if (foo) {
	{ // <-- explicit block
		let bar = foo * 2;
		bar = something( bar );
		console.log( bar );
	}
}

console.log( bar ); // ReferenceError
```

We can create an arbitrary block for `let` to bind to by simply including a `{ .. }` pair anywhere a statement is valid grammar. In this case, we've made an explicit block *inside* the if-statement, which may be easier as a whole block to move around later in refactoring, without affecting the position and semantics of the enclosing if-statement.

Note: For another way to express explicit block scopes, see Appendix B.

In Chapter 4, we will address hoisting, which talks about declarations being taken as existing for the entire scope in which they occur.

However, declarations made with `let` will *not* hoist to the entire scope of the block they appear in. Such declarations will not observably "exist" in the block until the declaration statement.

```
{
   console.log( bar ); // ReferenceError!
   let bar = 2;
}
```

Garbage Collection

Another reason block-scoping is useful relates to closures and garbage collection to reclaim memory. We'll briefly illustrate here, but the closure mechanism is explained in detail in Chapter 5.

Consider:

```
function process(data) {
	// do something interesting
}

var someReallyBigData = { .. };

process( someReallyBigData );

var btn = document.getElementById( "my_button" );

btn.addEventListener( "click", function click(evt){
	console.log("button clicked");
}, /*capturingPhase=*/false );
```

The `click` function click handler callback doesn't *need* the `someReallyBigData` variable at all. That means, theoretically, after `process(..)` runs, the big memory-heavy data structure could be garbage collected. However, it's quite likely (though implementation dependent) that the JS engine will still have to keep the structure around, since the `click` function has a closure over the entire scope.

Block-scoping can address this concern, making it clearer to the engine that it does not need to keep `someReallyBigData` around:

```
function process(data) {
	// do something interesting
}

// anything declared inside this block can go away after!
{
	let someReallyBigData = { .. };

	process( someReallyBigData );
}

var btn = document.getElementById( "my_button" );

btn.addEventListener( "click", function click(evt){
	console.log("button clicked");
}, /*capturingPhase=*/false );
```

Declaring explicit blocks for variables to locally bind to is a powerful tool that you can add to your code toolbox.

`let` Loops

A particular case where `let` shines is in the for-loop case as we discussed previously.

```
for (let i=0; i<10; i++) {
	console.log( i );
}

console.log( i ); // ReferenceError
```

Not only does `let` in the for-loop header bind the `i` to the for-loop body, but in fact, it **re-binds it** to each *iteration* of the loop, making sure to re-assign it the value from the end of the previous loop iteration.

Here's another way of illustrating the per-iteration binding behavior that occurs:

```
{
	let j;
	for (j=0; j<10; j++) {
		let i = j; // re-bound for each iteration!
		console.log( i );
	}
}
```

The reason why this per-iteration binding is interesting will become clear in Chapter 5 when we discuss closures.

Because `let` declarations attach to arbitrary blocks rather than to the enclosing function's scope (or global), there can be gotchas where existing code has a hidden reliance on function-scoped `var` declarations, and replacing the `var` with `let` may require additional care when refactoring code.

Consider:

```
var foo = true, baz = 10;

if (foo) {
	var bar = 3;

	if (baz > bar) {
		console.log( baz );
	}
```

```js
		// ...
}
```

This code is fairly easily re-factored as:

```js
var foo = true, baz = 10;

if (foo) {
	var bar = 3;

	// ...
}

if (baz > bar) {
	console.log( baz );
}
```

But, be careful of such changes when using block-scoped variables:

```js
var foo = true, baz = 10;

if (foo) {
	let bar = 3;

	if (baz > bar) { // <-- don't forget `bar` when moving!
		console.log( baz );
	}
}
```

See Appendix B for an alternate (more explicit) style of block-scoping which may provide easier to maintain/refactor code that's more robust to these scenarios.

`const`

In addition to `let`, ES6 introduces `const`, which also creates a block-scoped variable, but whose value is fixed (constant). Any attempt to change that value at a later time results in an error.

```
var foo = true;

if (foo) {
	var a = 2;
	const b = 3; // block-scoped to the containing `if`

	a = 3; // just fine!
	b = 4; // error!
}

console.log( a ); // 3
console.log( b ); // ReferenceError!
```

Review (TL;DR)

Functions are the most common unit of scope in JavaScript. Variables and functions that are declared inside another function are essentially "hidden" from any of the enclosing "scopes", which is an intentional design principle of good software.

But functions are by no means the only unit of scope. Block-scope refers to the idea that variables and functions can belong to an arbitrary block (generally, any `{ .. }` pair) of code, rather than only to the enclosing function.

Starting with ES3, the `try/catch` structure has block-scope in the `catch` clause.

In ES6, the `let` keyword (a cousin to the `var` keyword) is introduced to allow declarations of variables in any arbitrary block of code. `if (..) { let a = 2; }` will declare a variable `a` that essentially hijacks the scope of the `if`'s `{ .. }` block and attaches itself there.

Though some seem to believe so, block scope should not be taken as an outright replacement of `var` function scope. Both functionalities co-exist, and developers can and should use both function-scope and block-scope techniques where respectively appropriate to produce better, more readable/maintainable code.

[^note-leastprivilege]: Principle of Least Privilege

You Don't Know JS Yet: Scope & Closures - 2nd Edition

Chapter 4: Hoisting

NOTE:
Work in progress

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By now, you should be fairly comfortable with the idea of scope, and how variables are attached to different levels of scope depending on where and how they are declared. Both function scope and block scope behave by the same rules in this regard: any variable declared within a scope is attached to that scope.

But there's a subtle detail of how scope attachment works with declarations that appear in various locations within a scope, and that detail is what we will examine here.

Chicken Or The Egg?

There's a temptation to think that all of the code you see in a JavaScript program is interpreted line-by-line, top-down in order, as the program executes. While that is substantially true, there's one part of that assumption which can lead to incorrect thinking about your program.

Consider this code:

```
a = 2;

var a;

console.log( a );
```

What do you expect to be printed in the `console.log(..)` statement?

Many developers would expect `undefined`, since the `var a` statement comes after the `a = 2`, and it would seem natural to assume that the variable is re-defined, and thus assigned the default `undefined`. However, the output will be `2`.

Consider another piece of code:

```
console.log( a );

var a = 2;
```

You might be tempted to assume that, since the previous snippet exhibited some less-than-top-down looking behavior, perhaps in this snippet, `2` will also be printed. Others may think that since the `a` variable is used before it is declared, this must result in a `ReferenceError` being thrown.

Unfortunately, both guesses are incorrect. `undefined` is the output.

So, what's going on here? It would appear we have a chicken-and-the-egg question. Which comes first, the declaration ("egg"), or the assignment ("chicken")?

The Compiler Strikes Again

To answer this question, we need to refer back to Chapter 1, and our discussion of compilers. Recall that the *Engine* actually will compile your JavaScript code before it interprets it. Part of the compilation phase was to find and associate all declarations with their appropriate scopes. Chapter 2 showed us that this is the heart of Lexical Scope.

So, the best way to think about things is that all declarations, both variables and functions, are processed first, before any part of your code is executed.

When you see `var a = 2;` , you probably think of that as one statement. But JavaScript actually thinks of it as two statements: `var a;` and `a = 2;` . The first statement, the declaration, is processed during the compilation phase. The second statement, the assignment, is left **in place** for the execution phase.

Our first snippet then should be thought of as being handled like this:

```
var a;


a = 2;

console.log( a );
```

...where the first part is the compilation and the second part is the execution.

Similarly, our second snippet is actually processed as:

```
var a;


console.log( a );

a = 2;
```

So, one way of thinking, sort of metaphorically, about this process, is that variable and function declarations are "moved" from where they appear in the flow of the code to the top of the code. This gives rise to the name "Hoisting".

In other words, **the egg (declaration) comes before the chicken (assignment)**.

Note: Only the declarations themselves are hoisted, while any assignments or other executable logic are left *in place*. If hoisting were to re-arrange the executable logic of our code, that could wreak havoc.

```
foo();

function foo() {
	console.log( a ); // undefined

	var a = 2;
}
```

The function `foo`'s declaration (which in this case *includes* the implied value of it as an actual function) is hoisted, such that the call on the first line is able to execute.

It's also important to note that hoisting is **per-scope**. So while our previous snippets were simplified in that they only included global scope, the `foo(..)` function we are now examining itself exhibits that `var a` is hoisted to the top of `foo(..)` (not, obviously, to the top of the program). So the program can perhaps be more accurately interpreted like this:

```
function foo() {
	var a;

	console.log( a ); // undefined

	a = 2;
}

foo();
```

Function declarations are hoisted, as we just saw. But function expressions are not.

```
foo(); // not ReferenceError, but TypeError!

var foo = function bar() {
	// ...
};
```

The variable identifier `foo` is hoisted and attached to the enclosing scope (global) of this program, so `foo()` doesn't fail as a `ReferenceError` . But `foo` has no value yet (as it would if it had been a true function declaration instead of expression). So, `foo()` is attempting to invoke the `undefined` value, which is a `TypeError` illegal operation.

Also recall that even though it's a named function expression, the name identifier is not available in the enclosing scope:

```
foo(); // TypeError
bar(); // ReferenceError

var foo = function bar() {
        // ...
};
```

This snippet is more accurately interpreted (with hoisting) as:

```
var foo;

foo(); // TypeError
bar(); // ReferenceError

foo = function() {
        var bar = ...self...
        // ...
}
```

Functions First

Both function declarations and variable declarations are hoisted. But a subtle detail (that *can* show up in code with multiple "duplicate" declarations) is that functions are hoisted first, and then variables.

Consider:

```
foo(); // 1

var foo;

function foo() {
        console.log( 1 );
}

foo = function() {
	console.log( 2 );
};
```

`1` is printed instead of `2`! This snippet is interpreted by the *Engine* as:

```
function foo() {
	console.log( 1 );
}

foo(); // 1

foo = function() {
	console.log( 2 );
};
```

Notice that `var foo` was the duplicate (and thus ignored) declaration, even though it came before the `function foo()...` declaration, because function declarations are hoisted before normal variables.

While multiple/duplicate `var` declarations are effectively ignored, subsequent function declarations *do* override previous ones.

```
foo(); // 3

function foo() {
	console.log( 1 );
}

var foo = function() {
	console.log( 2 );
};

function foo() {
        console.log( 3 );
}
```

While this all may sound like nothing more than interesting academic trivia, it highlights the fact that duplicate definitions in the same scope are a really bad idea and will often lead to confusing results.

Function declarations that appear inside of normal blocks typically hoist to the enclosing scope, rather than being conditional as this code implies:

```
foo(); // "b"

var a = true;
if (a) {
   function foo() { console.log( "a" ); }
}
else {
   function foo() { console.log( "b" ); }
}
```

However, it's important to note that this behavior is not reliable and is subject to change in future versions of JavaScript, so it's probably best to avoid declaring functions in blocks.

Review (TL;DR)

We can be tempted to look at `var a = 2;` as one statement, but the JavaScript *Engine* does not see it that way. It sees `var a` and `a = 2` as two separate statements, the first one a compiler-phase task, and the second one an execution-phase task.

What this leads to is that all declarations in a scope, regardless of where they appear, are processed *first* before the code itself is executed. You can visualize this as declarations (variables and functions) being "moved" to the top of their respective scopes, which we call "hoisting".

Declarations themselves are hoisted, but assignments, even assignments of function expressions, are *not* hoisted.

Be careful about duplicate declarations, especially mixed between normal var declarations and function declarations -- peril awaits if you do!

You Don't Know JS Yet: Scope & Closures - 2nd Edition

Chapter 5: Scope Closure

NOTE:
Work in progress

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We arrive at this point with hopefully a very healthy, solid understanding of how scope works.

We turn our attention to an incredibly important, but persistently elusive, *almost mythological*, part of the language: **closure**. If you have followed our discussion of lexical scope thus far, the payoff is that closure is going to be, largely, anticlimactic, almost self-obvious. *There's a man behind the wizard's curtain, and we're about to see him*. No, his name is not Crockford!

If however you have nagging questions about lexical scope, now would be a good time to go back and review Chapter 2 before proceeding.

Enlightenment

For those who are somewhat experienced in JavaScript, but have perhaps never fully grasped the concept of closures, *understanding closure* can seem like a special nirvana that one must strive and sacrifice to attain.

I recall years back when I had a firm grasp on JavaScript, but had no idea what closure was. The hint that there was *this other side* to the language, one which promised even more capability than I already possessed, teased and taunted me. I remember reading through the source code of early frameworks trying to understand how it actually worked. I remember the first time something of the "module pattern" began to emerge in my mind. I remember the *a-ha!* moments quite vividly.

What I didn't know back then, what took me years to understand, and what I hope to impart to you presently, is this secret: **closure is all around you in JavaScript, you just have to recognize and embrace it.** Closures are not a special opt-in tool that you must learn new syntax and patterns for. No, closures are not even a weapon that you must learn to wield and master as Luke trained in The Force.

Closures happen as a result of writing code that relies on lexical scope. They just happen. You do not even really have to intentionally create closures to take advantage of them. Closures are created and used for you all over your code. What you are *missing* is the proper mental context to recognize, embrace, and leverage closures for your own will.

The enlightenment moment should be: **oh, closures are already occurring all over my code, I can finally *see* them now.** Understanding closures is like when Neo sees the Matrix for the first time.

Nitty Gritty

OK, enough hyperbole and shameless movie references.

Here's a down-n-dirty definition of what you need to know to understand and recognize closures:

> Closure is when a function is able to remember and access its lexical scope even when that function is executing outside its lexical scope.

Let's jump into some code to illustrate that definition.

```
function foo() {
	var a = 2;

	function bar() {
		console.log( a ); // 2
	}

	bar();
}

foo();
```

This code should look familiar from our discussions of Nested Scope. Function `bar()` has *access* to the variable `a` in the outer enclosing scope because of lexical scope look-up rules (in this case, it's an RHS reference look-up).

Is this "closure"?

Well, technically... *perhaps*. But by our what-you-need-to-know definition above... *not exactly*. I think the most accurate way to explain `bar()` referencing `a` is via lexical scope look-up rules, and those rules are *only* (an important!) **part** of what closure is.

From a purely academic perspective, what is said of the above snippet is that the function `bar()` has a *closure* over the scope of `foo()` (and indeed, even over the rest of the scopes it has access to, such as the global scope in our case). Put slightly differently, it's said that `bar()` closes over the scope of `foo()`. Why? Because `bar()` appears nested inside of `foo()`. Plain and simple.

But, closure defined in this way is not directly *observable*, nor do we see closure *exercised* in that snippet. We clearly see lexical scope, but closure remains sort of a mysterious shifting shadow behind the code.

Let us then consider code which brings closure into full light:

```
function foo() {
	var a = 2;

	function bar() {
		console.log( a );
	}

	return bar;
}

var baz = foo();

baz(); // 2 -- Whoa, closure was just observed, man.
```

The function `bar()` has lexical scope access to the inner scope of `foo()`. But then, we take `bar()`, the function itself, and pass it *as* a value. In this case, we `return` the function object itself that `bar` references.

After we execute `foo()`, we assign the value it returned (our inner `bar()` function) to a variable called `baz`, and then we actually invoke `baz()`, which of course is invoking our inner function `bar()`, just by a different identifier reference.

`bar()` is executed, for sure. But in this case, it's executed *outside* of its declared lexical scope.

After `foo()` executed, normally we would expect that the entirety of the inner scope of `foo()` would go away, because we know that the *Engine* employs a *Garbage Collector* that comes along and frees up memory once it's no longer in use. Since it would appear that the contents of `foo()` are no longer in use, it would seem natural that they should be considered *gone*.

But the "magic" of closures does not let this happen. That inner scope is in fact *still* "in use", and thus does not go away. Who's using it? **The function `bar()` itself**.

By virtue of where it was declared, `bar()` has a lexical scope closure over that inner scope of `foo()`, which keeps that scope alive for `bar()` to reference at any later time.

`bar()` still has a reference to that scope, and that reference is called closure.

So, a few microseconds later, when the variable `baz` is invoked (invoking the inner function we initially labeled `bar`), it duly has *access* to author-time lexical scope, so it can access the variable `a` just as we'd expect.

The function is being invoked well outside of its author-time lexical scope. **Closure** lets the function continue to access the lexical scope it was defined in at author-time.

Of course, any of the various ways that functions can be *passed around* as values, and indeed invoked in other locations, are all examples of observing/exercising closure.

```
function foo() {
	var a = 2;

	function baz() {
		console.log( a ); // 2
	}

	bar( baz );
}

function bar(fn) {
	fn(); // look ma, I saw closure!
}
```

We pass the inner function `baz` over to `bar`, and call that inner function (labeled `fn` now), and when we do, its closure over the inner scope of `foo()` is observed, by accessing `a`.

These passings-around of functions can be indirect, too.

```
var fn;

function foo() {
	var a = 2;

	function baz() {
		console.log( a );
	}

	fn = baz; // assign `baz` to global variable
}

function bar() {
	fn(); // look ma, I saw closure!
}

foo();

bar(); // 2
```

Whatever facility we use to *transport* an inner function outside of its lexical scope, it will maintain a scope reference to where it was originally declared, and wherever we execute it, that closure will be exercised.

Now I Can See

The previous code snippets are somewhat academic and artificially constructed to illustrate *using closure*. But I promised you something more than just a cool new toy. I promised that closure was something all around you in your existing code. Let us now *see* that truth.

```
function wait(message) {

	setTimeout( function timer(){
		console.log( message );
	}, 1000 );

}

wait( "Hello, closure!" );
```

We take an inner function (named `timer`) and pass it to `setTimeout(..)`. But `timer` has a scope closure over the scope of `wait(..)`, indeed keeping and using a reference to the variable `message`.

A thousand milliseconds after we have executed `wait(..)`, and its inner scope should otherwise be long gone, that inner function `timer` still has closure over that scope.

Deep down in the guts of the *Engine*, the built-in utility `setTimeout(..)` has reference to some parameter, probably called `fn` or `func` or something like that. *Engine* goes to invoke that function, which is invoking our inner `timer` function, and the lexical scope reference is still intact.

Closure.

Or, if you're of the jQuery persuasion (or any JS framework, for that matter):

```
function setupBot(name,selector) {
	$( selector ).click( function activator(){
		console.log( "Activating: " + name );
	} );
}
```

```
setupBot( "Closure Bot 1", "#bot_1" );
setupBot( "Closure Bot 2", "#bot_2" );
```

I am not sure what kind of code you write, but I regularly write code which is responsible for controlling an entire global drone army of closure bots, so this is totally realistic!

(Some) joking aside, essentially *whenever* and *wherever* you treat functions (which access their own respective lexical scopes) as first-class values and pass them around, you are likely to see those functions exercising closure. Be that timers, event handlers, Ajax requests, cross-window messaging, web workers, or any of the other asynchronous (or synchronous!) tasks, when you pass in a *callback function*, get ready to sling some closure around!

Note: Chapter 3 introduced the IIFE pattern. While it is often said that IIFE (alone) is an example of observed closure, I would somewhat disagree, by our definition above.

```
var a = 2;

(function IIFE(){
	console.log( a );
})();
```

This code "works", but it's not strictly an observation of closure. Why? Because the function (which we named "IIFE" here) is not executed outside its lexical scope. It's still invoked right there in the same scope as it was declared (the enclosing/global scope that also holds `a`). `a` is found via normal lexical scope look-up, not really via closure.

While closure might technically be happening at declaration time, it is *not* strictly observable, and so, as they say, *it's a tree falling in the forest with no one around to hear it.*

Though an IIFE is not *itself* an example of closure, it absolutely creates scope, and it's one of the most common tools we use to create scope which can be closed over. So IIFEs are indeed heavily related to closure, even if not exercising closure themselves.

Put this book down right now, dear reader. I have a task for you. Go open up some of your recent JavaScript code. Look for your functions-as-values and identify where you are already using closure and maybe didn't even know it before.

I'll wait.

Now... you see!

Loops + Closure

The most common canonical example used to illustrate closure involves the humble for-loop.

```
for (var i=1; i<=5; i++) {
	setTimeout( function timer(){
		console.log( i );
	}, i*1000 );
}
```

Note: Linters often complain when you put functions inside of loops, because the mistakes of not understanding closure are **so common among developers**. We explain how to do so properly here, leveraging the full power of closure. But that subtlety is often lost on linters and they will complain regardless, assuming you don't *actually* know what you're doing.

The spirit of this code snippet is that we would normally *expect* for the behavior to be that the numbers "1", "2", .. "5" would be printed out, one at a time, one per second, respectively.

In fact, if you run this code, you get "6" printed out 5 times, at the one-second intervals.

Huh?

Firstly, let's explain where `6` comes from. The terminating condition of the loop is when `i` is *not* `<=5`. The first time that's the case is when `i` is 6. So, the output is reflecting the final value of the `i` after the loop terminates.

This actually seems obvious on second glance. The timeout function callbacks are all running well after the completion of the loop. In fact, as timers go, even if it was `setTimeout(.., 0)` on each iteration, all those function callbacks would still run strictly after the completion of the loop, and thus print `6` each time.

But there's a deeper question at play here. What's *missing* from our code to actually have it behave as we semantically have implied?

What's missing is that we are trying to *imply* that each iteration of the loop "captures" its own copy of `i`, at the time of the iteration. But, the way scope works, all 5 of those functions, though they are defined separately in each loop iteration, all **are closed over the same shared global scope**, which has, in fact, only one `i` in it.

Put that way, *of course* all functions share a reference to the same `i`. Something about the loop structure tends to confuse us into thinking there's something else more sophisticated at work. There is not. There's no difference than if each of the 5 timeout callbacks were just declared one right after the other, with no loop at all.

OK, so, back to our burning question. What's missing? We need more ~~cowbell~~ closured scope. Specifically, we need a new closured scope for each iteration of the loop.

We learned in Chapter 3 that the IIFE creates scope by declaring a function and immediately executing it.

Let's try:

```
for (var i=1; i<=5; i++) {
	(function(){
		setTimeout( function timer(){
			console.log( i );
		}, i*1000 );
	})();
}
```

Does that work? Try it. Again, I'll wait.

I'll end the suspense for you. **Nope.** But why? We now obviously have more lexical scope. Each timeout function callback is indeed closing over its own per-iteration scope created respectively by each IIFE.

It's not enough to have a scope to close over **if that scope is empty**. Look closely. Our IIFE is just an empty do-nothing scope. It needs *something* in it to be useful to us.

It needs its own variable, with a copy of the `i` value at each iteration.

```
for (var i=1; i<=5; i++) {
	(function(){
		var j = i;
		setTimeout( function timer(){
			console.log( j );
		}, j*1000 );
	})();
}
```

Eureka! It works!

A slight variation some prefer is:

```
for (var i=1; i<=5; i++) {
	(function(j){
		setTimeout( function timer(){
			console.log( j );
		}, j*1000 );
	})( i );
}
```

Of course, since these IIFEs are just functions, we can pass in `i`, and we can call it `j` if we prefer, or we can even call it `i` again. Either way, the code works now.

The use of an IIFE inside each iteration created a new scope for each iteration, which gave our timeout function callbacks the opportunity to close over a new scope for each iteration, one which had a variable with the right per-iteration value in it for us to access.

Problem solved!

Block Scoping Revisited

Look carefully at our analysis of the previous solution. We used an IIFE to create new scope per-iteration. In other words, we actually *needed* a per-iteration **block scope**. Chapter 3 showed us the `let` declaration, which hijacks a block and declares a variable right there in the block.

It essentially turns a block into a scope that we can close over. So, the following awesome code "just works":

```
for (var i=1; i<=5; i++) {
	let j = i; // yay, block-scope for closure!
	setTimeout( function timer(){
		console.log( j );
	}, j*1000 );
}
```

But, that's not all! (in my best Bob Barker voice). There's a special behavior defined for `let` declarations used in the head of a for-loop. This behavior says that the variable will be declared not just once for the loop, **but each iteration**. And, it will, helpfully, be initialized at each subsequent iteration with the value from the end of the previous iteration.

```
for (let i=1; i<=5; i++) {
	setTimeout( function timer(){
		console.log( i );
	}, i*1000 );
}
```

How cool is that? Block scoping and closure working hand-in-hand, solving all the world's problems. I don't know about you, but that makes me a happy JavaScripter.

Modules

There are other code patterns which leverage the power of closure but which do not on the surface appear to be about callbacks. Let's examine the most powerful of them: *the module*.

```
function foo() {
	var something = "cool";
	var another = [1, 2, 3];

	function doSomething() {
		console.log( something );
	}

	function doAnother() {
		console.log( another.join( " ! " ) );
	}
}
```

As this code stands right now, there's no observable closure going on. We simply have some private data variables `something` and `another`, and a couple of inner functions `doSomething()` and `doAnother()`, which both have lexical scope (and thus closure!) over the inner scope of `foo()`.

But now consider:

```
function CoolModule() {
	var something = "cool";
	var another = [1, 2, 3];

	function doSomething() {
```

```
                console.log( something );
        }

        function doAnother() {
                console.log( another.join( " ! " ) );
        }

        return {
                doSomething: doSomething,
                doAnother: doAnother
        };
}

var foo = CoolModule();

foo.doSomething(); // cool
foo.doAnother(); // 1 ! 2 ! 3
```

This is the pattern in JavaScript we call *module*. The most common way of implementing the module pattern is often called "Revealing Module", and it's the variation we present here.

Let's examine some things about this code.

Firstly, `CoolModule()` is just a function, but it *has to be invoked* for there to be a module instance created. Without the execution of the outer function, the creation of the inner scope and the closures would not occur.

Secondly, the `CoolModule()` function returns an object, denoted by the object-literal syntax `{ key: value, ... }`. The object we return has references on it to our inner functions, but *not* to our inner data variables. We keep those hidden and private. It's appropriate to think of this object return value as essentially a **public API for our module**.

This object return value is ultimately assigned to the outer variable `foo`, and then we can access those property methods on the API, like `foo.doSomething()`.

Note: It is not required that we return an actual object (literal) from our module. We could just return back an inner function directly. jQuery is actually a good example of this. The `jQuery` and `$` identifiers are the public API for the jQuery "module", but they are, themselves, just a function (which can itself have properties, since all functions are objects).

The `doSomething()` and `doAnother()` functions have closure over the inner scope of the module "instance" (arrived at by actually invoking `CoolModule()`). When we transport those functions outside of the lexical scope, by way of property references on the object we return, we have now set up a condition by which closure can be observed and exercised.

To state it more simply, there are two "requirements" for the module pattern to be exercised:

1. There must be an outer enclosing function, and it must be invoked at least once (each time creates a new module instance).

2. The enclosing function must return back at least one inner function, so that this inner function has closure over the private scope, and can access and/or modify that private state.

An object with a function property on it alone is not *really* a module. An object which is returned from a function invocation which only has data properties on it and no closured functions is not *really* a module, in the observable sense.

The code snippet above shows a standalone module creator called `CoolModule()` which can be invoked any number of times, each time creating a new module instance. A slight variation on this pattern is when you only care to have one instance, a "singleton" of sorts:

```
var foo = (function CoolModule() {
	var something = "cool";
	var another = [1, 2, 3];

	function doSomething() {
		console.log( something );
	}

	function doAnother() {
		console.log( another.join( " ! " ) );
	}

	return {
		doSomething: doSomething,
		doAnother: doAnother
	};
})();

foo.doSomething(); // cool
foo.doAnother(); // 1 ! 2 ! 3
```

Here, we turned our module function into an IIFE (see Chapter 3), and we *immediately* invoked it and assigned its return value directly to our single module instance identifier `foo`.

Modules are just functions, so they can receive parameters:

```
function CoolModule(id) {
	function identify() {
		console.log( id );
	}

	return {
		identify: identify
	};
}

var foo1 = CoolModule( "foo 1" );
var foo2 = CoolModule( "foo 2" );

foo1.identify(); // "foo 1"
foo2.identify(); // "foo 2"
```

Another slight but powerful variation on the module pattern is to name the object you are returning as your public API:

```
var foo = (function CoolModule(id) {
	function change() {
		// modifying the public API
		publicAPI.identify = identify2;
	}

	function identify1() {
		console.log( id );
	}

	function identify2() {
		console.log( id.toUpperCase() );
	}

	var publicAPI = {
		change: change,
		identify: identify1
	};

	return publicAPI;
})( "foo module" );

foo.identify(); // foo module
foo.change();
foo.identify(); // FOO MODULE
```

By retaining an inner reference to the public API object inside your module instance, you can modify that module instance **from the inside**, including adding and removing methods, properties, *and* changing their values.

Modern Modules

Various module dependency loaders/managers essentially wrap up this pattern of module definition into a friendly API. Rather than examine any one particular library, let me present a *very simple* proof of concept **for illustration purposes (only)**:

```
var MyModules = (function Manager() {
	var modules = {};

	function define(name, deps, impl) {
		for (var i=0; i<deps.length; i++) {
			deps[i] = modules[deps[i]];
		}
		modules[name] = impl.apply( impl, deps );
	}

	function get(name) {
		return modules[name];
	}

	return {
		define: define,
		get: get
	};
})();
```

The key part of this code is `modules[name] = impl.apply(impl, deps)`. This is invoking the definition wrapper function for a module (passing in any dependencies), and storing the return value, the module's API, into an internal list of modules tracked by name.

And here's how I might use it to define some modules:

```
MyModules.define( "bar", [], function(){
	function hello(who) {
		return "Let me introduce: " + who;
	}

	return {
		hello: hello
	};
} );

MyModules.define( "foo", ["bar"], function(bar){
        var hungry = "hippo";

        function awesome() {
                console.log( bar.hello( hungry ).toUpperCase() );
        }

        return {
                awesome: awesome
        };
} );

var bar = MyModules.get( "bar" );
var foo = MyModules.get( "foo" );

console.log(
        bar.hello( "hippo" )
); // Let me introduce: hippo

foo.awesome(); // LET ME INTRODUCE: HIPPO
```

Both the "foo" and "bar" modules are defined with a function that returns a public API. "foo" even receives the instance of "bar" as a dependency parameter, and can use it accordingly.

Spend some time examining these code snippets to fully understand the power of closures put to use for our own good purposes. The key take-away is that there's not really any particular "magic" to module managers. They fulfill both characteristics of the module pattern I listed above: invoking a function definition wrapper, and keeping its return value as the API for that module.

In other words, modules are just modules, even if you put a friendly wrapper tool on top of them.

Future Modules

ES6 adds first-class syntax support for the concept of modules. When loaded via the module system, ES6 treats a file as a separate module. Each module can both import other modules or specific API members, as well export their own public API members.

Note: Function-based modules aren't a statically recognized pattern (something the compiler knows about), so their API semantics aren't considered until run-time. That is, you can actually modify a module's API during the run-time (see earlier `publicAPI` discussion).

By contrast, ES6 Module APIs are static (the APIs don't change at run-time). Since the compiler knows *that*, it can (and does!) check during (file loading and) compilation that a reference to a member of an imported module's API *actually exists*. If the API reference doesn't exist, the compiler throws an "early" error at compile-time, rather than waiting for traditional dynamic run-time resolution (and errors, if any).

ES6 modules **do not** have an "inline" format, they must be defined in separate files (one per module). The browsers/engines have a default "module loader" (which is overridable, but that's well-beyond our discussion here) which synchronously loads a module file when it's imported.

Consider:

bar.js

```js
function hello(who) {
	return "Let me introduce: " + who;
}

export hello;
```

foo.js

```js
// import only `hello()` from the "bar" module
import hello from "bar";
```

```
var hungry = "hippo";

function awesome() {
        console.log(
                hello( hungry ).toUpperCase()
        );
}

export awesome;
```

```
// import the entire "foo" and "bar" modules
module foo from "foo";
module bar from "bar";

console.log(
        bar.hello( "rhino" )
); // Let me introduce: rhino

foo.awesome(); // LET ME INTRODUCE: HIPPO
```

Note: Separate files **"foo.js"** and **"bar.js"** would need to be created, with the contents as shown in the first two snippets, respectively. Then, your program would load/import those modules to use them, as shown in the third snippet.

`import` imports one or more members from a module's API into the current scope, each to a bound variable (`hello` in our case). `module` imports an entire module API to a bound variable (`foo` , `bar` in our case). `export` exports an identifier (variable, function) to the public API for the current module. These operators can be used as many times in a module's definition as is necessary.

The contents inside the *module file* are treated as if enclosed in a scope closure, just like with the function-closure modules seen earlier.

Review (TL;DR)

Closure seems to the un-enlightened like a mystical world set apart inside of JavaScript which only the few bravest souls can reach. But it's actually just a standard and almost obvious fact of how we write code in a lexically scoped environment, where functions are values and can be passed around at will.

Closure is when a function can remember and access its lexical scope even when it's invoked outside its lexical scope.

Closures can trip us up, for instance with loops, if we're not careful to recognize them and how they work. But they are also an immensely powerful tool, enabling patterns like *modules* in their various forms.

Modules require two key characteristics: 1) an outer wrapping function being invoked, to create the enclosing scope 2) the return value of the wrapping function must include reference to at least one inner function that then has closure over the private inner scope of the wrapper.

Now we can see closures all around our existing code, and we have the ability to recognize and leverage them to our own benefit!

You Don't Know JS Yet: Scope & Closures - 2nd Edition

Appendix A: Dynamic Scope

NOTE:
Work in progress

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In Chapter 2, we talked about "Dynamic Scope" as a contrast to the "Lexical Scope" model, which is how scope works in JavaScript (and in fact, most other languages).

We will briefly examine dynamic scope, to hammer home the contrast. But, more importantly, dynamic scope actually is a near cousin to another mechanism (`this`) in JavaScript, which we covered in the "*this & Object Prototypes*" title of this book series.

As we saw in Chapter 2, lexical scope is the set of rules about how the *Engine* can look-up a variable and where it will find it. The key characteristic of lexical scope is that it is defined at author-time, when the code is written (assuming you don't cheat with `eval()` or `with`).

Dynamic scope seems to imply, and for good reason, that there's a model whereby scope can be determined dynamically at runtime, rather than statically at author-time. That is in fact the case. Let's illustrate via code:

```
function foo() {
        console.log( a ); // 2
}

function bar() {
        var a = 3;
        foo();
}

var a = 2;
```

```
bar();
```

Lexical scope holds that the RHS reference to `a` in `foo()` will be resolved to the global variable `a`, which will result in value `2` being output.

Dynamic scope, by contrast, doesn't concern itself with how and where functions and scopes are declared, but rather **where they are called from**. In other words, the scope chain is based on the call-stack, not the nesting of scopes in code.

So, if JavaScript had dynamic scope, when `foo()` is executed, **theoretically** the code below would instead result in `3` as the output.

```
function foo() {
	console.log( a ); // 3  (not 2!)
}

function bar() {
	var a = 3;
	foo();
}

var a = 2;

bar();
```

How can this be? Because when `foo()` cannot resolve the variable reference for `a`, instead of stepping up the nested (lexical) scope chain, it walks up the call-stack, to find where `foo()` was *called from*. Since `foo()` was called from `bar()`, it checks the variables in scope for `bar()`, and finds an `a` there with value `3`.

Strange? You're probably thinking so, at the moment.

But that's just because you've probably only ever worked on (or at least deeply considered) code which is lexically scoped. So dynamic scoping seems foreign. If you had only ever written code in a dynamically scoped language, it would seem natural, and lexical scope would be the odd-ball.

To be clear, JavaScript **does not, in fact, have dynamic scope**. It has lexical scope. Plain and simple. But the `this` mechanism is kind of like dynamic scope.

The key contrast: **lexical scope is write-time, whereas dynamic scope (and `this`!) are runtime**. Lexical scope cares *where a function was declared*, but dynamic scope cares where a function was *called from*.

Finally: `this` cares *how a function was called*, which shows how closely related the `this` mechanism is to the idea of dynamic scoping. To dig more into `this`, read the title "*this & Object Prototypes*".

You Don't Know JS Yet: Scope & Closures - 2nd Edition

Appendix B: Polyfilling Block Scope

NOTE:
Work in progress

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In Chapter 3, we explored Block Scope. We saw that `with` and the `catch` clause are both tiny examples of block scope that have existed in JavaScript since at least the introduction of ES3.

But it's ES6's introduction of `let` that finally gives full, unfettered block-scoping capability to our code. There are many exciting things, both functionally and code-stylistically, that block scope will enable.

But what if we wanted to use block scope in pre-ES6 environments?

Consider this code:

```
{
	let a = 2;
	console.log( a ); // 2
}

console.log( a ); // ReferenceError
```

This will work great in ES6 environments. But can we do so pre-ES6? `catch` is the answer.

```
try{throw 2}catch(a){
	console.log( a ); // 2
}

console.log( a ); // ReferenceError
```

Whoa! That's some ugly, weird looking code. We see a `try/catch` that appears to forcibly throw an error, but the "error" it throws is just a value `2`, and then the variable declaration that receives it is in the `catch(a)` clause. Mind: blown.

That's right, the `catch` clause has block-scoping to it, which means it can be used as a polyfill for block scope in pre-ES6 environments.

"But...", you say. "...no one wants to write ugly code like that!" That's true. No one writes (some of) the code output by the CoffeeScript compiler, either. That's not the point.

The point is that tools can transpile ES6 code to work in pre-ES6 environments. You can write code using block-scoping, and benefit from such functionality, and let a build-step tool take care of producing code that will actually *work* when deployed.

This is actually the preferred migration path for all (ahem, most) of ES6: to use a code transpiler to take ES6 code and produce ES5-compatible code during the transition from pre-ES6 to ES6.

Traceur

Google maintains a project called "Traceur" [^note-traceur], which is exactly tasked with transpiling ES6 features into pre-ES6 (mostly ES5, but not all!) for general usage. The TC39 committee relies on this tool (and others) to test out the semantics of the features they specify.

What does Traceur produce from our snippet? You guessed it!

```
{
	try {
		throw undefined;
	} catch (a) {
		a = 2;
		console.log( a );
	}
}
```

```
console.log( a );
```

So, with the use of such tools, we can start taking advantage of block scope regardless of if we are targeting ES6 or not, because `try/catch` has been around (and worked this way) from ES3 days.

Implicit vs. Explicit Blocks

In Chapter 3, we identified some potential pitfalls to code maintainability/refactorability when we introduce block-scoping. Is there another way to take advantage of block scope but to reduce this downside?

Consider this alternate form of `let`, called the "let block" or "let statement" (contrasted with "let declarations" from before).

```
let (a = 2) {
	console.log( a ); // 2
}

console.log( a ); // ReferenceError
```

Instead of implicitly hijacking an existing block, the let-statement creates an explicit block for its scope binding. Not only does the explicit block stand out more, and perhaps fare more robustly in code refactoring, it produces somewhat cleaner code by, grammatically, forcing all the declarations to the top of the block. This makes it easier to look at any block and know what's scoped to it and not.

As a pattern, it mirrors the approach many people take in function-scoping when they manually move/hoist all their `var` declarations to the top of the function. The let-statement puts them there at the top of the block by intent, and if you don't use `let` declarations strewn throughout, your block-scoping declarations are somewhat easier to identify and maintain.

But, there's a problem. The let-statement form is not included in ES6. Neither does the official Traceur compiler accept that form of code.

We have two options. We can format using ES6-valid syntax and a little sprinkle of code discipline:

```
/*let*/ { let a = 2;
        console.log( a );
}

console.log( a ); // ReferenceError
```

But, tools are meant to solve our problems. So the other option is to write explicit let statement blocks, and let a tool convert them to valid, working code.

So, I built a tool called "let-er" [^note-let_er] to address just this issue. *let-er* is a build-step code transpiler, but its only task is to find let-statement forms and transpile them. It will leave alone any of the rest of your code, including any let-declarations. You can safely use *let-er* as the first ES6 transpiler step, and then pass your code through something like Traceur if necessary.

Moreover, *let-er* has a configuration flag `--es6`, which when turned on (off by default), changes the kind of code produced. Instead of the `try/catch` ES3 polyfill hack, *let-er* would take our snippet and produce the fully ES6-compliant, non-hacky:

```
{
        let a = 2;
        console.log( a );
}

console.log( a ); // ReferenceError
```

So, you can start using *let-er* right away, and target all pre-ES6 environments, and when you only care about ES6, you can add the flag and instantly target only ES6.

And most importantly, **you can use the more preferable and more explicit let-statement form** even though it is not an official part of any ES version (yet).

Performance

Let me add one last quick note on the performance of `try/catch`, and/or to address the question, "why not just use an IIFE to create the scope?"

Firstly, the performance of `try/catch` *is* slower, but there's no reasonable assumption that it *has* to be that way, or even that it *always will be* that way. Since the official TC39-approved ES6 transpiler uses `try/catch`, the Traceur team has asked Chrome to improve the performance of `try/catch`, and they are obviously motivated to do so.

Secondly, IIFE is not a fair apples-to-apples comparison with `try/catch`, because a function wrapped around any arbitrary code changes the meaning, inside of that code, of `this`, `return`, `break`, and `continue`. IIFE is not a suitable general substitute. It could only be used manually in certain cases.

The question really becomes: do you want block-scoping, or not. If you do, these tools provide you that option. If not, keep using `var` and go on about your coding!

[^note-traceur]: Google Traceur

[^note-let_er]: let-er

You Don't Know JS Yet: Scope & Closures - 2nd Edition

Appendix C: Lexical-this

NOTE:
Work in progress

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Though this title does not address the `this` mechanism in any detail, there's one ES6 topic which relates `this` to lexical scope in an important way, which we will quickly examine.

ES6 adds a special syntactic form of function declaration called the "arrow function". It looks like this:

```
var foo = a => {
        console.log( a );
};

foo( 2 ); // 2
```

The so-called "fat arrow" is often mentioned as a short-hand for the *tediously verbose* (sarcasm) `function` keyword.

But there's something much more important going on with arrow-functions that has nothing to do with saving keystrokes in your declaration.

Briefly, this code suffers a problem:

```
var obj = {
	id: "awesome",
	cool: function coolFn() {
		console.log( this.id );
	}
};

var id = "not awesome";

obj.cool(); // awesome

setTimeout( obj.cool, 100 ); // not awesome
```

The problem is the loss of `this` binding on the `cool()` function. There are various ways to address that problem, but one often-repeated solution is `var self = this;`.

That might look like:

```
var obj = {
	count: 0,
	cool: function coolFn() {
		var self = this;

		if (self.count < 1) {
			setTimeout( function timer(){
				self.count++;
				console.log( "awesome?" );
			}, 100 );
		}
	}
};

obj.cool(); // awesome?
```

Without getting too much into the weeds here, the `var self = this` "solution" just dispenses with the whole problem of understanding and properly using `this` binding, and instead falls back to something we're perhaps more comfortable with: lexical scope. `self` becomes just an identifier that can be resolved via lexical scope and closure, and cares not what happened to the `this` binding along the way.

People don't like writing verbose stuff, especially when they do it over and over again. So, a motivation of ES6 is to help alleviate these scenarios, and indeed, *fix* common idiom problems, such as this one.

The ES6 solution, the arrow-function, introduces a behavior called "lexical this".

```
var obj = {
	count: 0,
	cool: function coolFn() {
		if (this.count < 1) {
			setTimeout( () => { // arrow-function ftw?
				this.count++;
				console.log( "awesome?" );
			}, 100 );
		}
	}
};

obj.cool(); // awesome?
```

The short explanation is that arrow-functions do not behave at all like normal functions when it comes to their `this` binding. They discard all the normal rules for `this` binding, and instead take on the `this` value of their immediate lexical enclosing scope, whatever it is.

So, in that snippet, the arrow-function doesn't get its `this` unbound in some unpredictable way, it just "inherits" the `this` binding of the `cool()` function (which is correct if we invoke it as shown!).

While this makes for shorter code, my perspective is that arrow-functions are really just codifying into the language syntax a common *mistake* of developers, which is to confuse and conflate "this binding" rules with "lexical scope" rules.

Put another way: why go to the trouble and verbosity of using the `this` style coding paradigm, only to cut it off at the knees by mixing it with lexical references. It seems natural to embrace one approach or the other for any given piece of code, and not mix them in the same piece of code.

Note: one other detraction from arrow-functions is that they are anonymous, not named. See Chapter 3 for the reasons why anonymous functions are less desirable than named functions.

A more appropriate approach, in my perspective, to this "problem", is to use and embrace the `this` mechanism correctly.

```
var obj = {
	count: 0,
	cool: function coolFn() {
		if (this.count < 1) {
			setTimeout( function timer(){
				this.count++; // `this` is safe because of `bind(..)`
				console.log( "more awesome" );
			}.bind( this ), 100 ); // look, `bind()`!
		}
	}
};

obj.cool(); // more awesome
```

Whether you prefer the new lexical-this behavior of arrow-functions, or you prefer the tried-and-true `bind()` , it's important to note that arrow-functions are **not** just about less typing of "function".

They have an *intentional behavioral difference* that we should learn and understand, and if we so choose, leverage.

Now that we fully understand lexical scoping (and closure!), understanding lexical-this should be a breeze!

You Don't Know JS Yet: *this* & Object Prototypes - 2nd Edition

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Foreword

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You Don't Know JS Yet - 2nd Edition

Preface

Welcome to the 2nd edition of the widely-acclaimed *You Don't Know JS* (**YDKJS**) book series: *You Don't Know JS **Yet*** (**YDKJSY**).

If you've read any of the 1st edition of the books, you can expect a refreshed approach in these new books, with plenty of new coverage of what's changed in JS over the last five years. But what I hope and believe you'll still *get* is the same committment to respecting JS and digging into what really makes it tick.

If this is your first time to read these books, I'm glad you're here. Prepare for a deep and extensive journey into all the corners of JavaScript.

The Parts

These books approach JavaScript intentionally the opposite of *The Good Parts*. No, not *the bad parts*, but rather, focused on **all the parts**.

You may have been told, or felt yourself, that JS is a deeply flawed language that was poorly designed and inconsistently implemented. Many have asserted that it's the worst most popular language in the world; that nobody writes JS because they want to, only because they have to given its place at the center of the web. That's a ridiculous, unhealthy, and wholly condescending claim.

Millions of developers write JavaScript every day, and many of them appreciate and respect the language.

Like any great language, it has its brilliant parts and it has its scars. Even the creator of JavaScript himself, Brendan Eich, laments some of those parts as mistakes. But he's wrong: they weren't mistakes at all. JS is what it is today -- the world's most ubiquitous and thus most influential programming language -- precisely because of *all those parts*.

Don't buy the lie that you should only learn and use a small collection of *good parts* while avoiding all the bad stuff. Don't buy the "X is the new Y" snake oil, that some new feature of the language instantly relegates all usage of a previous feature as obsolete and ignorant. Don't listen when someone says your code isn't "modern" because it isn't yet using a stage-0 feature that was only proposed a few weeks ago!

Every part of JS is useful. Some parts are more useful than others. Some parts require you to be more careful and intentional.

I find it absurd to try to be a truly effective JavaScript developer while only using a small sliver of what the language has to offer. Can you imagine a construction worker with a toolbox full of tools, who only uses his hammer and scoffs at the screwdriver or tape measure as inferior? That's just silly.

My unreserved claim is that you should go about learning all parts of JavaScript, and where appropriate, use them! And if I may be so bold as to suggest: it's time to discard any other JS books which tell you otherwise.

The Title?

So what's the title of the series all about?

I'm not trying to insult you with criticism about your current lack of knowledge or understanding of JavaScript. I'm not suggesting you can't or won't be able to learn JavaScript. I'm not boasting about secret advanced insider wisdom that I and only a select few possess.

Seriously, all those were real reactions to the original series title before folks even read the books. And they're baseless.

The primary point of the title "You Don't Know JS Yet" is to point out that most JS developers don't take the time to really understand how the code that they write, works. They know that it works -- that it produces a desired outcome. But they either don't understand exactly *how*, or worse, they have an inaccurate mental model for the *how* that falters on closer scrutiny.

I'm presenting a gentle but earnest challenge to you the reader, to set aside the assumptions you have about JS, and approach it with fresh eyes and an invigorated curiosity that leads you to ask *why* for every line of code you write. Why does it do what it does? Why is one way better or more appropriate than the other half dozen ways you could have accomplished it? Why do all the "popular kids" say to do X with your code, but it turns out that Y might be a better choice?

I added "Yet" to the title, not only because it's the second edition, but because ultimately I want these books to challenge you in a hopeful rather than discouraging way.

But let me be clear: I don't think it's possible to ever fully *know* JS. That's not an achievement to be obtained, but a goal to strive after. You don't finish knowing everything about JS, you just keep learning more and more as you spend more time with the language. And the deeper you go, the more you revisit what you *knew* before, and you re-learn it from that more experienced perspective.

I encourage you to adopt a mindset around JavaScript, and indeed all of software development, that you will never fully have mastered it, but that you can and should keep working to get closer to that end, a journey that will stretch for the entirety of your software development career, and beyond.

You can always know JS better than you currently do. That's what I hope these YDKJSY books represent.

The Mission

The case doesn't really need to be made for why developers should take JS seriously -- I think it's already more than proven worthy of first class status among the world's programming languages.

But a different, more important case still needs to be made, and these books rise to that challenge.

I've taught more than 5,000 developers from teams and companies all over the world, in more than 25 countries and six continents. And what I've seen is that far too often, what *counts* is generally just the result of the program, not how the program is written or how/why it works.

My experience not only as a developer but in teaching many other developers tells me: you will always be more effective in your development work if you more completely understand how your code works, than you are solely *just* getting it to produce a desired outcome.

In other words, *good enough to work* is not *good enough*.

All developers regularly struggle with some piece of code not working correctly, and they can't figure out why. But far too often, JS developers will blame this on the language rather than admitting it's their own understanding that is falling short. These books serve as both the question and answer: why did it do *this*, and here's how to get it to do *that* instead.

My mission with YDKJSY is to empower every single JavaScript developer to fully own the JS they write, to understand it and to write with intention and clarity.

The Path

Some of you have started reading this book with the goal of completing all six books, back-to-back.

I would like to caution you to consider changing that plan.

It is not my intention that YDKJSY be read straight through. The material in these books is dense, because JavaScript is powerful, sophisticated, and in parts rather complex. Nobody can really hope to *download* all this information to their brains in a single pass and retain any significant amount of it. That's unreasonable, and it's foolish to try.

My suggestion is you take your time going through YDKJSY. Take one chapter, read it completely through start to finish, and then go back and re-read it section by section. Stop in between each section, and practice the code or ideas from that section. For larger concepts, it probably is a good idea to expect to spend several days digesting, re-reading, practicing, then digesting some more.

You could spend a week or two on each chapter, and a month or two on each book, and a year or more on the whole series, and you would still not be squeezing every ounce of YDKJSY out.

Don't binge these books; be patient and spread out your reading. Interleave reading with lots of practice on real code in your job or on projects you participate in. Wrestle with the opinions I've presented along the way, debate with others, and most of all, disagree with me! Run a study group or book club. Teach mini-workshops at your office. Write blog posts on what you've learned. Speak about these topics at local JS meetups.

It's never my goal to convince you to agree with my opinion, but to own and be able to defend your opinions. You can't get *there* with an expedient read through of these books. That's something that takes a long while to emerge, little by little, as you study and ponder and re-visit.

These books are meant to be a field-guide on your wanderings through JavaScript, from wherever you currently are with the language, to a place of deeper understanding. And the deeper you understand JS, the more questions you will ask and the more you will have to explore! That's what I find so exciting!

I'm so glad you're embarking on this journey, and I am so honored you would consider and consult these books along the way. It's time to start *getting to know JS*.

You Don't Know JS Yet: *this* & Object Prototypes - 2nd Edition

Chapter 1: `this` Or That?

NOTE:
Work in progress

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One of the most confused mechanisms in JavaScript is the `this` keyword. It's a special identifier keyword that's automatically defined in the scope of every function, but what exactly it refers to bedevils even seasoned JavaScript developers.

> Any sufficiently *advanced* technology is indistinguishable from magic. -- Arthur C. Clarke

JavaScript's `this` mechanism isn't actually *that* advanced, but developers often paraphrase that quote in their own mind by inserting "complex" or "confusing", and there's no question that without lack of clear understanding, `this` can seem downright magical in *your* confusion.

Note: The word "this" is a terribly common pronoun in general discourse. So, it can be very difficult, especially verbally, to determine whether we are using "this" as a pronoun or using it to refer to the actual keyword identifier. For clarity, I will always use `this` to refer to the special keyword, and "this" or *this* or this otherwise.

Why `this`?

If the `this` mechanism is so confusing, even to seasoned JavaScript developers, one may wonder why it's even useful? Is it more trouble than it's worth? Before we jump into the *how*, we should examine the *why*.

Let's try to illustrate the motivation and utility of `this`:

```js
function identify() {
	return this.name.toUpperCase();
}

function speak() {
	var greeting = "Hello, I'm " + identify.call( this );
	console.log( greeting );
}

var me = {
	name: "Kyle"
};

var you = {
	name: "Reader"
};

identify.call( me ); // KYLE
identify.call( you ); // READER

speak.call( me ); // Hello, I'm KYLE
speak.call( you ); // Hello, I'm READER
```

If the *how* of this snippet confuses you, don't worry! We'll get to that shortly. Just set those questions aside briefly so we can look into the *why* more clearly.

This code snippet allows the `identify()` and `speak()` functions to be re-used against multiple *context* (`me` and `you`) objects, rather than needing a separate version of the function for each object.

Instead of relying on `this` , you could have explicitly passed in a context object to both `identify()` and `speak()` .

```
function identify(context) {
	return context.name.toUpperCase();
}

function speak(context) {
	var greeting = "Hello, I'm " + identify( context );
	console.log( greeting );
}

identify( you ); // READER
speak( me ); // Hello, I'm KYLE
```

However, the `this` mechanism provides a more elegant way of implicitly "passing along" an object reference, leading to cleaner API design and easier re-use.

The more complex your usage pattern is, the more clearly you'll see that passing context around as an explicit parameter is often messier than passing around a `this` context. When we explore objects and prototypes, you will see the helpfulness of a collection of functions being able to automatically reference the proper context object.

Confusions

We'll soon begin to explain how `this` *actually* works, but first we must dispel some misconceptions about how it *doesn't* actually work.

The name "this" creates confusion when developers try to think about it too literally. There are two meanings often assumed, but both are incorrect.

Itself

The first common temptation is to assume `this` refers to the function itself. That's a reasonable grammatical inference, at least.

Why would you want to refer to a function from inside itself? The most common reasons would be things like recursion (calling a function from inside itself) or having an event handler that can unbind itself when it's first called.

Developers new to JS's mechanisms often think that referencing the function as an object (all functions in JavaScript are objects!) lets you store *state* (values in properties) between function calls. While this is certainly possible and has some limited uses, the rest of the book will expound on many other patterns for *better* places to store state besides the function object.

But for just a moment, we'll explore that pattern, to illustrate how `this` doesn't let a function get a reference to itself like we might have assumed.

Consider the following code, where we attempt to track how many times a function (`foo`) was called:

```
function foo(num) {
	console.log( "foo: " + num );

	// keep track of how many times `foo` is called
	this.count++;
}

foo.count = 0;

var i;

for (i=0; i<10; i++) {
	if (i > 5) {
		foo( i );
	}
}
// foo: 6
// foo: 7
// foo: 8
// foo: 9

// how many times was `foo` called?
console.log( foo.count ); // 0 -- WTF?
```

`foo.count` is *still* `0` , even though the four `console.log` statements clearly indicate `foo(..)` was in fact called four times. The frustration stems from a *too literal* interpretation of what `this` (in `this.count++`) means.

When the code executes `foo.count = 0` , indeed it's adding a property `count` to the function object `foo` . But for the `this.count` reference inside of the function, `this` is not in fact pointing *at all* to that function object, and so even though the property names are the same, the root objects are different, and confusion ensues.

Note: A responsible developer *should* ask at this point, "If I was incrementing a `count` property but it wasn't the one I expected, which `count` *was* I incrementing?" In fact, were she to dig deeper, she would find that she had accidentally created a global variable `count` (see Chapter 2 for *how* that happened!), and it currently has the value `NaN`. Of course, once she identifies this peculiar outcome, she then has a whole other set of questions: "How was it global, and why did it end up `NaN` instead of some proper count value?" (see Chapter 2).

Instead of stopping at this point and digging into why the `this` reference doesn't seem to be behaving as *expected*, and answering those tough but important questions, many developers simply avoid the issue altogether, and hack toward some other solution, such as creating another object to hold the `count` property:

```
function foo(num) {
	console.log( "foo: " + num );

	// keep track of how many times `foo` is called
	data.count++;
}

var data = {
	count: 0
};

var i;

for (i=0; i<10; i++) {
	if (i > 5) {
		foo( i );
	}
}
// foo: 6
// foo: 7
// foo: 8
// foo: 9

// how many times was `foo` called?
console.log( data.count ); // 4
```

While it is true that this approach "solves" the problem, unfortunately it simply ignores the real problem -- lack of understanding what `this` means and how it works -- and instead falls back to the comfort zone of a more familiar mechanism: lexical scope.

Note: Lexical scope is a perfectly fine and useful mechanism; I am not belittling the use of it, by any means (see "*Scope & Closures*" title of this book series). But constantly *guessing* at how to use `this`, and usually being *wrong*, is not a good reason to retreat back to lexical scope and never learn *why* `this` eludes you.

To reference a function object from inside itself, `this` by itself will typically be insufficient. You generally need a reference to the function object via a lexical identifier (variable) that points at it.

Consider these two functions:

```
function foo() {
	foo.count = 4; // `foo` refers to itself
}

setTimeout( function(){
	// anonymous function (no name), cannot
	// refer to itself
}, 10 );
```

In the first function, called a "named function", `foo` is a reference that can be used to refer to the function from inside itself.

But in the second example, the function callback passed to `setTimeout(..)` has no name identifier (so called an "anonymous function"), so there's no proper way to refer to the function object itself.

Note: The old-school but now deprecated and frowned-upon `arguments.callee` reference inside a function *also* points to the function object of the currently executing function. This reference is typically the only way to access an anonymous function's object from inside itself. The best approach, however, is to avoid the use of anonymous functions altogether, at least for those which require a self-reference, and instead use a named function (expression). `arguments.callee` is deprecated and should not be used.

So another solution to our running example would have been to use the `foo` identifier as a function object reference in each place, and not use `this` at all, which *works*:

```
function foo(num) {
	console.log( "foo: " + num );

	// keep track of how many times `foo` is called
	foo.count++;
}

foo.count = 0;

var i;

for (i=0; i<10; i++) {
	if (i > 5) {
		foo( i );
	}
}
// foo: 6
// foo: 7
// foo: 8
// foo: 9

// how many times was `foo` called?
console.log( foo.count ); // 4
```

However, that approach similarly side-steps *actual* understanding of `this` and relies entirely on the lexical scoping of variable `foo`.

Yet another way of approaching the issue is to force `this` to actually point at the `foo` function object:

```
function foo(num) {
	console.log( "foo: " + num );

	// keep track of how many times `foo` is called
	// Note: `this` IS actually `foo` now, based on
	// how `foo` is called (see below)
	this.count++;
}

foo.count = 0;

var i;

for (i=0; i<10; i++) {
	if (i > 5) {
		// using `call(..)`, we ensure the `this`
		// points at the function object (`foo`) itself
		foo.call( foo, i );
	}
}
// foo: 6
// foo: 7
// foo: 8
// foo: 9

// how many times was `foo` called?
console.log( foo.count ); // 4
```

Instead of avoiding `this`, we embrace it. We'll explain in a little bit *how* such techniques work much more completely, so don't worry if you're still a bit confused!

Its Scope

The next most common misconception about the meaning of `this` is that it somehow refers to the function's scope. It's a tricky question, because in one sense there is some truth, but in the other sense, it's quite misguided.

To be clear, `this` does not, in any way, refer to a function's **lexical scope**. It is true that internally, scope is kind of like an object with properties for each of the available identifiers. But the scope "object" is not accessible to JavaScript code. It's an inner part of the *Engine*'s implementation.

Consider code which attempts (and fails!) to cross over the boundary and use `this` to implicitly refer to a function's lexical scope:

```
function foo() {
        var a = 2;
        this.bar();
}

function bar() {
        console.log( this.a );
}

foo(); //undefined
```

There's more than one mistake in this snippet. While it may seem contrived, the code you see is a distillation of actual real-world code that has been exchanged in public community help forums. It's a wonderful (if not sad) illustration of just how misguided `this` assumptions can be.

Firstly, an attempt is made to reference the `bar()` function via `this.bar()`. It is almost certainly an *accident* that it works, but we'll explain the *how* of that shortly. The most natural way to have invoked `bar()` would have been to omit the leading `this.` and just make a lexical reference to the identifier.

However, the developer who writes such code is attempting to use `this` to create a bridge between the lexical scopes of `foo()` and `bar()`, so that `bar()` has access to the variable `a` in the inner scope of `foo()`. **No such bridge is possible.** You cannot use a `this` reference to look something up in a lexical scope. It is not possible.

Every time you feel yourself trying to mix lexical scope look-ups with `this`, remind yourself: *there is no bridge*.

What's `this`?

Having set aside various incorrect assumptions, let us now turn our attention to how the `this` mechanism really works.

We said earlier that `this` is not an author-time binding but a runtime binding. It is contextual based on the conditions of the function's invocation. `this` binding has nothing to do with where a function is declared, but has instead everything to do with the manner in which the function is called.

When a function is invoked, an activation record, otherwise known as an execution context, is created. This record contains information about where the function was called from (the call-stack), *how* the function was invoked, what parameters were passed, etc. One of the properties of this record is the `this` reference which will be used for the duration of that function's execution.

In the next chapter, we will learn to find a function's **call-site** to determine how its execution will bind `this`.

Review (TL;DR)

`this` binding is a constant source of confusion for the JavaScript developer who does not take the time to learn how the mechanism actually works. Guesses, trial-and-error, and blind copy-n-paste from Stack Overflow answers is not an effective or proper way to leverage *this* important `this` mechanism.

To learn `this`, you first have to learn what `this` is *not*, despite any assumptions or misconceptions that may lead you down those paths. `this` is neither a reference to the function itself, nor is it a reference to the function's *lexical* scope.

`this` is actually a binding that is made when a function is invoked, and *what* it references is determined entirely by the call-site where the function is called.

You Don't Know JS Yet: *this* & Object Prototypes - 2nd Edition

Chapter 2: `this` All Makes Sense Now!

NOTE:
Work in progress

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In Chapter 1, we discarded various misconceptions about `this` and learned instead that `this` is a binding made for each function invocation, based entirely on its **call-site** (how the function is called).

Call-site

To understand `this` binding, we have to understand the call-site: the location in code where a function is called (**not where it's declared**). We must inspect the call-site to answer the question: what's *this* `this` a reference to?

Finding the call-site is generally: "go locate where a function is called from", but it's not always that easy, as certain coding patterns can obscure the *true* call-site.

What's important is to think about the **call-stack** (the stack of functions that have been called to get us to the current moment in execution). The call-site we care about is *in* the invocation *before* the currently executing function.

Let's demonstrate call-stack and call-site:

```js
function baz() {
    // call-stack is: `baz`
    // so, our call-site is in the global scope

    console.log( "baz" );
    bar(); // <-- call-site for `bar`
}

function bar() {
    // call-stack is: `baz` -> `bar`
    // so, our call-site is in `baz`

    console.log( "bar" );
    foo(); // <-- call-site for `foo`
}

function foo() {
    // call-stack is: `baz` -> `bar` -> `foo`
    // so, our call-site is in `bar`

    console.log( "foo" );
}

baz(); // <-- call-site for `baz`
```

Take care when analyzing code to find the actual call-site (from the call-stack), because it's the only thing that matters for `this` binding.

Note: You can visualize a call-stack in your mind by looking at the chain of function calls in order, as we did with the comments in the above snippet. But this is painstaking and error-prone. Another way of seeing the call-stack is using a debugger tool in your browser. Most modern desktop browsers have built-in developer tools, which includes a JS debugger. In the above snippet, you could have set a breakpoint in the tools for the first line of the `foo()` function, or simply inserted the `debugger;` statement on that first line. When you run the page, the debugger will pause at this location, and will show you a list of the functions that have been called to get to that line, which will be your call stack. So, if you're trying to diagnose `this` binding, use the developer tools to get the call-stack, then find the second item from the top, and that will show you the real call-site.

Nothing But Rules

We turn our attention now to *how* the call-site determines where `this` will point during the execution of a function.

You must inspect the call-site and determine which of 4 rules applies. We will first explain each of these 4 rules independently, and then we will illustrate their order of precedence, if multiple rules *could* apply to the call-site.

Default Binding

The first rule we will examine comes from the most common case of function calls: standalone function invocation. Think of *this* `this` rule as the default catch-all rule when none of the other rules apply.

Consider this code:

```
function foo() {
	console.log( this.a );
}

var a = 2;

foo(); // 2
```

The first thing to note, if you were not already aware, is that variables declared in the global scope, as `var a = 2` is, are synonymous with global-object properties of the same name. They're not copies of each other, they *are* each other. Think of it as two sides of the same coin.

Secondly, we see that when `foo()` is called, `this.a` resolves to our global variable `a`. Why? Because in this case, the *default binding* for `this` applies to the function call, and so points `this` at the global object.

How do we know that the *default binding* rule applies here? We examine the call-site to see how `foo()` is called. In our snippet, `foo()` is called with a plain, un-decorated function reference. None of the other rules we will demonstrate will apply here, so the *default binding* applies instead.

If `strict mode` is in effect, the global object is not eligible for the *default binding*, so the `this` is instead set to `undefined`.

```
function foo() {
	"use strict";

	console.log( this.a );
}

var a = 2;

foo(); // TypeError: `this` is `undefined`
```

A subtle but important detail is: even though the overall `this` binding rules are entirely based on the call-site, the global object is **only** eligible for the *default binding* if the **contents** of `foo()` are **not** running in `strict mode`; the `strict mode` state of the call-site of `foo()` is irrelevant.

```
function foo() {
	console.log( this.a );
}

var a = 2;

(function(){
	"use strict";

	foo(); // 2
})();
```

Note: Intentionally mixing `strict mode` and non-`strict mode` together in your own code is generally frowned upon. Your entire program should probably either be **Strict** or **non-Strict**. However, sometimes you include a third-party library that has different **Strict**'ness than your own code, so care must be taken over these subtle compatibility details.

Implicit Binding

Another rule to consider is: does the call-site have a context object, also referred to as an owning or containing object, though *these* alternate terms could be slightly misleading.

Consider:

```
function foo() {
	console.log( this.a );
}

var obj = {
	a: 2,
	foo: foo
};

obj.foo(); // 2
```

Firstly, notice the manner in which `foo()` is declared and then later added as a reference property onto `obj`. Regardless of whether `foo()` is initially declared *on* `obj`, or is added as a reference later (as this snippet shows), in neither case is the **function** really "owned" or "contained" by the `obj` object.

However, the call-site *uses* the `obj` context to **reference** the function, so you *could* say that the `obj` object "owns" or "contains" the **function reference** at the time the function is called.

Whatever you choose to call this pattern, at the point that `foo()` is called, it's preceded by an object reference to `obj`. When there is a context object for a function reference, the *implicit binding* rule says that it's *that* object which should be used for the function call's `this` binding.

Because `obj` is the `this` for the `foo()` call, `this.a` is synonymous with `obj.a`.

Only the top/last level of an object property reference chain matters to the call-site. For instance:

```
function foo() {
	console.log( this.a );
}

var obj2 = {
	a: 42,
	foo: foo
};

var obj1 = {
	a: 2,
	obj2: obj2
};
```

```
obj1.obj2.foo(); // 42
```

Implicitly Lost

One of the most common frustrations that `this` binding creates is when an *implicitly bound* function loses that binding, which usually means it falls back to the *default binding*, of either the global object or `undefined`, depending on `strict mode`.

Consider:

```
function foo() {
	console.log( this.a );
}

var obj = {
	a: 2,
	foo: foo
};

var bar = obj.foo; // function reference/alias!

var a = "oops, global"; // `a` also property on global object

bar(); // "oops, global"
```

Even though `bar` appears to be a reference to `obj.foo`, in fact, it's really just another reference to `foo` itself. Moreover, the call-site is what matters, and the call-site is `bar()`, which is a plain, un-decorated call and thus the *default binding* applies.

The more subtle, more common, and more unexpected way this occurs is when we consider passing a callback function:

```
function foo() {
	console.log( this.a );
}

function doFoo(fn) {
	// `fn` is just another reference to `foo`

	fn(); // <-- call-site!
}

var obj = {
	a: 2,
	foo: foo
};

var a = "oops, global"; // `a` also property on global object

doFoo( obj.foo ); // "oops, global"
```

Parameter passing is just an implicit assignment, and since we're passing a function, it's an implicit reference assignment, so the end result is the same as the previous snippet.

What if the function you're passing your callback to is not your own, but built-in to the language? No difference, same outcome.

```
function foo() {
	console.log( this.a );
}

var obj = {
	a: 2,
	foo: foo
};

var a = "oops, global"; // `a` also property on global object

setTimeout( obj.foo, 100 ); // "oops, global"
```

Think about this crude theoretical pseudo-implementation of `setTimeout()` provided as a built-in from the JavaScript environment:

```
function setTimeout(fn,delay) {
	// wait (somehow) for `delay` milliseconds
	fn(); // <-- call-site!
}
```

It's quite common that our function callbacks *lose* their `this` binding, as we've just seen. But another way that `this` can surprise us is when the function we've passed our callback to intentionally changes the `this` for the call. Event handlers in popular JavaScript libraries are quite fond of forcing your callback to have a `this` which points to, for instance, the DOM element that triggered the event. While that may sometimes be useful, other times it can be downright infuriating. Unfortunately, these tools rarely let you choose.

Either way the `this` is changed unexpectedly, you are not really in control of how your callback function reference will be executed, so you have no way (yet) of controlling the call-site to give your intended binding. We'll see shortly a way of "fixing" that problem by *fixing* the `this` .

Explicit Binding

With *implicit binding* as we just saw, we had to mutate the object in question to include a reference on itself to the function, and use this property function reference to indirectly (implicitly) bind `this` to the object.

But, what if you want to force a function call to use a particular object for the `this` binding, without putting a property function reference on the object?

"All" functions in the language have some utilities available to them (via their `[[Prototype]]` -- more on that later) which can be useful for this task. Specifically, functions have `call(..)` and `apply(..)` methods. Technically, JavaScript host environments sometimes provide functions which are special enough (a kind way of putting it!) that they do not have such functionality. But those are few. The vast majority of functions provided, and certainly all functions you will create, do have access to `call(..)` and `apply(..)`.

How do these utilities work? They both take, as their first parameter, an object to use for the `this`, and then invoke the function with that `this` specified. Since you are directly stating what you want the `this` to be, we call it *explicit binding*.

Consider:

```
function foo() {
	console.log( this.a );
}

var obj = {
	a: 2
};

foo.call( obj ); // 2
```

Invoking `foo` with *explicit binding* by `foo.call(..)` allows us to force its `this` to be `obj`.

If you pass a simple primitive value (of type `string`, `boolean`, or `number`) as the `this` binding, the primitive value is wrapped in its object-form (`new String(..)`, `new Boolean(..)`, or `new Number(..)`, respectively). This is often referred to as "boxing".

Note: With respect to `this` binding, `call(..)` and `apply(..)` are identical. They *do* behave differently with their additional parameters, but that's not something we care about presently.

Unfortunately, *explicit binding* alone still doesn't offer any solution to the issue mentioned previously, of a function "losing" its intended `this` binding, or just having it paved over by a framework, etc.

Hard Binding

But a variation pattern around *explicit binding* actually does the trick. Consider:

```
function foo() {
	console.log( this.a );
}

var obj = {
	a: 2
};

var bar = function() {
	foo.call( obj );
};

bar(); // 2
setTimeout( bar, 100 ); // 2

// `bar` hard binds `foo`'s `this` to `obj`
// so that it cannot be overriden
bar.call( window ); // 2
```

Let's examine how this variation works. We create a function `bar()` which, internally, manually calls `foo.call(obj)`, thereby forcibly invoking `foo` with `obj` binding for `this`. No matter how you later invoke the function `bar`, it will always manually invoke `foo` with `obj`. This binding is both explicit and strong, so we call it *hard binding*.

The most typical way to wrap a function with a *hard binding* creates a pass-thru of any arguments passed and any return value received:

```
function foo(something) {
	console.log( this.a, something );
	return this.a + something;
}
```

```
var obj = {
	a: 2
};

var bar = function() {
	return foo.apply( obj, arguments );
};

var b = bar( 3 ); // 2 3
console.log( b ); // 5
```

Another way to express this pattern is to create a re-usable helper:

```
function foo(something) {
	console.log( this.a, something );
	return this.a + something;
}

// simple `bind` helper
function bind(fn, obj) {
	return function() {
		return fn.apply( obj, arguments );
	};
}

var obj = {
	a: 2
};

var bar = bind( foo, obj );

var b = bar( 3 ); // 2 3
console.log( b ); // 5
```

Since *hard binding* is such a common pattern, it's provided with a built-in utility as of ES5: `Function.prototype.bind`, and it's used like this:

```
function foo(something) {
	console.log( this.a, something );
	return this.a + something;
}

var obj = {
	a: 2
};

var bar = foo.bind( obj );

var b = bar( 3 ); // 2 3
console.log( b ); // 5
```

`bind(..)` returns a new function that is hard-coded to call the original function with the `this` context set as you specified.

Note: As of ES6, the hard-bound function produced by `bind(..)` has a `.name` property that derives from the original *target function*. For example: `bar = foo.bind(..)` should have a `bar.name` value of `"bound foo"`, which is the function call name that should show up in a stack trace.

API Call "Contexts"

Many libraries' functions, and indeed many new built-in functions in the JavaScript language and host environment, provide an optional parameter, usually called "context", which is designed as a work-around for you not having to use `bind(..)` to ensure your callback function uses a particular `this`.

For instance:

```
function foo(el) {
	console.log( el, this.id );
}

var obj = {
        id: "awesome"
};

// use `obj` as `this` for `foo(..)` calls
[1, 2, 3].forEach( foo, obj ); // 1 awesome  2 awesome  3 awesome
```

Internally, these various functions almost certainly use *explicit binding* via `call(..)` or `apply(..)`, saving you the trouble.

`new` Binding

The fourth and final rule for `this` binding requires us to re-think a very common misconception about functions and objects in JavaScript.

In traditional class-oriented languages, "constructors" are special methods attached to classes, that when the class is instantiated with a `new` operator, the constructor of that class is called. This usually looks something like:

```
something = new MyClass(..);
```

JavaScript has a `new` operator, and the code pattern to use it looks basically identical to what we see in those class-oriented languages; most developers assume that JavaScript's mechanism is doing something similar. However, there really is *no connection* to class-oriented functionality implied by `new` usage in JS.

First, let's re-define what a "constructor" in JavaScript is. In JS, constructors are **just functions** that happen to be called with the `new` operator in front of them. They are not attached to classes, nor are they instantiating a class. They are not even special types of functions. They're just regular functions that are, in essence, hijacked by the use of `new` in their invocation.

For example, the `Number(..)` function acting as a constructor, quoting from the ES5.1 spec:

> 15.7.2 The Number Constructor

> When Number is called as part of a new expression it is a constructor: it initialises the newly created object.

So, pretty much any ol' function, including the built-in object functions like `Number(..)` (see Chapter 3) can be called with `new` in front of it, and that makes that function call a *constructor call*. This is an important but subtle distinction: there's really no such thing as "constructor functions", but rather construction calls *of* functions.

When a function is invoked with `new` in front of it, otherwise known as a constructor call, the following things are done automatically:

1. a brand new object is created (aka, constructed) out of thin air
2. *the newly constructed object is* `[[Prototype]]` *-linked*
3. the newly constructed object is set as the `this` binding for that function call
4. unless the function returns its own alternate **object**, the `new` -invoked function call will *automatically* return the newly constructed object.

Steps 1, 3, and 4 apply to our current discussion. We'll skip over step 2 for now and come back to it in Chapter 5.

Consider this code:

```
function foo(a) {
	this.a = a;
}

var bar = new foo( 2 );
console.log( bar.a ); // 2
```

By calling `foo(..)` with `new` in front of it, we've constructed a new object and set that new object as the `this` for the call of `foo(..)` . **So `new` is the final way that a function call's `this` can be bound.** We'll call this *new binding*.

Everything In Order

So, now we've uncovered the 4 rules for binding `this` in function calls. *All* you need to do is find the call-site and inspect it to see which rule applies. But, what if the call-site has multiple eligible rules? There must be an order of precedence to these rules, and so we will next demonstrate what order to apply the rules.

It should be clear that the *default binding* is the lowest priority rule of the 4. So we'll just set that one aside.

Which is more precedent, *implicit binding* or *explicit binding*? Let's test it:

```
function foo() {
	console.log( this.a );
}

var obj1 = {
	a: 2,
	foo: foo
};

var obj2 = {
	a: 3,
	foo: foo
};

obj1.foo(); // 2
obj2.foo(); // 3

obj1.foo.call( obj2 ); // 3
obj2.foo.call( obj1 ); // 2
```

So, *explicit binding* takes precedence over *implicit binding*, which means you should ask **first** if *explicit binding* applies before checking for *implicit binding*.

Now, we just need to figure out where *new binding* fits in the precedence.

```
function foo(something) {
	this.a = something;
}

var obj1 = {
	foo: foo
};

var obj2 = {};

obj1.foo( 2 );
console.log( obj1.a ); // 2

obj1.foo.call( obj2, 3 );
console.log( obj2.a ); // 3

var bar = new obj1.foo( 4 );
console.log( obj1.a ); // 2
console.log( bar.a ); // 4
```

OK, *new binding* is more precedent than *implicit binding*. But do you think *new binding* is more or less precedent than *explicit binding*?

Note: `new` and `call` / `apply` cannot be used together, so `new foo.call(obj1)` is not allowed, to test *new binding* directly against *explicit binding*. But we can still use a *hard binding* to test the precedence of the two rules.

Before we explore that in a code listing, think back to how *hard binding* physically works, which is that `Function.prototype.bind(..)` creates a new wrapper function that is hard-coded to ignore its own `this` binding (whatever it may be), and use a manual one we provide.

By that reasoning, it would seem obvious to assume that *hard binding* (which is a form of *explicit binding*) is more precedent than *new binding*, and thus cannot be overridden with `new` .

Let's check:

```
function foo(something) {
	this.a = something;
}

var obj1 = {};

var bar = foo.bind( obj1 );
bar( 2 );
console.log( obj1.a ); // 2

var baz = new bar( 3 );
console.log( obj1.a ); // 2
console.log( baz.a ); // 3
```

Whoa! `bar` is hard-bound against `obj1`, but `new bar(3)` did **not** change `obj1.a` to be `3` as we would have expected. Instead, the *hard bound* (to `obj1`) call to `bar(..)` ***is*** able to be overridden with `new`. Since `new` was applied, we got the newly created object back, which we named `baz`, and we see in fact that `baz.a` has the value `3`.

This should be surprising if you go back to our "fake" bind helper:

```
function bind(fn, obj) {
	return function() {
		fn.apply( obj, arguments );
	};
}
```

If you reason about how the helper's code works, it does not have a way for a `new` operator call to override the hard-binding to `obj` as we just observed.

But the built-in `Function.prototype.bind(..)` as of ES5 is more sophisticated, quite a bit so in fact. Here is the (slightly reformatted) polyfill provided by the MDN page for `bind(..)`:

```
if (!Function.prototype.bind) {
	Function.prototype.bind = function(oThis) {
		if (typeof this !== "function") {
			// closest thing possible to the ECMAScript 5
			// internal IsCallable function
			throw new TypeError( "Function.prototype.bind - what " +
				"is trying to be bound is not callable"
			);
		}

		var aArgs = Array.prototype.slice.call( arguments, 1 ),
			fToBind = this,
			fNOP = function(){},
			fBound = function(){
				return fToBind.apply(
					(
						this instanceof fNOP &&
						oThis ? this : oThis
					),
					aArgs.concat( Array.prototype.slice.call( arguments ) )
				);
			}
		;

		fNOP.prototype = this.prototype;
		fBound.prototype = new fNOP();

		return fBound;
	};
}
```

Note: The `bind(..)` polyfill shown above differs from the built-in `bind(..)` in ES5 with respect to hard-bound functions that will be used with `new` (see below for why that's useful). Because the polyfill cannot create a function without a `.prototype` as the built-in utility does, there's some nuanced indirection to approximate the same behavior. Tread carefully if you plan to use `new` with a hard-bound function and you rely on this polyfill.

The part that's allowing `new` overriding is:

```
this instanceof fNOP &&
oThis ? this : oThis

// ... and:

fNOP.prototype = this.prototype;
fBound.prototype = new fNOP();
```

We won't actually dive into explaining how this trickery works (it's complicated and beyond our scope here), but essentially the utility determines whether or not the hard-bound function has been called with `new` (resulting in a newly constructed object being its `this`), and if so, it uses *that* newly created `this` rather than the previously specified *hard binding* for `this` .

Why is `new` being able to override *hard binding* useful?

The primary reason for this behavior is to create a function (that can be used with `new` for constructing objects) that essentially ignores the `this` *hard binding* but which presets some or all of the function's arguments. One of the capabilities of `bind(..)` is that any arguments passed after the first `this` binding argument are defaulted as standard arguments to the underlying function (technically called "partial application", which is a subset of "currying").

For example:

```
function foo(p1,p2) {
        this.val = p1 + p2;
}

// using `null` here because we don't care about
// the `this` hard-binding in this scenario, and
// it will be overridden by the `new` call anyway!
var bar = foo.bind( null, "p1" );

var baz = new bar( "p2" );
```

```js
baz.val; // p1p2
```

Determining `this`

Now, we can summarize the rules for determining `this` from a function call's call-site, in their order of precedence. Ask these questions in this order, and stop when the first rule applies.

1. Is the function called with `new` (**new binding**)? If so, `this` is the newly constructed object.

   ```js
   var bar = new foo()
   ```

2. Is the function called with `call` or `apply` (**explicit binding**), even hidden inside a `bind` *hard binding*? If so, `this` is the explicitly specified object.

   ```js
   var bar = foo.call( obj2 )
   ```

3. Is the function called with a context (**implicit binding**), otherwise known as an owning or containing object? If so, `this` is *that* context object.

   ```js
   var bar = obj1.foo()
   ```

4. Otherwise, default the `this` (**default binding**). If in `strict mode`, pick `undefined`, otherwise pick the `global` object.

   ```js
   var bar = foo()
   ```

That's it. That's *all it takes* to understand the rules of `this` binding for normal function calls. Well... almost.

Binding Exceptions

As usual, there are some *exceptions* to the "rules".

The `this` -binding behavior can in some scenarios be surprising, where you intended a different binding but you end up with binding behavior from the *default binding* rule (see previous).

Ignored `this`

If you pass `null` or `undefined` as a `this` binding parameter to `call` , `apply` , or `bind` , those values are effectively ignored, and instead the *default binding* rule applies to the invocation.

```
function foo() {
	console.log( this.a );
}

var a = 2;

foo.call( null ); // 2
```

Why would you intentionally pass something like `null` for a `this` binding?

It's quite common to use `apply(..)` for spreading out arrays of values as parameters to a function call. Similarly, `bind(..)` can curry parameters (pre-set values), which can be very helpful.

```
function foo(a,b) {
	console.log( "a:" + a + ", b:" + b );
}

// spreading out array as parameters
foo.apply( null, [2, 3] ); // a:2, b:3

// currying with `bind(..)`
var bar = foo.bind( null, 2 );
bar( 3 ); // a:2, b:3
```

Both these utilities require a `this` binding for the first parameter. If the functions in question don't care about `this`, you need a placeholder value, and `null` might seem like a reasonable choice as shown in this snippet.

Note: We don't cover it in this book, but ES6 has the `...` spread operator which will let you syntactically "spread out" an array as parameters without needing `apply(..)`, such as `foo(...[1,2])`, which amounts to `foo(1,2)` -- syntactically avoiding a `this` binding if it's unnecessary. Unfortunately, there's no ES6 syntactic substitute for currying, so the `this` parameter of the `bind(..)` call still needs attention.

However, there's a slight hidden "danger" in always using `null` when you don't care about the `this` binding. If you ever use that against a function call (for instance, a third-party library function that you don't control), and that function *does* make a `this` reference, the *default binding* rule means it might inadvertently reference (or worse, mutate!) the `global` object (`window` in the browser).

Obviously, such a pitfall can lead to a variety of *very difficult* to diagnose/track-down bugs.

Safer `this`

Perhaps a somewhat "safer" practice is to pass a specifically set up object for `this` which is guaranteed not to be an object that can create problematic side effects in your program. Borrowing terminology from networking (and the military), we can create a "DMZ" (de-militarized zone) object -- nothing more special than a completely empty, non-delegated (see Chapters 5 and 6) object.

If we always pass a DMZ object for ignored `this` bindings we don't think we need to care about, we're sure any hidden/unexpected usage of `this` will be restricted to the empty object, which insulates our program's `global` object from side-effects.

Since this object is totally empty, I personally like to give it the variable name `ø` (the lowercase mathematical symbol for the empty set). On many keyboards (like US-layout on Mac), this symbol is easily typed with `⌥ + o` (option+ `o`). Some systems also let you set up hotkeys for specific symbols. If you don't like the `ø` symbol, or your keyboard doesn't make that as easy to type, you can of course call it whatever you want.

Whatever you call it, the easiest way to set it up as **totally empty** is `Object.create(null)` (see Chapter 5). `Object.create(null)` is similar to `{ }`, but without the delegation to `Object.prototype`, so it's "more empty" than just `{ }`.

```
function foo(a,b) {
	console.log( "a:" + a + ", b:" + b );
}

// our DMZ empty object
var ø = Object.create( null );

// spreading out array as parameters
foo.apply( ø, [2, 3] ); // a:2, b:3

// currying with `bind(..)`
var bar = foo.bind( ø, 2 );
bar( 3 ); // a:2, b:3
```

Not only functionally "safer", there's a sort of stylistic benefit to `ø`, in that it semantically conveys "I want the `this` to be empty" a little more clearly than `null` might. But again, name your DMZ object whatever you prefer.

Indirection

Another thing to be aware of is you can (intentionally or not!) create "indirect references" to functions, and in those cases, when that function reference is invoked, the *default binding* rule also applies.

One of the most common ways that *indirect references* occur is from an assignment:

```
function foo() {
	console.log( this.a );
}

var a = 2;
var o = { a: 3, foo: foo };
var p = { a: 4 };

o.foo(); // 3
(p.foo = o.foo)(); // 2
```

The *result value* of the assignment expression `p.foo = o.foo` is a reference to just the underlying function object. As such, the effective call-site is just `foo()`, not `p.foo()` or `o.foo()` as you might expect. Per the rules above, the *default binding* rule applies.

Reminder: regardless of how you get to a function invocation using the *default binding* rule, the `strict mode` status of the **contents** of the invoked function making the `this` reference -- not the function call-site -- determines the *default binding* value: either the `global` object if in non-`strict mode` or `undefined` if in `strict mode`.

Softening Binding

We saw earlier that *hard binding* was one strategy for preventing a function call falling back to the *default binding* rule inadvertently, by forcing it to be bound to a specific `this` (unless you use `new` to override it!). The problem is, *hard-binding* greatly reduces the flexibility of a function, preventing manual `this` override with either the *implicit binding* or even subsequent *explicit binding* attempts.

It would be nice if there was a way to provide a different default for *default binding* (not `global` or `undefined`), while still leaving the function able to be manually `this` bound via *implicit binding* or *explicit binding* techniques.

We can construct a so-called *soft binding* utility which emulates our desired behavior.

```
if (!Function.prototype.softBind) {
	Function.prototype.softBind = function(obj) {
		var fn = this,
			curried = [].slice.call( arguments, 1 ),
			bound = function bound() {
				return fn.apply(
                                        (!this ||
                                                (typeof window !== "undefined" &&
                                                        this === window) ||
                                                (typeof global !== "undefined" &&
                                                        this === global)
                                        ) ? obj : this,
                                        curried.concat.apply( curried, arguments )
                                );
                        };
                bound.prototype = Object.create( fn.prototype );
                return bound;
        };
}
```

The `softBind(..)` utility provided here works similarly to the built-in ES5 `bind(..)` utility, except with our *soft binding* behavior. It wraps the specified function in logic that checks the `this` at call-time and if it's `global` or `undefined`, uses a pre-specified alternate *default* (`obj`). Otherwise the `this` is left untouched. It also provides optional currying (see the `bind(..)` discussion earlier).

Let's demonstrate its usage:

```
function foo() {
   console.log("name: " + this.name);
}

var obj = { name: "obj" },
    obj2 = { name: "obj2" },
    obj3 = { name: "obj3" };

var fooOBJ = foo.softBind( obj );

fooOBJ(); // name: obj

obj2.foo = foo.softBind(obj);
obj2.foo(); // name: obj2   <---- look!!!
```

```
fooOBJ.call( obj3 ); // name: obj3   <---- look!

setTimeout( obj2.foo, 10 ); // name: obj   <---- falls back to soft-binding
```

The soft-bound version of the `foo()` function can be manually `this` -bound to `obj2` or `obj3` as shown, but it falls back to `obj` if the *default binding* would otherwise apply.

Lexical `this`

Normal functions abide by the 4 rules we just covered. But ES6 introduces a special kind of function that does not use these rules: arrow-function.

Arrow-functions are signified not by the `function` keyword, but by the `=>` so called "fat arrow" operator. Instead of using the four standard `this` rules, arrow-functions adopt the `this` binding from the enclosing (function or global) scope.

Let's illustrate arrow-function lexical scope:

```
function foo() {
	// return an arrow function
	return (a) => {
		// `this` here is lexically adopted from `foo()`
		console.log( this.a );
	};
}

var obj1 = {
	a: 2
};

var obj2 = {
	a: 3
};
```

```
var bar = foo.call( obj1 );
bar.call( obj2 ); // 2, not 3!
```

The arrow-function created in `foo()` lexically captures whatever `foo()` s `this` is at its call-time. Since `foo()` was `this` -bound to `obj1` , `bar` (a reference to the returned arrow-function) will also be `this` -bound to `obj1` . The lexical binding of an arrow-function cannot be overridden (even with `new` !).

The most common use-case will likely be in the use of callbacks, such as event handlers or timers:

```
function foo() {
        setTimeout(() => {
                // `this` here is lexically adopted from `foo()`
                console.log( this.a );
        },100);
}

var obj = {
        a: 2
};

foo.call( obj ); // 2
```

While arrow-functions provide an alternative to using `bind(..)` on a function to ensure its `this` , which can seem attractive, it's important to note that they essentially are disabling the traditional `this` mechanism in favor of more widely-understood lexical scoping. Pre-ES6, we already have a fairly common pattern for doing so, which is basically almost indistinguishable from the spirit of ES6 arrow-functions:

```
function foo() {
        var self = this; // lexical capture of `this`
        setTimeout( function(){
                console.log( self.a );
        }, 100 );
}

var obj = {
	a: 2
};

foo.call( obj ); // 2
```

While `self = this` and arrow-functions both seem like good "solutions" to not wanting to use `bind(..)`, they are essentially fleeing from `this` instead of understanding and embracing it.

If you find yourself writing `this`-style code, but most or all the time, you defeat the `this` mechanism with lexical `self = this` or arrow-function "tricks", perhaps you should either:

1. Use only lexical scope and forget the false pretense of `this`-style code.

2. Embrace `this`-style mechanisms completely, including using `bind(..)` where necessary, and try to avoid `self = this` and arrow-function "lexical this" tricks.

A program can effectively use both styles of code (lexical and `this`), but inside of the same function, and indeed for the same sorts of look-ups, mixing the two mechanisms is usually asking for harder-to-maintain code, and probably working too hard to be clever.

Review (TL;DR)

Determining the `this` binding for an executing function requires finding the direct call-site of that function. Once examined, four rules can be applied to the call-site, in *this* order of precedence:

1. Called with `new`? Use the newly constructed object.

2. Called with `call` or `apply` (or `bind`)? Use the specified object.

3. Called with a context object owning the call? Use that context object.

4. Default: `undefined` in `strict mode`, global object otherwise.

Be careful of accidental/unintentional invoking of the *default binding* rule. In cases where you want to "safely" ignore a `this` binding, a "DMZ" object like `ø = Object.create(null)` is a good placeholder value that protects the `global` object from unintended side-effects.

Instead of the four standard binding rules, ES6 arrow-functions use lexical scoping for `this` binding, which means they adopt the `this` binding (whatever it is) from its enclosing function call. They are essentially a syntactic replacement of `self = this` in pre-ES6 coding.

You Don't Know JS Yet: *this* & Object Prototypes - 2nd Edition

Chapter 3: Objects

NOTE:
Work in progress

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In Chapters 1 and 2, we explained how the `this` binding points to various objects depending on the call-site of the function invocation. But what exactly are objects, and why do we need to point to them? We will explore objects in detail in this chapter.

Syntax

Objects come in two forms: the declarative (literal) form, and the constructed form.

The literal syntax for an object looks like this:

```
var myObj = {
        key: value
        // ...
};
```

The constructed form looks like this:

```
var myObj = new Object();
myObj.key = value;
```

The constructed form and the literal form result in exactly the same sort of object. The only difference really is that you can add one or more key/value pairs to the literal declaration, whereas with constructed-form objects, you must add the properties one-by-one.

Note: It's extremely uncommon to use the "constructed form" for creating objects as just shown. You would pretty much always want to use the literal syntax form. The same will be true of most of the built-in objects (see below).

Type

Objects are the general building block upon which much of JS is built. They are one of the 6 primary types (called "language types" in the specification) in JS:

- `string`
- `number`
- `boolean`
- `null`
- `undefined`
- `object`

Note that the *simple primitives* (`string` , `number` , `boolean` , `null` , and `undefined`) are **not** themselves `objects` . `null` is sometimes referred to as an object type, but this misconception stems from a bug in the language which causes `typeof null` to return the string `"object"` incorrectly (and confusingly). In fact, `null` is its own primitive type.

It's a common mis-statement that "everything in JavaScript is an object". This is clearly not true.

By contrast, there *are* a few special object sub-types, which we can refer to as *complex primitives*.

`function` is a sub-type of object (technically, a "callable object"). Functions in JS are said to be "first class" in that they are basically just normal objects (with callable behavior semantics bolted on), and so they can be handled like any other plain object.

Arrays are also a form of objects, with extra behavior. The organization of contents in arrays is slightly more structured than for general objects.

Built-in Objects

There are several other object sub-types, usually referred to as built-in objects. For some of them, their names seem to imply they are directly related to their simple primitives counter-parts, but in fact, their relationship is more complicated, which we'll explore shortly.

- `String`
- `Number`
- `Boolean`
- `Object`
- `Function`
- `Array`
- `Date`
- `RegExp`
- `Error`

These built-ins have the appearance of being actual types, even classes, if you rely on the similarity to other languages such as Java's `String` class.

But in JS, these are actually just built-in functions. Each of these built-in functions can be used as a constructor (that is, a function call with the `new` operator -- see Chapter 2), with the result being a newly *constructed* object of the sub-type in question. For instance:

```
var strPrimitive = "I am a string";
typeof strPrimitive;                                                // "string"
strPrimitive instanceof String;                             // false

var strObject = new String( "I am a string" );
typeof strObject;                                                       // "object"
strObject instanceof String;                                // true
```

```
// inspect the object sub-type
Object.prototype.toString.call( strObject );    // [object String]
```

We'll see in detail in a later chapter exactly how the `Object.prototype.toString...` bit works, but briefly, we can inspect the internal sub-type by borrowing the base default `toString()` method, and you can see it reveals that `strObject` is an object that was in fact created by the `String` constructor.

The primitive value `"I am a string"` is not an object, it's a primitive literal and immutable value. To perform operations on it, such as checking its length, accessing its individual character contents, etc, a `String` object is required.

Luckily, the language automatically coerces a `"string"` primitive to a `String` object when necessary, which means you almost never need to explicitly create the Object form. It is **strongly preferred** by the majority of the JS community to use the literal form for a value, where possible, rather than the constructed object form.

Consider:

```
var strPrimitive = "I am a string";

console.log( strPrimitive.length );                     // 13

console.log( strPrimitive.charAt( 3 ) );        // "m"
```

In both cases, we call a property or method on a string primitive, and the engine automatically coerces it to a `String` object, so that the property/method access works.

The same sort of coercion happens between the number literal primitive `42` and the `new Number(42)` object wrapper, when using methods like `42.359.toFixed(2)`. Likewise for `Boolean` objects from `"boolean"` primitives.

`null` and `undefined` have no object wrapper form, only their primitive values. By contrast, `Date` values can *only* be created with their constructed object form, as they have no literal form counter-part.

`Object`s, `Array`s, `Function`s, and `RegExp`s (regular expressions) are all objects regardless of whether the literal or constructed form is used. The constructed form does offer, in some cases, more options in creation than the literal form counterpart. Since objects are created either way, the simpler literal form is almost universally preferred. **Only use the constructed form if you need the extra options.**

`Error` objects are rarely created explicitly in code, but usually created automatically when exceptions are thrown. They can be created with the constructed form `new Error(..)`, but it's often unnecessary.

Contents

As mentioned earlier, the contents of an object consist of values (any type) stored at specifically named *locations*, which we call properties.

It's important to note that while we say "contents" which implies that these values are *actually* stored inside the object, that's merely an appearance. The engine stores values in implementation-dependent ways, and may very well not store them *in* some object container. What *is* stored in the container are these property names, which act as pointers (technically, *references*) to where the values are stored.

Consider:

```
var myObject = {
	a: 2
};

myObject.a;		// 2

myObject["a"];	// 2
```

To access the value at the *location* `a` in `myObject`, we need to use either the `.` operator or the `[ ]` operator. The `.a` syntax is usually referred to as "property" access, whereas the `["a"]` syntax is usually referred to as "key" access. In reality, they both access the same *location*, and will pull out the same value, `2`, so the terms can be used interchangeably. We will use the most common term, "property access" from here on.

The main difference between the two syntaxes is that the `.` operator requires an `Identifier` compatible property name after it, whereas the `[".."]` syntax can take basically any UTF-8/unicode compatible string as the name for the property. To reference a property of the name "Super-Fun!", for instance, you would have to use the `["Super-Fun!"]` access syntax, as `Super-Fun!` is not a valid `Identifier` property name.

Also, since the `[".."]` syntax uses a string's **value** to specify the location, this means the program can programmatically build up the value of the string, such as:

```
var wantA = true;
var myObject = {
	a: 2
};

var idx;

if (wantA) {
	idx = "a";
}

// later

console.log( myObject[idx] ); // 2
```

In objects, property names are **always** strings. If you use any other value besides a `string` (primitive) as the property, it will first be converted to a string. This even includes numbers, which are commonly used as array indexes, so be careful not to confuse the use of numbers between objects and arrays.

```
var myObject = { };

myObject[true] = "foo";
myObject[3] = "bar";
myObject[myObject] = "baz";

myObject["true"];                               // "foo"
myObject["3"];                                  // "bar"
myObject["[object Object]"];    // "baz"
```

Computed Property Names

The `myObject[..]` property access syntax we just described is useful if you need to use a computed expression value *as* the key name, like `myObject[prefix + name]`. But that's not really helpful when declaring objects using the object-literal syntax.

ES6 adds *computed property names*, where you can specify an expression, surrounded by a `[ ]` pair, in the key-name position of an object-literal declaration:

```
var prefix = "foo";

var myObject = {
        [prefix + "bar"]: "hello",
        [prefix + "baz"]: "world"
};

myObject["foobar"]; // hello
myObject["foobaz"]; // world
```

The most common usage of *computed property names* will probably be for ES6 `Symbol` s, which we will not be covering in detail in this book. In short, they're a new primitive data type which has an opaque unguessable value (technically a `string` value). You will be strongly discouraged from working with the *actual value* of a `Symbol` (which can theoretically be different between different JS engines), so the name of the `Symbol` , like `Symbol.Something` (just a made up name!), will be what you use:

```
var myObject = {
        [Symbol.Something]: "hello world"
};
```

Property vs. Method

Some developers like to make a distinction when talking about a property access on an object, if the value being accessed happens to be a function. Because it's tempting to think of the function as *belonging* to the object, and in other languages, functions which belong to objects (aka, "classes") are referred to as "methods", it's not uncommon to hear, "method access" as opposed to "property access".

The specification makes this same distinction, interestingly.

Technically, functions never "belong" to objects, so saying that a function that just happens to be accessed on an object reference is automatically a "method" seems a bit of a stretch of semantics.

It *is* true that some functions have `this` references in them, and that *sometimes* these `this` references refer to the object reference at the call-site. But this usage really does not make that function any more a "method" than any other function, as `this` is dynamically bound at run-time, at the call-site, and thus its relationship to the object is indirect, at best.

Every time you access a property on an object, that is a **property access**, regardless of the type of value you get back. If you *happen* to get a function from that property access, it's not magically a "method" at that point. There's nothing special (outside of possible implicit `this` binding as explained earlier) about a function that comes from a property access.

For instance:

```
function foo() {
	console.log( "foo" );
}

var someFoo = foo;	// variable reference to `foo`

var myObject = {
	someFoo: foo
};

foo;				// function foo(){..}

someFoo;			// function foo(){..}

myObject.someFoo;	// function foo(){..}
```

`someFoo` and `myObject.someFoo` are just two separate references to the same function, and neither implies anything about the function being special or "owned" by any other object. If `foo()` above was defined to have a `this` reference inside it, that `myObject.someFoo` *implicit binding* would be the **only** observable difference between the two references. Neither reference really makes sense to be called a "method".

Perhaps one could argue that a function *becomes a method*, not at definition time, but during run-time just for that invocation, depending on how it's called at its call-site (with an object reference context or not -- see Chapter 2 for more details). Even this interpretation is a bit of a stretch.

The safest conclusion is probably that "function" and "method" are interchangeable in JavaScript.

Note: ES6 adds a `super` reference, which is typically going to be used with `class` (see Appendix A). The way `super` behaves (static binding rather than late binding as `this`) gives further weight to the idea that a function which is `super` bound somewhere is more a "method" than "function". But again, these are just subtle semantic (and mechanical) nuances.

Even when you declare a function expression as part of the object-literal, that function doesn't magically *belong* more to the object -- still just multiple references to the same function object:

```
var myObject = {
        foo: function foo() {
                console.log( "foo" );
        }
};

var someFoo = myObject.foo;

someFoo;                // function foo(){..}

myObject.foo;   // function foo(){..}
```

Note: In Chapter 6, we will cover an ES6 short-hand for that `foo: function foo(){ .. }` declaration syntax in our object-literal.

Arrays

Arrays also use the `[ ]` access form, but as mentioned above, they have slightly more structured organization for how and where values are stored (though still no restriction on what *type* of values are stored). Arrays assume *numeric indexing*, which means that values are stored in locations, usually called *indices*, at non-negative integers, such as `0` and `42`.

```
var myArray = [ "foo", 42, "bar" ];

myArray.length;         // 3

myArray[0];                     // "foo"

myArray[2];                     // "bar"
```

Arrays *are* objects, so even though each index is a positive integer, you can *also* add properties onto the array:

```
var myArray = [ "foo", 42, "bar" ];

myArray.baz = "baz";

myArray.length; // 3

myArray.baz;    // "baz"
```

Notice that adding named properties (regardless of `.` or `[ ]` operator syntax) does not change the reported `length` of the array.

You *could* use an array as a plain key/value object, and never add any numeric indices, but this is a bad idea because arrays have behavior and optimizations specific to their intended use, and likewise with plain objects. Use objects to store key/value pairs, and arrays to store values at numeric indices.

Be careful: If you try to add a property to an array, but the property name *looks* like a number, it will end up instead as a numeric index (thus modifying the array contents):

```
var myArray = [ "foo", 42, "bar" ];

myArray["3"] = "baz";

myArray.length; // 4

myArray[3];             // "baz"
```

Duplicating Objects

One of the most commonly requested features when developers newly take up the JavaScript language is how to duplicate an object. It would seem like there should just be a built-in `copy()` method, right? It turns out that it's a little more complicated than that, because it's not fully clear what, by default, should be the algorithm for the duplication.

For example, consider this object:

```js
function anotherFunction() { /*..*/ }

var anotherObject = {
        c: true
};

var anotherArray = [];

var myObject = {
        a: 2,
        b: anotherObject,       // reference, not a copy!
        c: anotherArray,        // another reference!
        d: anotherFunction
};

anotherArray.push( anotherObject, myObject );
```

What exactly should be the representation of a *copy* of `myObject` ?

Firstly, we should answer if it should be a *shallow* or *deep* copy. A *shallow copy* would end up with `a` on the new object as a copy of the value `2` , but `b` , `c` , and `d` properties as just references to the same places as the references in the original object. A *deep copy* would duplicate not only `myObject` , but `anotherObject` and `anotherArray` . But then we have issues that `anotherArray` has references to `anotherObject` and `myObject` in it, so *those* should also be duplicated rather than reference-preserved. Now we have an infinite circular duplication problem because of the circular reference.

Should we detect a circular reference and just break the circular traversal (leaving the deep element not fully duplicated)? Should we error out completely? Something in between?

Moreover, it's not really clear what "duplicating" a function would mean? There are some hacks like pulling out the `toString()` serialization of a function's source code (which varies across implementations and is not even reliable in all engines depending on the type of function being inspected).

So how do we resolve all these tricky questions? Various JS frameworks have each picked their own interpretations and made their own decisions. But which of these (if any) should JS adopt as *the* standard? For a long time, there was no clear answer.

One subset solution is that objects which are JSON-safe (that is, can be serialized to a JSON string and then re-parsed to an object with the same structure and values) can easily be *duplicated* with:

```
var newObj = JSON.parse( JSON.stringify( someObj ) );
```

Of course, that requires you to ensure your object is JSON safe. For some situations, that's trivial. For others, it's insufficient.

At the same time, a shallow copy is fairly understandable and has far less issues, so ES6 has now defined `Object.assign(..)` for this task. `Object.assign(..)` takes a *target* object as its first parameter, and one or more *source* objects as its subsequent parameters. It iterates over all the *enumerable* (see below), *owned keys* (**immediately present**) on the *source* object(s) and copies them (via `=` assignment only) to *target*. It also, helpfully, returns *target*, as you can see below:

```
var newObj = Object.assign( {}, myObject );

newObj.a;                                               // 2
newObj.b === anotherObject;             // true
newObj.c === anotherArray;              // true
newObj.d === anotherFunction;   // true
```

Note: In the next section, we describe "property descriptors" (property characteristics) and show the use of `Object.defineProperty(..)`. The duplication that occurs for `Object.assign(..)` however is purely `=` style assignment, so any special characteristics of a property (like `writable`) on a source object **are not preserved** on the target object.

Property Descriptors

Prior to ES5, the JavaScript language gave no direct way for your code to inspect or draw any distinction between the characteristics of properties, such as whether the property was read-only or not.

But as of ES5, all properties are described in terms of a **property descriptor**.

Consider this code:

```
var myObject = {
	a: 2
};

Object.getOwnPropertyDescriptor( myObject, "a" );
// {
//    value: 2,
//    writable: true,
//    enumerable: true,
//    configurable: true
// }
```

As you can see, the property descriptor (called a "data descriptor" since it's only for holding a data value) for our normal object property `a` is much more than just its `value` of `2`. It includes 3 other characteristics: `writable`, `enumerable`, and `configurable`.

While we can see what the default values for the property descriptor characteristics are when we create a normal property, we can use `Object.defineProperty(..)` to add a new property, or modify an existing one (if it's `configurable`!), with the desired characteristics.

For example:

```
var myObject = {};

Object.defineProperty( myObject, "a", {
	value: 2,
	writable: true,
	configurable: true,
	enumerable: true
} );

myObject.a; // 2
```

Using `defineProperty(..)`, we added the plain, normal `a` property to `myObject` in a manually explicit way. However, you generally wouldn't use this manual approach unless you wanted to modify one of the descriptor characteristics from its normal behavior.

Writable

The ability for you to change the value of a property is controlled by `writable`.

Consider:

```
var myObject = {};

Object.defineProperty( myObject, "a", {
        value: 2,
        writable: false, // not writable!
        configurable: true,
        enumerable: true
} );

myObject.a = 3;

myObject.a; // 2
```

As you can see, our modification of the `value` silently failed. If we try in `strict mode`, we get an error:

```
"use strict";

var myObject = {};
```

```
Object.defineProperty( myObject, "a", {
        value: 2,
        writable: false, // not writable!
        configurable: true,
        enumerable: true
} );

myObject.a = 3; // TypeError
```

The `TypeError` tells us we cannot change a non-writable property.

Note: We will discuss getters/setters shortly, but briefly, you can observe that `writable:false` means a value cannot be changed, which is somewhat equivalent to if you defined a no-op setter. Actually, your no-op setter would need to throw a `TypeError` when called, to be truly conformant to `writable:false`.

Configurable

As long as a property is currently configurable, we can modify its descriptor definition, using the same `defineProperty(..)` utility.

```
var myObject = {
        a: 2
};

myObject.a = 3;
myObject.a;                                 // 3

Object.defineProperty( myObject, "a", {
        value: 4,
        writable: true,
        configurable: false,    // not configurable!
        enumerable: true
} );
```

```
myObject.a;                                     // 4
myObject.a = 5;
myObject.a;                                     // 5

Object.defineProperty( myObject, "a", {
        value: 6,
        writable: true,
        configurable: true,
        enumerable: true
} ); // TypeError
```

The final `defineProperty(..)` call results in a TypeError, regardless of `strict mode`, if you attempt to change the descriptor definition of a non-configurable property. Be careful: as you can see, changing `configurable` to `false` is a **one-way action, and cannot be undone!**

Note: There's a nuanced exception to be aware of: even if the property is already `configurable:false`, `writable` can always be changed from `true` to `false` without error, but not back to `true` if already `false`.

Another thing `configurable:false` prevents is the ability to use the `delete` operator to remove an existing property.

```
var myObject = {
        a: 2
};

myObject.a;                             // 2
delete myObject.a;
myObject.a;                             // undefined

Object.defineProperty( myObject, "a", {
        value: 2,
        writable: true,
        configurable: false,
        enumerable: true
} );
```

```
myObject.a;                     // 2
delete myObject.a;
myObject.a;                     // 2
```

As you can see, the last `delete` call failed (silently) because we made the `a` property non-configurable.

`delete` is only used to remove object properties (which can be removed) directly from the object in question. If an object property is the last remaining *reference* to some object/function, and you `delete` it, that removes the reference and now that unreferenced object/function can be garbage collected. But, it is **not** proper to think of `delete` as a tool to free up allocated memory as it does in other languages (like C/C++). `delete` is just an object property removal operation -- nothing more.

Enumerable

The final descriptor characteristic we will mention here (there are two others, which we deal with shortly when we discuss getter/setters) is `enumerable`.

The name probably makes it obvious, but this characteristic controls if a property will show up in certain object-property enumerations, such as the `for..in` loop. Set to `false` to keep it from showing up in such enumerations, even though it's still completely accessible. Set to `true` to keep it present.

All normal user-defined properties are defaulted to `enumerable`, as this is most commonly what you want. But if you have a special property you want to hide from enumeration, set it to `enumerable:false`.

We'll demonstrate enumerability in much more detail shortly, so keep a mental bookmark on this topic.

Immutability

It is sometimes desired to make properties or objects that cannot be changed (either by accident or intentionally). ES5 adds support for handling that in a variety of different nuanced ways.

It's important to note that **all** of these approaches create shallow immutability. That is, they affect only the object and its direct property characteristics. If an object has a reference to another object (array, object, function, etc), the *contents* of that object are not affected, and remain mutable.

```
myImmutableObject.foo; // [1,2,3]
myImmutableObject.foo.push( 4 );
myImmutableObject.foo; // [1,2,3,4]
```

We assume in this snippet that `myImmutableObject` is already created and protected as immutable. But, to also protect the contents of `myImmutableObject.foo` (which is its own object -- array), you would also need to make `foo` immutable, using one or more of the following functionalities.

Note: It is not terribly common to create deeply entrenched immutable objects in JS programs. Special cases can certainly call for it, but as a general design pattern, if you find yourself wanting to *seal* or *freeze* all your objects, you may want to take a step back and reconsider your program design to be more robust to potential changes in objects' values.

Object Constant

By combining `writable:false` and `configurable:false`, you can essentially create a *constant* (cannot be changed, redefined or deleted) as an object property, like:

```
var myObject = {};

Object.defineProperty( myObject, "FAVORITE_NUMBER", {
	value: 42,
	writable: false,
	configurable: false
} );
```

Prevent Extensions

If you want to prevent an object from having new properties added to it, but otherwise leave the rest of the object's properties alone, call `Object.preventExtensions(..)` :

```
var myObject = {
        a: 2
};

Object.preventExtensions( myObject );

myObject.b = 3;
myObject.b; // undefined
```

In `non-strict mode` , the creation of `b` fails silently. In `strict mode` , it throws a `TypeError` .

Seal

`Object.seal(..)` creates a "sealed" object, which means it takes an existing object and essentially calls `Object.preventExtensions(..)` on it, but also marks all its existing properties as `configurable:false` .

So, not only can you not add any more properties, but you also cannot reconfigure or delete any existing properties (though you *can* still modify their values).

Freeze

`Object.freeze(..)` creates a frozen object, which means it takes an existing object and essentially calls `Object.seal(..)` on it, but it also marks all "data accessor" properties as `writable:false` , so that their values cannot be changed.

This approach is the highest level of immutability that you can attain for an object itself, as it prevents any changes to the object or to any of its direct properties (though, as mentioned above, the contents of any referenced other objects are unaffected).

You could "deep freeze" an object by calling `Object.freeze(..)` on the object, and then recursively iterating over all objects it references (which would have been unaffected thus far), and calling `Object.freeze(..)` on them as well. Be careful, though, as that could affect other (shared) objects you're not intending to affect.

`[[Get]]`

There's a subtle, but important, detail about how property accesses are performed.

Consider:

```
var myObject = {
        a: 2
};

myObject.a; // 2
```

The `myObject.a` is a property access, but it doesn't *just* look in `myObject` for a property of the name `a`, as it might seem.

According to the spec, the code above actually performs a `[[Get]]` operation (kinda like a function call: `[[Get]]()`) on the `myObject`. The default built-in `[[Get]]` operation for an object *first* inspects the object for a property of the requested name, and if it finds it, it will return the value accordingly.

However, the `[[Get]]` algorithm defines other important behavior if it does *not* find a property of the requested name. We will examine in Chapter 5 what happens *next* (traversal of the `[[Prototype]]` chain, if any).

But one important result of this `[[Get]]` operation is that if it cannot through any means come up with a value for the requested property, it instead returns the value `undefined`.

```
var myObject = {
        a: 2
};
```

```
myObject.b; // undefined
```

This behavior is different from when you reference *variables* by their identifier names. If you reference a variable that cannot be resolved within the applicable lexical scope look-up, the result is not `undefined` as it is for object properties, but instead a `ReferenceError` is thrown.

```
var myObject = {
        a: undefined
};

myObject.a; // undefined

myObject.b; // undefined
```

From a *value* perspective, there is no difference between these two references -- they both result in `undefined` . However, the `[[Get]]` operation underneath, though subtle at a glance, potentially performed a bit more "work" for the reference `myObject.b` than for the reference `myObject.a` .

Inspecting only the value results, you cannot distinguish whether a property exists and holds the explicit value `undefined` , or whether the property does *not* exist and `undefined` was the default return value after `[[Get]]` failed to return something explicitly. However, we will see shortly how you *can* distinguish these two scenarios.

`[[Put]]`

Since there's an internally defined `[[Get]]` operation for getting a value from a property, it should be obvious there's also a default `[[Put]]` operation.

It may be tempting to think that an assignment to a property on an object would just invoke `[[Put]]` to set or create that property on the object in question. But the situation is more nuanced than that.

When invoking `[[Put]]` , how it behaves differs based on a number of factors, including (most impactfully) whether the property is already present on the object or not.

If the property is present, the `[[Put]]` algorithm will roughly check:

1. Is the property an accessor descriptor (see "Getters & Setters" section below)? **If so, call the setter, if any.**
2. Is the property a data descriptor with `writable` of `false` ? **If so, silently fail in `non-strict mode` , or throw `TypeError` in `strict mode` .**
3. Otherwise, set the value to the existing property as normal.

If the property is not yet present on the object in question, the `[[Put]]` operation is even more nuanced and complex. We will revisit this scenario in Chapter 5 when we discuss `[[Prototype]]` to give it more clarity.

Getters & Setters

The default `[[Put]]` and `[[Get]]` operations for objects completely control how values are set to existing or new properties, or retrieved from existing properties, respectively.

Note: Using future/advanced capabilities of the language, it may be possible to override the default `[[Get]]` or `[[Put]]` operations for an entire object (not just per property). This is beyond the scope of our discussion in this book, but will be covered later in the "You Don't Know JS" series.

ES5 introduced a way to override part of these default operations, not on an object level but a per-property level, through the use of getters and setters. Getters are properties which actually call a hidden function to retrieve a value. Setters are properties which actually call a hidden function to set a value.

When you define a property to have either a getter or a setter or both, its definition becomes an "accessor descriptor" (as opposed to a "data descriptor"). For accessor-descriptors, the `value` and `writable` characteristics of the descriptor are moot and ignored, and instead JS considers the `set` and `get` characteristics of the property (as well as `configurable` and `enumerable`).

Consider:

```
var myObject = {
	// define a getter for `a`
	get a() {
		return 2;
	}
};

Object.defineProperty(
	myObject,	// target
	"b",		// property name
	{			// descriptor
		// define a getter for `b`
		get: function(){ return this.a * 2 },

		// make sure `b` shows up as an object property
		enumerable: true
	}
);

myObject.a; // 2

myObject.b; // 4
```

Either through object-literal syntax with `get a() { .. }` or through explicit definition with `defineProperty(..)`, in both cases we created a property on the object that actually doesn't hold a value, but whose access automatically results in a hidden function call to the getter function, with whatever value it returns being the result of the property access.

```
var myObject = {
	// define a getter for `a`
	get a() {
		return 2;
	}
};
```

```js
myObject.a = 3;

myObject.a; // 2
```

Since we only defined a getter for `a`, if we try to set the value of `a` later, the set operation won't throw an error but will just silently throw the assignment away. Even if there was a valid setter, our custom getter is hard-coded to return only `2`, so the set operation would be moot.

To make this scenario more sensible, properties should also be defined with setters, which override the default `[[Put]]` operation (aka, assignment), per-property, just as you'd expect. You will almost certainly want to always declare both getter and setter (having only one or the other often leads to unexpected/surprising behavior):

```js
var myObject = {
	// define a getter for `a`
	get a() {
		return this._a_;
	},

	// define a setter for `a`
	set a(val) {
		this._a_ = val * 2;
	}
};

myObject.a = 2;

myObject.a; // 4
```

Note: In this example, we actually store the specified value `2` of the assignment (`[[Put]]` operation) into another variable `_a_`. The `_a_` name is purely by convention for this example and implies nothing special about its behavior -- it's a normal property like any other.

Existence

We showed earlier that a property access like `myObject.a` may result in an `undefined` value if either the explicit `undefined` is stored there or the `a` property doesn't exist at all. So, if the value is the same in both cases, how else do we distinguish them?

We can ask an object if it has a certain property *without* asking to get that property's value:

```
var myObject = {
        a: 2
};

("a" in myObject);                              // true
("b" in myObject);                              // false

myObject.hasOwnProperty( "a" ); // true
myObject.hasOwnProperty( "b" ); // false
```

The `in` operator will check to see if the property is *in* the object, or if it exists at any higher level of the `[[Prototype]]` chain object traversal (see Chapter 5). By contrast, `hasOwnProperty(..)` checks to see if *only* `myObject` has the property or not, and will *not* consult the `[[Prototype]]` chain. We'll come back to the important differences between these two operations in Chapter 5 when we explore `[[Prototype]]` s in detail.

`hasOwnProperty(..)` is accessible for all normal objects via delegation to `Object.prototype` (see Chapter 5). But it's possible to create an object that does not link to `Object.prototype` (via `Object.create(null)` -- see Chapter 5). In this case, a method call like `myObject.hasOwnProperty(..)` would fail.

In that scenario, a more robust way of performing such a check is `Object.prototype.hasOwnProperty.call(myObject,"a")` , which borrows the base `hasOwnProperty(..)` method and uses *explicit* `this` *binding* (see Chapter 2) to apply it against our `myObject` .

Note: The `in` operator has the appearance that it will check for the existence of a *value* inside a container, but it actually checks for the existence of a property name. This difference is important to note with respect to arrays, as the temptation to try a check like `4 in [2, 4, 6]` is strong, but this will not behave as expected.

Enumeration

Previously, we explained briefly the idea of "enumerability" when we looked at the `enumerable` property descriptor characteristic. Let's revisit that and examine it in more close detail.

```
var myObject = { };

Object.defineProperty(
        myObject,
        "a",
        // make `a` enumerable, as normal
        { enumerable: true, value: 2 }
);

Object.defineProperty(
        myObject,
        "b",
        // make `b` NON-enumerable
        { enumerable: false, value: 3 }
);

myObject.b; // 3
("b" in myObject); // true
myObject.hasOwnProperty( "b" ); // true

// .......

for (var k in myObject) {
        console.log( k, myObject[k] );
}
// "a" 2
```

You'll notice that `myObject.b` in fact **exists** and has an accessible value, but it doesn't show up in a `for..in` loop (though, surprisingly, it **is** revealed by the `in` operator existence check). That's because "enumerable" basically means "will be included if the object's properties are iterated through".

Note: `for..in` loops applied to arrays can give somewhat unexpected results, in that the enumeration of an array will include not only all the numeric indices, but also any enumerable properties. It's a good idea to use `for..in` loops *only* on objects, and traditional `for` loops with numeric index iteration for the values stored in arrays.

Another way that enumerable and non-enumerable properties can be distinguished:

```
var myObject = { };

Object.defineProperty(
        myObject,
        "a",
        // make `a` enumerable, as normal
        { enumerable: true, value: 2 }
);

Object.defineProperty(
        myObject,
        "b",
        // make `b` non-enumerable
        { enumerable: false, value: 3 }
);

myObject.propertyIsEnumerable( "a" ); // true
myObject.propertyIsEnumerable( "b" ); // false

Object.keys( myObject ); // ["a"]
Object.getOwnPropertyNames( myObject ); // ["a", "b"]
```

`propertyIsEnumerable(..)` tests whether the given property name exists *directly* on the object and is also `enumerable:true` .

`Object.keys(..)` returns an array of all enumerable properties, whereas `Object.getOwnPropertyNames(..)` returns an array of *all* properties, enumerable or not.

Whereas `in` vs. `hasOwnProperty(..)` differ in whether they consult the `[[Prototype]]` chain or not, `Object.keys(..)` and `Object.getOwnPropertyNames(..)` both inspect *only* the direct object specified.

There's (currently) no built-in way to get a list of **all properties** which is equivalent to what the `in` operator test would consult (traversing all properties on the entire `[[Prototype]]` chain, as explained in Chapter 5). You could approximate such a utility by recursively traversing the `[[Prototype]]` chain of an object, and for each level, capturing the list from `Object.keys(..)` -- only enumerable properties.

Iteration

The `for..in` loop iterates over the list of enumerable properties on an object (including its `[[Prototype]]` chain). But what if you instead want to iterate over the values?

With numerically-indexed arrays, iterating over the values is typically done with a standard `for` loop, like:

```
var myArray = [1, 2, 3];

for (var i = 0; i < myArray.length; i++) {
	console.log( myArray[i] );
}
// 1 2 3
```

This isn't iterating over the values, though, but iterating over the indices, where you then use the index to reference the value, as `myArray[i]`.

ES5 also added several iteration helpers for arrays, including `forEach(..)`, `every(..)`, and `some(..)`. Each of these helpers accepts a function callback to apply to each element in the array, differing only in how they respectively respond to a return value from the callback.

`forEach(..)` will iterate over all values in the array, and ignores any callback return values. `every(..)` keeps going until the end *or* the callback returns a `false` (or "falsy") value, whereas `some(..)` keeps going until the end *or* the callback returns a `true` (or "truthy") value.

These special return values inside `every(..)` and `some(..)` act somewhat like a `break` statement inside a normal `for` loop, in that they stop the iteration early before it reaches the end.

If you iterate on an object with a `for..in` loop, you're also only getting at the values indirectly, because it's actually iterating only over the enumerable properties of the object, leaving you to access the properties manually to get the values.

Note: As contrasted with iterating over an array's indices in a numerically ordered way (`for` loop or other iterators), the order of iteration over an object's properties is **not guaranteed** and may vary between different JS engines. **Do not rely** on any observed ordering for anything that requires consistency among environments, as any observed agreement is unreliable.

But what if you want to iterate over the values directly instead of the array indices (or object properties)? Helpfully, ES6 adds a `for..of` loop syntax for iterating over arrays (and objects, if the object defines its own custom iterator):

```
var myArray = [ 1, 2, 3 ];

for (var v of myArray) {
	console.log( v );
}
// 1
// 2
// 3
```

The `for..of` loop asks for an iterator object (from a default internal function known as `@@iterator` in spec-speak) of the *thing* to be iterated, and the loop then iterates over the successive return values from calling that iterator object's `next()` method, once for each loop iteration.

Arrays have a built-in `@@iterator` , so `for..of` works easily on them, as shown. But let's manually iterate the array, using the built-in `@@iterator` , to see how it works:

```
var myArray = [ 1, 2, 3 ];
var it = myArray[Symbol.iterator]();

it.next(); // { value:1, done:false }
it.next(); // { value:2, done:false }
it.next(); // { value:3, done:false }
it.next(); // { done:true }
```

Note: We get at the `@@iterator` *internal property* of an object using an ES6 `Symbol` : `Symbol.iterator` . We briefly mentioned `Symbol` semantics earlier in the chapter (see "Computed Property Names"), so the same reasoning applies here. You'll always want to reference such special properties by `Symbol` name reference instead of by the special value it may hold. Also, despite the name's implications, `@@iterator` is **not the iterator object** itself, but a **function that returns** the iterator object -- a subtle but important detail!

As the above snippet reveals, the return value from an iterator's `next()` call is an object of the form `{ value: .. , done: .. }` , where `value` is the current iteration value, and `done` is a `boolean` that indicates if there's more to iterate.

Notice the value `3` was returned with a `done:false` , which seems strange at first glance. You have to call the `next()` a fourth time (which the `for..of` loop in the previous snippet automatically does) to get `done:true` and know you're truly done iterating. The reason for this quirk is beyond the scope of what we'll discuss here, but it comes from the semantics of ES6 generator functions.

While arrays do automatically iterate in `for..of` loops, regular objects **do not have a built-in `@@iterator`** . The reasons for this intentional omission are more complex than we will examine here, but in general it was better to not include some implementation that could prove troublesome for future types of objects.

It *is* possible to define your own default `@@iterator` for any object that you care to iterate over. For example:

```
var myObject = {
        a: 2,
        b: 3
};
```

```
Object.defineProperty( myObject, Symbol.iterator, {
	enumerable: false,
	writable: false,
	configurable: true,
	value: function() {
		var o = this;
		var idx = 0;
		var ks = Object.keys( o );
		return {
			next: function() {
				return {
					value: o[ks[idx++]],
					done: (idx > ks.length)
				};
			}
		};
	}
} );

// iterate `myObject` manually
var it = myObject[Symbol.iterator]();
it.next(); // { value:2, done:false }
it.next(); // { value:3, done:false }
it.next(); // { value:undefined, done:true }

// iterate `myObject` with `for..of`
for (var v of myObject) {
	console.log( v );
}
// 2
// 3
```

Note: We used `Object.defineProperty(..)` to define our custom `@@iterator` (mostly so we could make it non-enumerable), but using the `Symbol` as a *computed property name* (covered earlier in this chapter), we could have declared it directly, like `var myObject = { a:2, b:3, [Symbol.iterator]: function(){ /* .. */ } }`.

Each time the `for..of` loop calls `next()` on `myObject` 's iterator object, the internal pointer will advance and return back the next value from the object's properties list (see a previous note about iteration ordering on object properties/values).

The iteration we just demonstrated is a simple value-by-value iteration, but you can of course define arbitrarily complex iterations for your custom data structures, as you see fit. Custom iterators combined with ES6's `for..of` loop are a powerful new syntactic tool for manipulating user-defined objects.

For example, a list of `Pixel` objects (with `x` and `y` coordinate values) could decide to order its iteration based on the linear distance from the `(0,0)` origin, or filter out points that are "too far away", etc. As long as your iterator returns the expected `{ value: .. }` return values from `next()` calls, and a `{ done: true }` after the iteration is complete, ES6's `for..of` can iterate over it.

In fact, you can even generate "infinite" iterators which never "finish" and always return a new value (such as a random number, an incremented value, a unique identifier, etc), though you probably will not use such iterators with an unbounded `for..of` loop, as it would never end and would hang your program.

```
var randoms = {
	[Symbol.iterator]: function() {
		return {
			next: function() {
				return { value: Math.random() };
			}
		};
	}
};

var randoms_pool = [];
for (var n of randoms) {
	randoms_pool.push( n );

	// don't proceed unbounded!
	if (randoms_pool.length === 100) break;
}
```

This iterator will generate random numbers "forever", so we're careful to only pull out 100 values so our program doesn't hang.

Review (TL;DR)

Objects in JS have both a literal form (such as `var a = { .. }`) and a constructed form (such as `var a = new Array(..)`). The literal form is almost always preferred, but the constructed form offers, in some cases, more creation options.

Many people mistakenly claim "everything in JavaScript is an object", but this is incorrect. Objects are one of the 6 (or 7, depending on your perspective) primitive types. Objects have sub-types, including `function`, and also can be behavior-specialized, like `[object Array]` as the internal label representing the array object sub-type.

Objects are collections of key/value pairs. The values can be accessed as properties, via `.propName` or `["propName"]` syntax. Whenever a property is accessed, the engine actually invokes the internal default `[[Get]]` operation (and `[[Put]]` for setting values), which not only looks for the property directly on the object, but which will traverse the `[[Prototype]]` chain (see Chapter 5) if not found.

Properties have certain characteristics that can be controlled through property descriptors, such as `writable` and `configurable`. In addition, objects can have their mutability (and that of their properties) controlled to various levels of immutability using `Object.preventExtensions(..)`, `Object.seal(..)`, and `Object.freeze(..)`.

Properties don't have to contain values -- they can be "accessor properties" as well, with getters/setters. They can also be either *enumerable* or not, which controls if they show up in `for..in` loop iterations, for instance.

You can also iterate over **the values** in data structures (arrays, objects, etc) using the ES6 `for..of` syntax, which looks for either a built-in or custom `@@iterator` object consisting of a `next()` method to advance through the data values one at a time.

You Don't Know JS yet: *this* & Object Prototypes - 2nd Edition

Chapter 4: Mixing (Up) "Class" Objects

NOTE:
Work in progress

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Following our exploration of objects from the previous chapter, it's natural that we now turn our attention to "object oriented (OO) programming", with "classes". We'll first look at "class orientation" as a design pattern, before examining the mechanics of "classes": "instantiation", "inheritance" and "(relative) polymorphism".

We'll see that these concepts don't really map very naturally to the object mechanism in JS, and the lengths (mixins, etc.) many JavaScript developers go to overcome such challenges.

Note: This chapter spends quite a bit of time (the first half!) on heavy "objected oriented programming" theory. We eventually relate these ideas to real concrete JavaScript code in the second half, when we talk about "Mixins". But there's a lot of concept and pseudo-code to wade through first, so don't get lost -- just stick with it!

Class Theory

"Class/Inheritance" describes a certain form of code organization and architecture -- a way of modeling real world problem domains in our software.

OO or class oriented programming stresses that data intrinsically has associated behavior (of course, different depending on the type and nature of the data!) that operates on it, so proper design is to package up (aka, encapsulate) the data and the behavior together. This is sometimes called "data structures" in formal computer science.

For example, a series of characters that represents a word or phrase is usually called a "string". The characters are the data. But you almost never just care about the data, you usually want to *do things* with the data, so the behaviors that can apply *to* that data (calculating its length, appending data, searching, etc.) are all designed as methods of a `String` class.

Any given string is just an instance of this class, which means that it's a neatly collected packaging of both the character data and the functionality we can perform on it.

Classes also imply a way of *classifying* a certain data structure. The way we do this is to think about any given structure as a specific variation of a more general base definition.

Let's explore this classification process by looking at a commonly cited example. A *car* can be described as a specific implementation of a more general "class" of thing, called a *vehicle*.

We model this relationship in software with classes by defining a `Vehicle` class and a `Car` class.

The definition of `Vehicle` might include things like propulsion (engines, etc.), the ability to carry people, etc., which would all be the behaviors. What we define in `Vehicle` is all the stuff that is common to all (or most of) the different types of vehicles (the "planes, trains, and automobiles").

It might not make sense in our software to re-define the basic essence of "ability to carry people" over and over again for each different type of vehicle. Instead, we define that capability once in `Vehicle`, and then when we define `Car`, we simply indicate that it "inherits" (or "extends") the base definition from `Vehicle`. The definition of `Car` is said to specialize the general `Vehicle` definition.

While `Vehicle` and `Car` collectively define the behavior by way of methods, the data in an instance would be things like the unique VIN of a specific car, etc.

And thus, classes, inheritance, and instantiation emerge.

Another key concept with classes is "polymorphism", which describes the idea that a general behavior from a parent class can be overridden in a child class to give it more specifics. In fact, relative polymorphism lets us reference the base behavior from the overridden behavior.

Class theory strongly suggests that a parent class and a child class share the same method name for a certain behavior, so that the child overrides the parent (differentially). As we'll see later, doing so in your JavaScript code is opting into frustration and code brittleness.

"Class" Design Pattern

You may never have thought about classes as a "design pattern", since it's most common to see discussion of popular "OO Design Patterns", like "Iterator", "Observer", "Factory", "Singleton", etc. As presented this way, it's almost an assumption that OO classes are the lower-level mechanics by which we implement all (higher level) design patterns, as if OO is a given foundation for *all* (proper) code.

Depending on your level of formal education in programming, you may have heard of "procedural programming" as a way of describing code which only consists of procedures (aka, functions) calling other functions, without any higher abstractions. You may have been taught that classes were the *proper* way to transform procedural-style "spaghetti code" into well-formed, well-organized code.

Of course, if you have experience with "functional programming" (Monads, etc.), you know very well that classes are just one of several common design patterns. But for others, this may be the first time you've asked yourself if classes really are a fundamental foundation for code, or if they are an optional abstraction on top of code.

Some languages (like Java) don't give you the choice, so it's not very *optional* at all -- everything's a class. Other languages like C/C++ or PHP give you both procedural and class-oriented syntaxes, and it's left more to the developer's choice which style or mixture of styles is appropriate.

JavaScript "Classes"

Where does JavaScript fall in this regard? JS has had *some* class-like syntactic elements (like `new` and `instanceof`) for quite awhile, and more recently in ES6, some additions, like the `class` keyword (see Appendix A).

But does that mean JavaScript actually *has* classes? Plain and simple: **No.**

Since classes are a design pattern, you *can*, with quite a bit of effort (as we'll see throughout the rest of this chapter), implement approximations for much of classical class functionality. JS tries to satisfy the extremely pervasive *desire* to design with classes by providing seemingly class-like syntax.

While we may have a syntax that looks like classes, it's as if JavaScript mechanics are fighting against you using the *class design pattern*, because behind the curtain, the mechanisms that you build on are operating quite differently. Syntactic sugar and (extremely widely used) JS "Class" libraries go a long way toward hiding this reality from you, but sooner or later you will face the fact that the *classes* you have in other languages are not like the "classes" you're faking in JS.

What this boils down to is that classes are an optional pattern in software design, and you have the choice to use them in JavaScript or not. Since many developers have a strong affinity to class oriented software design, we'll spend the rest of this chapter exploring what it takes to maintain the illusion of classes with what JS provides, and the pain points we experience.

Class Mechanics

In many class-oriented languages, the "standard library" provides a "stack" data structure (push, pop, etc.) as a `Stack` class. This class would have an internal set of variables that stores the data, and it would have a set of publicly accessible behaviors ("methods") provided by the class, which gives your code the ability to interact with the (hidden) data (adding & removing data, etc.).

But in such languages, you don't really operate directly on `Stack` (unless making a **Static** class member reference, which is outside the scope of our discussion). The `Stack` class is merely an abstract explanation of what *any* "stack" should do, but it's not itself *a* "stack". You must **instantiate** the `Stack` class before you have a concrete data structure *thing* to operate against.

Building

The traditional metaphor for "class" and "instance" based thinking comes from a building construction.

An architect plans out all the characteristics of a building: how wide, how tall, how many windows and in what locations, even what type of material to use for the walls and roof. She doesn't necessarily care, at this point, *where* the building will be built, nor does she care *how many* copies of that building will be built.

She also doesn't care very much about the contents of the building -- the furniture, wall paper, ceiling fans, etc. -- only what type of structure they will be contained by.

The architectural blue-prints she produces are only *plans* for a building. They don't actually constitute a building we can walk into and sit down. We need a builder for that task. A builder will take those plans and follow them, exactly, as he *builds* the building. In a very real sense, he is *copying* the intended characteristics from the plans to the physical building.

Once complete, the building is a physical instantiation of the blue-print plans, hopefully an essentially perfect *copy*. And then the builder can move to the open lot next door and do it all over again, creating yet another *copy*.

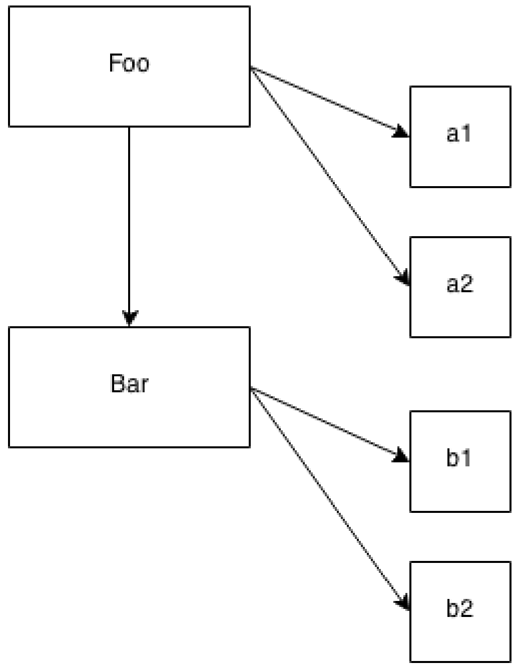
The relationship between building and blue-print is indirect. You can examine a blue-print to understand how the building was structured, for any parts where direct inspection of the building itself was insufficient. But if you want to open a door, you have to go to the building itself -- the blue-print merely has lines drawn on a page that *represent* where the door should be.

A class is a blue-print. To actually *get* an object we can interact with, we must build (aka, "instantiate") something from the class. The end result of such "construction" is an object, typically called an "instance", which we can directly call methods on and access any public data properties from, as necessary.

This object is a *copy* of all the characteristics described by the class.

You likely wouldn't expect to walk into a building and find, framed and hanging on the wall, a copy of the blue-prints used to plan the building, though the blue-prints are probably on file with a public records office. Similarly, you don't generally use an object instance to directly access and manipulate its class, but it is usually possible to at least determine *which class* an object instance comes from.

It's more useful to consider the direct relationship of a class to an object instance, rather than any indirect relationship between an object instance and the class it came from. **A class is instantiated into object form by a copy operation.**



As you can see, the arrows move from left to right, and from top to bottom, which indicates the copy operations that occur, both conceptually and physically.

Constructor

Instances of classes are constructed by a special method of the class, usually of the same name as the class, called a *constructor*. This method's explicit job is to initialize any information (state) the instance will need.

For example, consider this loose pseudo-code (invented syntax) for classes:

```
class CoolGuy {
	specialTrick = nothing

	CoolGuy( trick ) {
		specialTrick = trick
	}
```

```
        showOff() {
                output( "Here's my trick: ", specialTrick )
        }
}
```

To *make* a `CoolGuy` instance, we would call the class constructor:

```
Joe = new CoolGuy( "jumping rope" )

Joe.showOff() // Here's my trick: jumping rope
```

Notice that the `CoolGuy` class has a constructor `CoolGuy()`, which is actually what we call when we say `new CoolGuy(..)`. We get an object back (an instance of our class) from the constructor, and we can call the method `showOff()`, which prints out that particular `CoolGuy` s special trick.

Obviously, jumping rope makes Joe a pretty cool guy.

The constructor of a class *belongs* to the class, almost universally with the same name as the class. Also, constructors pretty much always need to be called with `new` to let the language engine know you want to construct a *new* class instance.

Class Inheritance

In class-oriented languages, not only can you define a class which can be instantiated itself, but you can define another class that **inherits** from the first class.

The second class is often said to be a "child class" whereas the first is the "parent class". These terms obviously come from the metaphor of parents and children, though the metaphors here are a bit stretched, as you'll see shortly.

When a parent has a biological child, the genetic characteristics of the parent are copied into the child. Obviously, in most biological reproduction systems, there are two parents who co-equally contribute genes to the mix. But for the purposes of the metaphor, we'll assume just one parent.

Once the child exists, he or she is separate from the parent. The child was heavily influenced by the inheritance from his or her parent, but is unique and distinct. If a child ends up with red hair, that doesn't mean the parent's hair *was* or automatically *becomes* red.

In a similar way, once a child class is defined, it's separate and distinct from the parent class. The child class contains an initial copy of the behavior from the parent, but can then override any inherited behavior and even define new behavior.

It's important to remember that we're talking about parent and child **classes**, which aren't physical things. This is where the metaphor of parent and child gets a little confusing, because we actually should say that a parent class is like a parent's DNA and a child class is like a child's DNA. We have to make (aka "instantiate") a person out of each set of DNA to actually have a physical person to have a conversation with.

Let's set aside biological parents and children, and look at inheritance through a slightly different lens: different types of vehicles. That's one of the most canonical (and often groan-worthy) metaphors to understand inheritance.

Let's revisit the `Vehicle` and `Car` discussion from earlier in this chapter. Consider this loose pseudo-code (invented syntax) for inherited classes:

```
class Vehicle {
	engines = 1

	ignition() {
		output( "Turning on my engine." )
	}

	drive() {
		ignition()
		output( "Steering and moving forward!" )
	}
}

class Car inherits Vehicle {
        wheels = 4

        drive() {
                inherited:drive()
                output( "Rolling on all ", wheels, " wheels!" )
        }
}

class SpeedBoat inherits Vehicle {
        engines = 2

        ignition() {
                output( "Turning on my ", engines, " engines." )
        }

        pilot() {
                inherited:drive()
                output( "Speeding through the water with ease!" )
        }
}
```

Note: For clarity and brevity, constructors for these classes have been omitted.

We define the `Vehicle` class to assume an engine, a way to turn on the ignition, and a way to drive around. But you wouldn't ever manufacture just a generic "vehicle", so it's really just an abstract concept at this point.

So then we define two specific kinds of vehicle: `Car` and `SpeedBoat` . They each inherit the general characteristics of `Vehicle` , but then they specialize the characteristics appropriately for each kind. A car needs 4 wheels, and a speed boat needs 2 engines, which means it needs extra attention to turn on the ignition of both engines.

Polymorphism

`Car` defines its own `drive()` method, which overrides the method of the same name it inherited from `Vehicle`. But then, `Car` s `drive()` method calls `inherited:drive()`, which indicates that `Car` can reference the original pre-overridden `drive()` it inherited. `SpeedBoat` s `pilot()` method also makes a reference to its inherited copy of `drive()`.

This technique is called "polymorphism", or "virtual polymorphism". More specifically to our current point, we'll call it "relative polymorphism".

Polymorphism is a much broader topic than we will exhaust here, but our current "relative" semantics refers to one particular aspect: the idea that any method can reference another method (of the same or different name) at a higher level of the inheritance hierarchy. We say "relative" because we don't absolutely define which inheritance level (aka, class) we want to access, but rather relatively reference it by essentially saying "look one level up".

In many languages, the keyword `super` is used, in place of this example's `inherited:`, which leans on the idea that a "super class" is the parent/ancestor of the current class.

Another aspect of polymorphism is that a method name can have multiple definitions at different levels of the inheritance chain, and these definitions are automatically selected as appropriate when resolving which methods are being called.

We see two occurrences of that behavior in our example above: `drive()` is defined in both `Vehicle` and `Car`, and `ignition()` is defined in both `Vehicle` and `SpeedBoat`.

Note: Another thing that traditional class-oriented languages give you via `super` is a direct way for the constructor of a child class to reference the constructor of its parent class. This is largely true because with real classes, the constructor belongs to the class. However, in JS, it's the reverse -- it's actually more appropriate to think of the "class" belonging to the constructor (the `Foo.prototype...` type references). Since in JS the relationship between child and parent exists only between the two `.prototype` objects of the respective constructors, the constructors themselves are not directly related, and thus there's no simple way to relatively reference one from the other (see Appendix A for ES6 `class` which "solves" this with `super`).

An interesting implication of polymorphism can be seen specifically with `ignition()`. Inside `pilot()`, a relative-polymorphic reference is made to (the inherited) `Vehicle` s version of `drive()`. But that `drive()` references an `ignition()` method just by name (no relative reference).

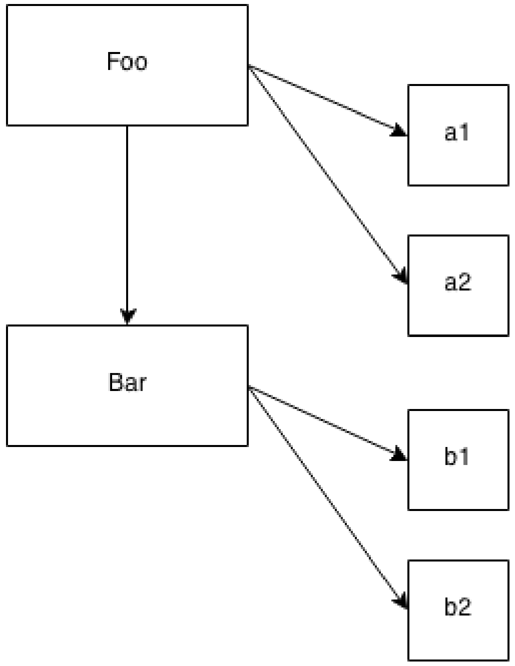
Which version of `ignition()` will the language engine use, the one from `Vehicle` or the one from `SpeedBoat`? **It uses the `SpeedBoat` version of `ignition()`.** If you *were* to instantiate `Vehicle` class itself, and then call its `drive()`, the language engine would instead just use `Vehicle`s `ignition()` method definition.

Put another way, the definition for the method `ignition()` *polymorphs* (changes) depending on which class (level of inheritance) you are referencing an instance of.

This may seem like overly deep academic detail. But understanding these details is necessary to properly contrast similar (but distinct) behaviors in JavaScript's `[[Prototype]]` mechanism.

When classes are inherited, there is a way **for the classes themselves** (not the object instances created from them!) to *relatively* reference the class inherited from, and this relative reference is usually called `super`.

Remember this figure from earlier:



Notice how for both instantiation (`a1`, `a2`, `b1`, and `b2`) *and* inheritance (`Bar`), the arrows indicate a copy operation.

Conceptually, it would seem a child class `Bar` can access behavior in its parent class `Foo` using a relative polymorphic reference (aka, `super`). However, in reality, the child class is merely given a copy of the inherited behavior from its parent class. If the child "overrides" a method it inherits, both the original and overridden versions of the method are actually maintained, so that they are both accessible.

Don't let polymorphism confuse you into thinking a child class is linked to its parent class. A child class instead gets a copy of what it needs from the parent class. **Class inheritance implies copies.**

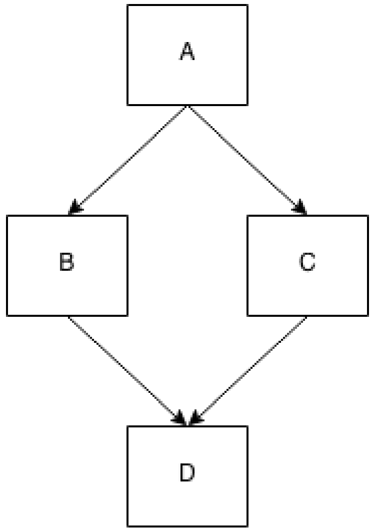
Multiple Inheritance

Recall our earlier discussion of parent(s) and children and DNA? We said that the metaphor was a bit weird because biologically most offspring come from two parents. If a class could inherit from two other classes, it would more closely fit the parent/child metaphor.

Some class-oriented languages allow you to specify more than one "parent" class to "inherit" from. Multiple-inheritance means that each parent class definition is copied into the child class.

On the surface, this seems like a powerful addition to class-orientation, giving us the ability to compose more functionality together. However, there are certainly some complicating questions that arise. If both parent classes provide a method called `drive()`, which version would a `drive()` reference in the child resolve to? Would you always have to manually specify which parent's `drive()` you meant, thus losing some of the gracefulness of polymorphic inheritance?

There's another variation, the so called "Diamond Problem", which refers to the scenario where a child class "D" inherits from two parent classes ("B" and "C"), and each of those in turn inherits from a common "A" parent. If "A" provides a method `drive()`, and both "B" and "C" override (polymorph) that method, when `D` references `drive()`, which version should it use (`B:drive()` or `C:drive()`)?



These complications go even much deeper than this quick glance. We address them here only so we can contrast to how JavaScript's mechanisms work.

JavaScript is simpler: it does not provide a native mechanism for "multiple inheritance". Many see this as a good thing, because the complexity savings more than make up for the "reduced" functionality. But this doesn't stop developers from trying to fake it in various ways, as we'll see next.

Mixins

JavaScript's object mechanism does not *automatically* perform copy behavior when you "inherit" or "instantiate". Plainly, there are no "classes" in JavaScript to instantiate, only objects. And objects don't get copied to other objects, they get *linked together* (more on that in Chapter 5).

Since observed class behaviors in other languages imply copies, let's examine how JS developers **fake** the *missing* copy behavior of classes in JavaScript: mixins. We'll look at two types of "mixin": **explicit** and **implicit**.

Explicit Mixins

Let's again revisit our `Vehicle` and `Car` example from before. Since JavaScript will not automatically copy behavior from `Vehicle` to `Car`, we can instead create a utility that manually copies. Such a utility is often called `extend(..)` by many libraries/frameworks, but we will call it `mixin(..)` here for illustrative purposes.

```
// vastly simplified `mixin(..)` example:
function mixin( sourceObj, targetObj ) {
	for (var key in sourceObj) {
		// only copy if not already present
		if (!(key in targetObj)) {
			targetObj[key] = sourceObj[key];
		}
	}

	return targetObj;
}

var Vehicle = {
	engines: 1,

	ignition: function() {
		console.log( "Turning on my engine." );
	},

	drive: function() {
		this.ignition();
		console.log( "Steering and moving forward!" );
	}
};

var Car = mixin( Vehicle, {
	wheels: 4,

	drive: function() {
		Vehicle.drive.call( this );
		console.log( "Rolling on all " + this.wheels + " wheels!" );
		}
	} );
```

Note: Subtly but importantly, we're not dealing with classes anymore, because there are no classes in JavaScript. `Vehicle` and `Car` are just objects that we make copies from and to, respectively.

`Car` now has a copy of the properties and functions from `Vehicle`. Technically, functions are not actually duplicated, but rather *references* to the functions are copied. So, `Car` now has a property called `ignition`, which is a copied reference to the `ignition()` function, as well as a property called `engines` with the copied value of `1` from `Vehicle`.

`Car` *already* had a `drive` property (function), so that property reference was not overridden (see the `if` statement in `mixin(..)` above).

"Polymorphism" Revisited

Let's examine this statement: `Vehicle.drive.call( this )`. This is what I call "explicit pseudo-polymorphism". Recall in our previous pseudo-code this line was `inherited:drive()`, which we called "relative polymorphism".

JavaScript does not have (prior to ES6; see Appendix A) a facility for relative polymorphism. So, **because both `Car` and `Vehicle` had a function of the same name: `drive()`**, to distinguish a call to one or the other, we must make an absolute (not relative) reference. We explicitly specify the `Vehicle` object by name, and call the `drive()` function on it.

But if we said `Vehicle.drive()`, the `this` binding for that function call would be the `Vehicle` object instead of the `Car` object (see Chapter 2), which is not what we want. So, instead we use `.call( this )` (Chapter 2) to ensure that `drive()` is executed in the context of the `Car` object.

Note: If the function name identifier for `Car.drive()` hadn't overlapped with (aka, "shadowed"; see Chapter 5) `Vehicle.drive()`, we wouldn't have been exercising "method polymorphism". So, a reference to `Vehicle.drive()` would have been copied over by the `mixin(..)` call, and we could have accessed directly with `this.drive()`. The chosen identifier overlap **shadowing** is *why* we have to use the more complex *explicit pseudo-polymorphism* approach.

In class-oriented languages, which have relative polymorphism, the linkage between `Car` and `Vehicle` is established once, at the top of the class definition, which makes for only one place to maintain such relationships.

But because of JavaScript's peculiarities, explicit pseudo-polymorphism (because of shadowing!) creates brittle manual/explicit linkage **in every single function where you need such a (pseudo-)polymorphic reference**. This can significantly increase the maintenance cost. Moreover, while explicit pseudo-polymorphism can emulate the behavior of "multiple inheritance", it only increases the complexity and brittleness.

The result of such approaches is usually more complex, harder-to-read, *and* harder-to-maintain code. **Explicit pseudo-polymorphism should be avoided wherever possible**, because the cost outweighs the benefit in most respects.

Mixing Copies

Recall the `mixin(..)` utility from above:

```js
// vastly simplified `mixin()` example:
function mixin( sourceObj, targetObj ) {
	for (var key in sourceObj) {
		// only copy if not already present
		if (!(key in targetObj)) {
			targetObj[key] = sourceObj[key];
		}
	}

	return targetObj;
}
```

Now, let's examine how `mixin(..)` works. It iterates over the properties of `sourceObj` (`Vehicle` in our example) and if there's no matching property of that name in `targetObj` (`Car` in our example), it makes a copy. Since we're making the copy after the initial object exists, we are careful to not copy over a target property.

If we made the copies first, before specifying the `Car` specific contents, we could omit this check against `targetObj`, but that's a little more clunky and less efficient, so it's generally less preferred:

```
// alternate mixin, less "safe" to overwrites
function mixin( sourceObj, targetObj ) {
	for (var key in sourceObj) {
		targetObj[key] = sourceObj[key];
	}

	return targetObj;
}

var Vehicle = {
	// ...
};

// first, create an empty object with
// Vehicle's stuff copied in
var Car = mixin( Vehicle, { } );

// now copy the intended contents into Car
mixin( {
	wheels: 4,

	drive: function() {
		// ...
	}
}, Car );
```

Either approach, we have explicitly copied the non-overlapping contents of `Vehicle` into `Car`. The name "mixin" comes from an alternate way of explaining the task: `Car` has `Vehicle`s contents **mixed-in**, just like you mix in chocolate chips into your favorite cookie dough.

As a result of the copy operation, `Car` will operate somewhat separately from `Vehicle`. If you add a property onto `Car`, it will not affect `Vehicle`, and vice versa.

Note: A few minor details have been skimmed over here. There are still some subtle ways the two objects can "affect" each other even after copying, such as if they both share a reference to a common object (such as an array).

Since the two objects also share references to their common functions, that means that **even manual copying of functions (aka, mixins) from one object to another doesn't *actually emulate* the real duplication from class to instance that occurs in class-oriented languages**.

JavaScript functions can't really be duplicated (in a standard, reliable way), so what you end up with instead is a **duplicated reference** to the same shared function object (functions are objects; see Chapter 3). If you modified one of the shared **function objects** (like `ignition()`) by adding properties on top of it, for instance, both `Vehicle` and `Car` would be "affected" via the shared reference.

Explicit mixins are a fine mechanism in JavaScript. But they appear more powerful than they really are. Not much benefit is *actually* derived from copying a property from one object to another, **as opposed to just defining the properties twice**, once on each object. And that's especially true given the function-object reference nuance we just mentioned.

If you explicitly mix-in two or more objects into your target object, you can **partially emulate** the behavior of "multiple inheritance", but there's no direct way to handle collisions if the same method or property is being copied from more than one source. Some developers/libraries have come up with "late binding" techniques and other exotic work-arounds, but fundamentally these "tricks" are *usually* more effort (and lesser performance!) than the pay-off.

Take care only to use explicit mixins where it actually helps make more readable code, and avoid the pattern if you find it making code that's harder to trace, or if you find it creates unnecessary or unwieldy dependencies between objects.

If it starts to get *harder* to properly use mixins than before you used them, you should probably stop using mixins. In fact, if you have to use a complex library/utility to work out all these details, it might be a sign that you're going about it the harder way, perhaps unnecessarily. In Chapter 6, we'll try to distill a simpler way that accomplishes the desired outcomes without all the fuss.

Parasitic Inheritance

A variation on this explicit mixin pattern, which is both in some ways explicit and in other ways implicit, is called "parasitic inheritance", popularized mainly by Douglas Crockford.

Here's how it can work:

```
// "Traditional JS Class" `Vehicle`
function Vehicle() {
	this.engines = 1;
}
Vehicle.prototype.ignition = function() {
	console.log( "Turning on my engine." );
};
Vehicle.prototype.drive = function() {
	this.ignition();
	console.log( "Steering and moving forward!" );
};

// "Parasitic Class" `Car`
function Car() {
	// first, `car` is a `Vehicle`
	var car = new Vehicle();

	// now, let's modify our `car` to specialize it
	car.wheels = 4;

	// save a privileged reference to `Vehicle::drive()`
	var vehDrive = car.drive;

	// override `Vehicle::drive()`
	car.drive = function() {
		vehDrive.call( this );
		console.log( "Rolling on all " + this.wheels + " wheels!" );
	};
```

```
		return car;
}

var myCar = new Car();

myCar.drive();
// Turning on my engine.
// Steering and moving forward!
// Rolling on all 4 wheels!
```

As you can see, we initially make a copy of the definition from the `Vehicle` "parent class" (object), then mixin our "child class" (object) definition (preserving privileged parent-class references as needed), and pass off this composed object `car` as our child instance.

Note: when we call `new Car()`, a new object is created and referenced by `Car` s `this` reference (see Chapter 2). But since we don't use that object, and instead return our own `car` object, the initially created object is just discarded. So, `Car()` could be called without the `new` keyword, and the functionality above would be identical, but without the wasted object creation/garbage-collection.

Implicit Mixins

Implicit mixins are closely related to *explicit pseudo-polymorphism* as explained previously. As such, they come with the same caveats and warnings.

Consider this code:

```
var Something = {
	cool: function() {
		this.greeting = "Hello World";
		this.count = this.count ? this.count + 1 : 1;
	}
};
```

```
Something.cool();
Something.greeting; // "Hello World"
Something.count; // 1

var Another = {
	cool: function() {
		// implicit mixin of `Something` to `Another`
		Something.cool.call( this );
	}
};

Another.cool();
Another.greeting; // "Hello World"
Another.count; // 1 (not shared state with `Something`)
```

With `Something.cool.call( this )`, which can happen either in a "constructor" call (most common) or in a method call (shown here), we essentially "borrow" the function `Something.cool()` and call it in the context of `Another` (via its `this` binding; see Chapter 2) instead of `Something`. The end result is that the assignments that `Something.cool()` makes are applied against the `Another` object rather than the `Something` object.

So, it is said that we "mixed in" `Something`s behavior with (or into) `Another`.

While this sort of technique seems to take useful advantage of `this` rebinding functionality, it is the brittle `Something.cool.call( this )` call, which cannot be made into a relative (and thus more flexible) reference, that you should **heed with caution**. Generally, **avoid such constructs where possible** to keep cleaner and more maintainable code.

Review (TL;DR)

Classes are a design pattern. Many languages provide syntax which enables natural class-oriented software design. JS also has a similar syntax, but it behaves **very differently** from what you're used to with classes in those other languages.

Classes mean copies.

When traditional classes are instantiated, a copy of behavior from class to instance occurs. When classes are inherited, a copy of behavior from parent to child also occurs.

Polymorphism (having different functions at multiple levels of an inheritance chain with the same name) may seem like it implies a referential relative link from child back to parent, but it's still just a result of copy behavior.

JavaScript **does not automatically** create copies (as classes imply) between objects.

The mixin pattern (both explicit and implicit) is often used to *sort of* emulate class copy behavior, but this usually leads to ugly and brittle syntax like explicit pseudo-polymorphism (`OtherObj.methodName.call(this, ...)`), which often results in harder to understand and maintain code.

Explicit mixins are also not exactly the same as class *copy*, since objects (and functions!) only have shared references duplicated, not the objects/functions duplicated themselves. Not paying attention to such nuance is the source of a variety of gotchas.

In general, faking classes in JS often sets more landmines for future coding than solving present *real* problems.

You Don't Know JS Yet: *this* & Object Prototypes - 2nd Edition

Chapter 5: Prototypes

NOTE:
Work in progress

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In Chapters 3 and 4, we mentioned the `[[Prototype]]` chain several times, but haven't said what exactly it is. We will now examine prototypes in detail.

Note: All of the attempts to emulate class-copy behavior, as described previously in Chapter 4, labeled as variations of "mixins", completely circumvent the `[[Prototype]]` chain mechanism we examine here in this chapter.

`[[Prototype]]`

Objects in JavaScript have an internal property, denoted in the specification as `[[Prototype]]`, which is simply a reference to another object. Almost all objects are given a non-`null` value for this property, at the time of their creation.

Note: We will see shortly that it *is* possible for an object to have an empty `[[Prototype]]` linkage, though this is somewhat less common.

Consider:

```
var myObject = {
	a: 2
};
```

```
myObject.a; // 2
```

What is the `[[Prototype]]` reference used for? In Chapter 3, we examined the `[[Get]]` operation that is invoked when you reference a property on an object, such as `myObject.a`. For that default `[[Get]]` operation, the first step is to check if the object itself has a property `a` on it, and if so, it's used.

Note: ES6 Proxies are outside of our discussion scope in this book (will be covered in a later book in the series!), but everything we discuss here about normal `[[Get]]` and `[[Put]]` behavior does not apply if a `Proxy` is involved.

But it's what happens if `a` **isn't** present on `myObject` that brings our attention now to the `[[Prototype]]` link of the object.

The default `[[Get]]` operation proceeds to follow the `[[Prototype]]` **link** of the object if it cannot find the requested property on the object directly.

```
var anotherObject = {
	a: 2
};

// create an object linked to `anotherObject`
var myObject = Object.create( anotherObject );

myObject.a; // 2
```

Note: We will explain what `Object.create(..)` does, and how it operates, shortly. For now, just assume it creates an object with the `[[Prototype]]` linkage we're examining to the object specified.

So, we have `myObject` that is now `[[Prototype]]` linked to `anotherObject`. Clearly `myObject.a` doesn't actually exist, but nevertheless, the property access succeeds (being found on `anotherObject` instead) and indeed finds the value `2`.

But, if `a` weren't found on `anotherObject` either, its `[[Prototype]]` chain, if non-empty, is again consulted and followed.

This process continues until either a matching property name is found, or the `[[Prototype]]` chain ends. If no matching property is *ever* found by the end of the chain, the return result from the `[[Get]]` operation is `undefined`.

Similar to this `[[Prototype]]` chain look-up process, if you use a `for..in` loop to iterate over an object, any property that can be reached via its chain (and is also `enumerable` -- see Chapter 3) will be enumerated. If you use the `in` operator to test for the existence of a property on an object, `in` will check the entire chain of the object (regardless of *enumerability*).

```
var anotherObject = {
	a: 2
};

// create an object linked to `anotherObject`
var myObject = Object.create( anotherObject );

for (var k in myObject) {
	console.log("found: " + k);
}
// found: a

("a" in myObject); // true
```

So, the `[[Prototype]]` chain is consulted, one link at a time, when you perform property look-ups in various fashions. The look-up stops once the property is found or the chain ends.

`Object.prototype`

But *where* exactly does the `[[Prototype]]` chain "end"?

The top-end of every *normal* `[[Prototype]]` chain is the built-in `Object.prototype`. This object includes a variety of common utilities used all over JS, because all normal (built-in, not host-specific extension) objects in JavaScript "descend from" (aka, have at the top of their `[[Prototype]]` chain) the `Object.prototype` object.

Some utilities found here you may be familiar with include `.toString()` and `.valueOf()` . In Chapter 3, we introduced another: `.hasOwnProperty(..)` . And yet another function on `Object.prototype` you may not be familiar with, but which we'll address later in this chapter, is `.isPrototypeOf(..)` .

Setting & Shadowing Properties

Back in Chapter 3, we mentioned that setting properties on an object was more nuanced than just adding a new property to the object or changing an existing property's value. We will now revisit this situation more completely.

```
myObject.foo = "bar";
```

If the `myObject` object already has a normal data accessor property called `foo` directly present on it, the assignment is as simple as changing the value of the existing property.

If `foo` is not already present directly on `myObject` , the `[[Prototype]]` chain is traversed, just like for the `[[Get]]` operation. If `foo` is not found anywhere in the chain, the property `foo` is added directly to `myObject` with the specified value, as expected.

However, if `foo` is already present somewhere higher in the chain, nuanced (and perhaps surprising) behavior can occur with the `myObject.foo = "bar"` assignment. We'll examine that more in just a moment.

If the property name `foo` ends up both on `myObject` itself and at a higher level of the `[[Prototype]]` chain that starts at `myObject` , this is called *shadowing*. The `foo` property directly on `myObject` *shadows* any `foo` property which appears higher in the chain, because the `myObject.foo` look-up would always find the `foo` property that's lowest in the chain.

As we just hinted, shadowing `foo` on `myObject` is not as simple as it may seem. We will now examine three scenarios for the `myObject.foo = "bar"` assignment when `foo` is **not** already on `myObject` directly, but **is** at a higher level of `myObject` 's `[[Prototype]]` chain:

1. If a normal data accessor (see Chapter 3) property named `foo` is found anywhere higher on the `[[Prototype]]` chain, **and it's not marked as read-only (`writable:false`)** then a new property called `foo` is added directly to `myObject` ,

resulting in a **shadowed property**.

2. If a `foo` is found higher on the `[[Prototype]]` chain, but it's marked as **read-only (`writable:false`)**, then both the setting of that existing property as well as the creation of the shadowed property on `myObject` **are disallowed**. If the code is running in `strict mode`, an error will be thrown. Otherwise, the setting of the property value will silently be ignored. Either way, **no shadowing occurs**.
3. If a `foo` is found higher on the `[[Prototype]]` chain and it's a setter (see Chapter 3), then the setter will always be called. No `foo` will be added to (aka, shadowed on) `myObject`, nor will the `foo` setter be redefined.

Most developers assume that assignment of a property (`[[Put]]`) will always result in shadowing if the property already exists higher on the `[[Prototype]]` chain, but as you can see, that's only true in one (#1) of the three situations just described.

If you want to shadow `foo` in cases #2 and #3, you cannot use `=` assignment, but must instead use `Object.defineProperty(..)` (see Chapter 3) to add `foo` to `myObject`.

Note: Case #2 may be the most surprising of the three. The presence of a *read-only* property prevents a property of the same name being implicitly created (shadowed) at a lower level of a `[[Prototype]]` chain. The reason for this restriction is primarily to reinforce the illusion of class-inherited properties. If you think of the `foo` at a higher level of the chain as having been inherited (copied down) to `myObject`, then it makes sense to enforce the non-writable nature of that `foo` property on `myObject`. If you however separate the illusion from the fact, and recognize that no such inheritance copying *actually* occurred (see Chapters 4 and 5), it's a little unnatural that `myObject` would be prevented from having a `foo` property just because some other object had a non-writable `foo` on it. It's even stranger that this restriction only applies to `=` assignment, but is not enforced when using `Object.defineProperty(..)`.

Shadowing with **methods** leads to ugly *explicit pseudo-polymorphism* (see Chapter 4) if you need to delegate between them. Usually, shadowing is more complicated and nuanced than it's worth, **so you should try to avoid it if possible**. See Chapter 6 for an alternative design pattern, which among other things discourages shadowing in favor of cleaner alternatives.

Shadowing can even occur implicitly in subtle ways, so care must be taken if trying to avoid it. Consider:

```
var anotherObject = {
        a: 2
};

var myObject = Object.create( anotherObject );

anotherObject.a; // 2
myObject.a; // 2

anotherObject.hasOwnProperty( "a" ); // true
myObject.hasOwnProperty( "a" ); // false

myObject.a++; // oops, implicit shadowing!

anotherObject.a; // 2
myObject.a; // 3

myObject.hasOwnProperty( "a" ); // true
```

Though it may appear that `myObject.a++` should (via delegation) look-up and just increment the `anotherObject.a` property itself *in place*, instead the `++` operation corresponds to `myObject.a = myObject.a + 1`. The result is `[[Get]]` looking up `a` property via `[[Prototype]]` to get the current value `2` from `anotherObject.a`, incrementing the value by one, then `[[Put]]` assigning the `3` value to a new shadowed property `a` on `myObject`. Oops!

Be very careful when dealing with delegated properties that you modify. If you wanted to increment `anotherObject.a`, the only proper way is `anotherObject.a++`.

"Class"

At this point, you might be wondering: "*Why* does one object need to link to another object?" What's the real benefit? That is a very appropriate question to ask, but we must first understand what `[[Prototype]]` is **not** before we can fully understand and appreciate what it *is* and how it's useful.

As we explained in Chapter 4, in JavaScript, there are no abstract patterns/blueprints for objects called "classes" as there are in class-oriented languages. JavaScript **just** has objects.

In fact, JavaScript is **almost unique** among languages as perhaps the only language with the right to use the label "object oriented", because it's one of a very short list of languages where an object can be created directly, without a class at all.

In JavaScript, classes can't (being that they don't exist!) describe what an object can do. The object defines its own behavior directly. **There's *just* the object.**

"Class" Functions

There's a peculiar kind of behavior in JavaScript that has been shamelessly abused for years to *hack* something that *looks* like "classes". We'll examine this approach in detail.

The peculiar "sort-of class" behavior hinges on a strange characteristic of functions: all functions by default get a public, non-enumerable (see Chapter 3) property on them called `prototype`, which points at an otherwise arbitrary object.

```
function Foo() {
	// ...
}

Foo.prototype; // { }
```

This object is often called "Foo's prototype", because we access it via an unfortunately-named `Foo.prototype` property reference. However, that terminology is hopelessly destined to lead us into confusion, as we'll see shortly. Instead, I will call it "the object formerly known as Foo's prototype". Just kidding. How about: "object arbitrarily labeled 'Foo dot prototype'"?

Whatever we call it, what exactly is this object?

The most direct way to explain it is that each object created from calling `new Foo()` (see Chapter 2) will end up (somewhat arbitrarily) `[[Prototype]]`-linked to this "Foo dot prototype" object.

Let's illustrate:

```
function Foo() {
        // ...
}

var a = new Foo();

Object.getPrototypeOf( a ) === Foo.prototype; // true
```

When `a` is created by calling `new Foo()`, one of the things (see Chapter 2 for all *four* steps) that happens is that `a` gets an internal `[[Prototype]]` link to the object that `Foo.prototype` is pointing at.

Stop for a moment and ponder the implications of that statement.

In class-oriented languages, multiple **copies** (aka, "instances") of a class can be made, like stamping something out from a mold. As we saw in Chapter 4, this happens because the process of instantiating (or inheriting from) a class means, "copy the behavior plan from that class into a physical object", and this is done again for each new instance.

But in JavaScript, there are no such copy-actions performed. You don't create multiple instances of a class. You can create multiple objects that `[[Prototype]]` *link* to a common object. But by default, no copying occurs, and thus these objects don't end up totally separate and disconnected from each other, but rather, quite ***linked***.

`new Foo()` results in a new object (we called it `a`), and **that** new object `a` is internally `[[Prototype]]` linked to the `Foo.prototype` object.

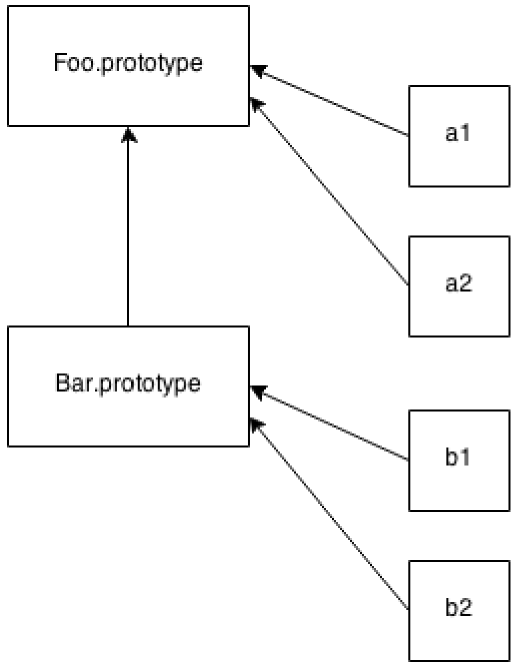
We end up with two objects, linked to each other. That's *it*. We didn't instantiate a class. We certainly didn't do any copying of behavior from a "class" into a concrete object. We just caused two objects to be linked to each other.

In fact, the secret, which eludes most JS developers, is that the `new Foo()` function calling had really almost nothing *direct* to do with the process of creating the link. **It was sort of an accidental side-effect.** `new Foo()` is an indirect, round-about way to end up with what we want: **a new object linked to another object**.

Can we get what we want in a more *direct* way? **Yes!** The hero is `Object.create(..)` . But we'll get to that in a little bit.

What's in a name?

In JavaScript, we don't make *copies* from one object ("class") to another ("instance"). We make *links* between objects. For the `[[Prototype]]` mechanism, visually, the arrows move from right to left, and from bottom to top.



This mechanism is often called "prototypal inheritance" (we'll explore the code in detail shortly), which is commonly said to be the dynamic-language version of "classical inheritance". It's an attempt to piggy-back on the common understanding of what "inheritance" means in the class-oriented world, but *tweak* (**read: pave over**) the understood semantics, to fit dynamic scripting.

The word "inheritance" has a very strong meaning (see Chapter 4), with plenty of mental precedent. Merely adding "prototypal" in front to distinguish the *actually nearly opposite* behavior in JavaScript has left in its wake nearly two decades of miry confusion.

I like to say that sticking "prototypal" in front of "inheritance" to drastically reverse its actual meaning is like holding an orange in one hand, an apple in the other, and insisting on calling the apple a "red orange". No matter what confusing label I put in front of it, that doesn't change the *fact* that one fruit is an apple and the other is an orange.

The better approach is to plainly call an apple an apple -- to use the most accurate and direct terminology. That makes it easier to understand both their similarities and their **many differences**, because we all have a simple, shared understanding of what "apple" means.

Because of the confusion and conflation of terms, I believe the label "prototypal inheritance" itself (and trying to mis-apply all its associated class-orientation terminology, like "class", "constructor", "instance", "polymorphism", etc) has done **more harm than good** in explaining how JavaScript's mechanism *really* works.

"Inheritance" implies a *copy* operation, and JavaScript doesn't copy object properties (natively, by default). Instead, JS creates a link between two objects, where one object can essentially *delegate* property/function access to another object. "Delegation" (see Chapter 6) is a much more accurate term for JavaScript's object-linking mechanism.

Another term which is sometimes thrown around in JavaScript is "differential inheritance". The idea here is that we describe an object's behavior in terms of what is *different* from a more general descriptor. For example, you explain that a car is a kind of vehicle, but one that has exactly 4 wheels, rather than re-describing all the specifics of what makes up a general vehicle (engine, etc).

If you try to think of any given object in JS as the sum total of all behavior that is *available* via delegation, and **in your mind you flatten** all that behavior into one tangible *thing*, then you can (sorta) see how "differential inheritance" might fit.

But just like with "prototypal inheritance", "differential inheritance" pretends that your mental model is more important than what is physically happening in the language. It overlooks the fact that object `B` is not actually differentially constructed, but is instead built with specific characteristics defined, alongside "holes" where nothing is defined. It is in these "holes" (gaps in, or lack of, definition) that delegation *can* take over and, on the fly, "fill them in" with delegated behavior.

The object is not, by native default, flattened into the single differential object, **through copying**, that the mental model of "differential inheritance" implies. As such, "differential inheritance" is just not as natural a fit for describing how JavaScript's `[[Prototype]]` mechanism actually works.

You *can choose* to prefer the "differential inheritance" terminology and mental model, as a matter of taste, but there's no denying the fact that it *only* fits the mental acrobatics in your mind, not the physical behavior in the engine.

"Constructors"

Let's go back to some earlier code:

```
function Foo() {
	// ...
}

var a = new Foo();
```

What exactly leads us to think `Foo` is a "class"?

For one, we see the use of the `new` keyword, just like class-oriented languages do when they construct class instances. For another, it appears that we are in fact executing a *constructor* method of a class, because `Foo()` is actually a method that gets called, just like how a real class's constructor gets called when you instantiate that class.

To further the confusion of "constructor" semantics, the arbitrarily labeled `Foo.prototype` object has another trick up its sleeve. Consider this code:

```
function Foo() {
	// ...
}

Foo.prototype.constructor === Foo; // true

var a = new Foo();
a.constructor === Foo; // true
```

The `Foo.prototype` object by default (at declaration time on line 1 of the snippet!) gets a public, non-enumerable (see Chapter 3) property called `.constructor`, and this property is a reference back to the function (`Foo` in this case) that the object is associated with. Moreover, we see that object `a` created by the "constructor" call `new Foo()` *seems* to also have a property on it called `.constructor` which similarly points to "the function which created it".

Note: This is not actually true. `a` has no `.constructor` property on it, and though `a.constructor` does in fact resolve to the `Foo` function, "constructor" **does not actually mean** "was constructed by", as it appears. We'll explain this strangeness shortly.

Oh, yeah, also... by convention in the JavaScript world, "class"es are named with a capital letter, so the fact that it's `Foo` instead of `foo` is a strong clue that we intend it to be a "class". That's totally obvious to you, right!?

Note: This convention is so strong that many JS linters actually *complain* if you call `new` on a method with a lowercase name, or if we don't call `new` on a function that happens to start with a capital letter. That sort of boggles the mind that we struggle so much to get (fake) "class-orientation" *right* in JavaScript that we create linter rules to ensure we use capital letters, even though the capital letter doesn't mean ***anything* at all** to the JS engine.

Constructor Or Call?

In the above snippet, it's tempting to think that `Foo` is a "constructor", because we call it with `new` and we observe that it "constructs" an object.

In reality, `Foo` is no more a "constructor" than any other function in your program. Functions themselves are **not** constructors. However, when you put the `new` keyword in front of a normal function call, that makes that function call a "constructor call". In fact, `new` sort of hijacks any normal function and calls it in a fashion that constructs an object, **in addition to whatever else it was going to do**.

For example:

```
function NothingSpecial() {
	console.log( "Don't mind me!" );
}
```

```
var a = new NothingSpecial();
// "Don't mind me!"

a; // {}
```

`NothingSpecial` is just a plain old normal function, but when called with `new`, it *constructs* an object, almost as a side-effect, which we happen to assign to `a`. The **call** was a *constructor call*, but `NothingSpecial` is not, in and of itself, a *constructor*.

In other words, in JavaScript, it's most appropriate to say that a "constructor" is **any function called with the `new` keyword** in front of it.

Functions aren't constructors, but function calls are "constructor calls" if and only if `new` is used.

Mechanics

Are *those* the only common triggers for ill-fated "class" discussions in JavaScript?

Not quite. JS developers have strived to simulate as much as they can of class-orientation:

```
function Foo(name) {
	this.name = name;
}

Foo.prototype.myName = function() {
	return this.name;
};

var a = new Foo( "a" );
var b = new Foo( "b" );

a.myName(); // "a"
b.myName(); // "b"
```

This snippet shows two additional "class-orientation" tricks in play:

1. `this.name = name` : adds the `.name` property onto each object (`a` and `b` , respectively; see Chapter 2 about `this` binding), similar to how class instances encapsulate data values.

2. `Foo.prototype.myName = ...` : perhaps the more interesting technique, this adds a property (function) to the `Foo.prototype` object. Now, `a.myName()` works, but perhaps surprisingly. How?

In the above snippet, it's strongly tempting to think that when `a` and `b` are created, the properties/functions on the `Foo.prototype` object are *copied* over to each of `a` and `b` objects. **However, that's not what happens.**

At the beginning of this chapter, we explained the `[[Prototype]]` link, and how it provides the fall-back look-up steps if a property reference isn't found directly on an object, as part of the default `[[Get]]` algorithm.

So, by virtue of how they are created, `a` and `b` each end up with an internal `[[Prototype]]` linkage to `Foo.prototype` . When `myName` is not found on `a` or `b` , respectively, it's instead found (through delegation, see Chapter 6) on `Foo.prototype` .

"Constructor" Redux

Recall the discussion from earlier about the `.constructor` property, and how it *seems* like `a.constructor === Foo` being true means that `a` has an actual `.constructor` property on it, pointing at `Foo` ? **Not correct.**

This is just unfortunate confusion. In actuality, the `.constructor` reference is also *delegated* up to `Foo.prototype` , which **happens to**, by default, have a `.constructor` that points at `Foo` .

It *seems* awfully convenient that an object `a` "constructed by" `Foo` would have access to a `.constructor` property that points to `Foo` . But that's nothing more than a false sense of security. It's a happy accident, almost tangentially, that `a.constructor` *happens* to point at `Foo` via this default `[[Prototype]]` delegation. There are actually several ways that the ill-fated assumption of `.constructor` meaning "was constructed by" can come back to bite you.

For one, the `.constructor` property on `Foo.prototype` is only there by default on the object created when `Foo` the function is declared. If you create a new object, and replace a function's default `.prototype` object reference, the new object will not by default magically get a `.constructor` on it.

Consider:

```
function Foo() { /* .. */ }

Foo.prototype = { /* .. */ }; // create a new prototype object

var a1 = new Foo();
a1.constructor === Foo; // false!
a1.constructor === Object; // true!
```

`Object(..)` didn't "construct" `a1` did it? It sure seems like `Foo()` "constructed" it. Many developers think of `Foo()` as doing the construction, but where everything falls apart is when you think "constructor" means "was constructed by", because by that reasoning, `a1.constructor` should be `Foo`, but it isn't!

What's happening? `a1` has no `.constructor` property, so it delegates up the `[[Prototype]]` chain to `Foo.prototype`. But that object doesn't have a `.constructor` either (like the default `Foo.prototype` object would have had!), so it keeps delegating, this time up to `Object.prototype`, the top of the delegation chain. *That* object indeed has a `.constructor` on it, which points to the built-in `Object(..)` function.

Misconception, busted.

Of course, you can add `.constructor` back to the `Foo.prototype` object, but this takes manual work, especially if you want to match native behavior and have it be non-enumerable (see Chapter 3).

For example:

```
function Foo() { /* .. */ }
```

```
Foo.prototype = { /* .. */ }; // create a new prototype object

// Need to properly "fix" the missing `.constructor`
// property on the new object serving as `Foo.prototype`.
// See Chapter 3 for `defineProperty(..)`.
Object.defineProperty( Foo.prototype, "constructor" , {
        enumerable: false,
        writable: true,
        configurable: true,
        value: Foo    // point `.constructor` at `Foo`
} );
```

That's a lot of manual work to fix `.constructor`. Moreover, all we're really doing is perpetuating the misconception that "constructor" means "was constructed by". That's an *expensive* illusion.

The fact is, `.constructor` on an object arbitrarily points, by default, at a function who, reciprocally, has a reference back to the object -- a reference which it calls `.prototype`. The words "constructor" and "prototype" only have a loose default meaning that might or might not hold true later. The best thing to do is remind yourself, "constructor does not mean constructed by".

`.constructor` is not a magic immutable property. It *is* non-enumerable (see snippet above), but its value is writable (can be changed), and moreover, you can add or overwrite (intentionally or accidentally) a property of the name `constructor` on any object in any `[[Prototype]]` chain, with any value you see fit.

By virtue of how the `[[Get]]` algorithm traverses the `[[Prototype]]` chain, a `.constructor` property reference found anywhere may resolve quite differently than you'd expect.

See how arbitrary its meaning actually is?

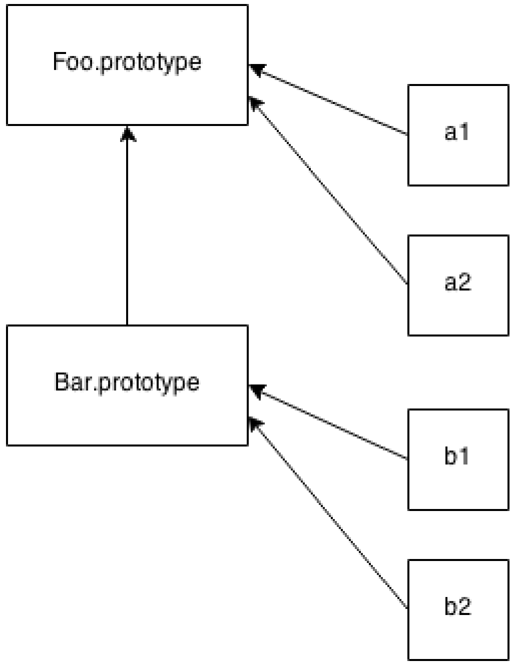
The result? Some arbitrary object-property reference like `a1.constructor` cannot actually be *trusted* to be the assumed default function reference. Moreover, as we'll see shortly, just by simple omission, `a1.constructor` can even end up pointing somewhere quite surprising and insensible.

`.constructor` is extremely unreliable, and an unsafe reference to rely upon in your code. **Generally, such references should be avoided where possible.**

"(Prototypal) Inheritance"

We've seen some approximations of "class" mechanics as typically hacked into JavaScript programs. But JavaScript "class"es would be rather hollow if we didn't have an approximation of "inheritance".

Actually, we've already seen the mechanism which is commonly called "prototypal inheritance" at work when `a` was able to "inherit from" `Foo.prototype`, and thus get access to the `myName()` function. But we traditionally think of "inheritance" as being a relationship between two "classes", rather than between "class" and "instance".



Recall this figure from earlier, which shows not only delegation from an object (aka, "instance") `a1` to object `Foo.prototype`, but from `Bar.prototype` to `Foo.prototype`, which somewhat resembles the concept of Parent-Child class inheritance. *Resembles*, except of course for the direction of the arrows, which show these are delegation links rather than copy operations.

And, here's the typical "prototype style" code that creates such links:

```
function Foo(name) {
	this.name = name;
}

Foo.prototype.myName = function() {
	return this.name;
};

function Bar(name,label) {
	Foo.call( this, name );
	this.label = label;
}

// here, we make a new `Bar.prototype`
// linked to `Foo.prototype`
Bar.prototype = Object.create( Foo.prototype );

// Beware! Now `Bar.prototype.constructor` is gone,
// and might need to be manually "fixed" if you're
// in the habit of relying on such properties!

Bar.prototype.myLabel = function() {
	return this.label;
};

var a = new Bar( "a", "obj a" );
```

```
a.myName(); // "a"
a.myLabel(); // "obj a"
```

Note: To understand why `this` points to `a` in the above code snippet, see Chapter 2.

The important part is `Bar.prototype = Object.create( Foo.prototype )`. `Object.create(..)` *creates* a "new" object out of thin air, and links that new object's internal `[[Prototype]]` to the object you specify (`Foo.prototype` in this case).

In other words, that line says: "make a *new* 'Bar dot prototype' object that's linked to 'Foo dot prototype'."

When `function Bar() { .. }` is declared, `Bar`, like any other function, has a `.prototype` link to its default object. But *that* object is not linked to `Foo.prototype` like we want. So, we create a *new* object that *is* linked as we want, effectively throwing away the original incorrectly-linked object.

Note: A common mis-conception/confusion here is that either of the following approaches would *also* work, but they do not work as you'd expect:

```
// doesn't work like you want!
Bar.prototype = Foo.prototype;

// works kinda like you want, but with
// side-effects you probably don't want :(
Bar.prototype = new Foo();
```

`Bar.prototype = Foo.prototype` doesn't create a new object for `Bar.prototype` to be linked to. It just makes `Bar.prototype` be another reference to `Foo.prototype`, which effectively links `Bar` directly to **the same object as** `Foo` links to: `Foo.prototype`. This means when you start assigning, like `Bar.prototype.myLabel = ...`, you're modifying **not a separate object** but *the* shared `Foo.prototype` object itself, which would affect any objects linked to `Foo.prototype`. This is almost certainly not what you want. If it *is* what you want, then you likely don't need `Bar` at all, and should just use only `Foo` and make your code simpler.

`Bar.prototype = new Foo()` **does in fact** create a new object which is duly linked to `Foo.prototype` as we'd want. But, it uses the `Foo(..)` "constructor call" to do it. If that function has any side-effects (such as logging, changing state, registering against other objects, **adding data properties to `this`**, etc.), those side-effects happen at the time of this linking (and likely against the wrong object!), rather than only when the eventual `Bar()` "descendants" are created, as would likely be expected.

So, we're left with using `Object.create(..)` to make a new object that's properly linked, but without having the side-effects of calling `Foo(..)`. The slight downside is that we have to create a new object, throwing the old one away, instead of modifying the existing default object we're provided.

It would be *nice* if there was a standard and reliable way to modify the linkage of an existing object. Prior to ES6, there's a non-standard and not fully-cross-browser way, via the `.__proto__` property, which is settable. ES6 adds a `Object.setPrototypeOf(..)` helper utility, which does the trick in a standard and predictable way.

Compare the pre-ES6 and ES6-standardized techniques for linking `Bar.prototype` to `Foo.prototype`, side-by-side:

```
// pre-ES6
// throws away default existing `Bar.prototype`
Bar.prototype = Object.create( Foo.prototype );

// ES6+
// modifies existing `Bar.prototype`
Object.setPrototypeOf( Bar.prototype, Foo.prototype );
```

Ignoring the slight performance disadvantage (throwing away an object that's later garbage collected) of the `Object.create(..)` approach, it's a little bit shorter and may be perhaps a little easier to read than the ES6+ approach. But it's probably a syntactic wash either way.

Inspecting "Class" Relationships

What if you have an object like `a` and want to find out what object (if any) it delegates to? Inspecting an instance (just an object in JS) for its inheritance ancestry (delegation linkage in JS) is often called *introspection* (or *reflection*) in traditional class-oriented environments.

Consider:

```
function Foo() {
	// ...
}

Foo.prototype.blah = ...;

var a = new Foo();
```

How do we then introspect `a` to find out its "ancestry" (delegation linkage)? The first approach embraces the "class" confusion:

```
a instanceof Foo; // true
```

The `instanceof` operator takes a plain object as its left-hand operand and a **function** as its right-hand operand. The question `instanceof` answers is: **in the entire `[[Prototype]]` chain of `a`, does the object arbitrarily pointed to by `Foo.prototype` ever appear?**

Unfortunately, this means that you can only inquire about the "ancestry" of some object (`a`) if you have some **function** (`Foo` , with its attached `.prototype` reference) to test with. If you have two arbitrary objects, say `a` and `b` , and want to find out if *the objects* are related to each other through a `[[Prototype]]` chain, `instanceof` alone can't help.

Note: If you use the built-in `.bind(..)` utility to make a hard-bound function (see Chapter 2), the function created will not have a `.prototype` property. Using `instanceof` with such a function transparently substitutes the `.prototype` of the *target function* that the hard-bound function was created from.

It's fairly uncommon to use hard-bound functions as "constructor calls", but if you do, it will behave as if the original *target function* was invoked instead, which means that using `instanceof` with a hard-bound function also behaves according to the original function.

This snippet illustrates the ridiculousness of trying to reason about relationships between **two objects** using "class" semantics and `instanceof`:

```
// helper utility to see if `o1` is
// related to (delegates to) `o2`
function isRelatedTo(o1, o2) {
	function F(){}
	F.prototype = o2;
	return o1 instanceof F;
}

var a = {};
var b = Object.create( a );

isRelatedTo( b, a ); // true
```

Inside `isRelatedTo(..)`, we borrow a throw-away function `F`, reassign its `.prototype` to arbitrarily point to some object `o2`, then ask if `o1` is an "instance of" `F`. Obviously `o1` isn't *actually* inherited or descended or even constructed from `F`, so it should be clear why this kind of exercise is silly and confusing. **The problem comes down to the awkwardness of class semantics forced upon JavaScript**, in this case as revealed by the indirect semantics of `instanceof`.

The second, and much cleaner, approach to `[[Prototype]]` reflection is:

```
Foo.prototype.isPrototypeOf( a ); // true
```

Notice that in this case, we don't really care about (or even *need*) `Foo`, we just need an **object** (in our case, arbitrarily labeled `Foo.prototype`) to test against another **object**. The question `isPrototypeOf(..)` answers is: **in the entire `[[Prototype]]` chain of `a`, does `Foo.prototype` ever appear?**

Same question, and exact same answer. But in this second approach, we don't actually need the indirection of referencing a **function** (`Foo`) whose `.prototype` property will automatically be consulted.

We *just need* two **objects** to inspect a relationship between them. For example:

```
// Simply: does `b` appear anywhere in
// `c`s [[Prototype]] chain?
b.isPrototypeOf( c );
```

Notice, this approach doesn't require a function ("class") at all. It just uses object references directly to `b` and `c`, and inquires about their relationship. In other words, our `isRelatedTo(..)` utility above is built-in to the language, and it's called `isPrototypeOf(..)`.

We can also directly retrieve the `[[Prototype]]` of an object. As of ES5, the standard way to do this is:

```
Object.getPrototypeOf( a );
```

And you'll notice that object reference is what we'd expect:

```
Object.getPrototypeOf( a ) === Foo.prototype; // true
```

Most browsers (not all!) have also long supported a non-standard alternate way of accessing the internal `[[Prototype]]`:

```
a.__proto__ === Foo.prototype; // true
```

The strange `.__proto__` (not standardized until ES6!) property "magically" retrieves the internal `[[Prototype]]` of an object as a reference, which is quite helpful if you want to directly inspect (or even traverse: `.__proto__.__proto__...`) the chain.

Just as we saw earlier with `.constructor`, `.__proto__` doesn't actually exist on the object you're inspecting (`a` in our running example). In fact, it exists (non-enumerable; see Chapter 2) on the built-in `Object.prototype`, along with the other common utilities (`.toString()`, `.isPrototypeOf(..)`, etc).

Moreover, `.__proto__` looks like a property, but it's actually more appropriate to think of it as a getter/setter (see Chapter 3).

Roughly, we could envision `.__proto__` implemented (see Chapter 3 for object property definitions) like this:

```
Object.defineProperty( Object.prototype, "__proto__", {
	get: function() {
		return Object.getPrototypeOf( this );
	},
	set: function(o) {
		// setPrototypeOf(..) as of ES6
		Object.setPrototypeOf( this, o );
		return o;
	}
} );
```

So, when we access (retrieve the value of) `a.__proto__`, it's like calling `a.__proto__()` (calling the getter function). *That* function call has `a` as its `this` even though the getter function exists on the `Object.prototype` object (see Chapter 2 for `this` binding rules), so it's just like saying `Object.getPrototypeOf( a )`.

`.__proto__` is also a settable property, just like using ES6's `Object.setPrototypeOf(..)` shown earlier. However, generally you **should not change the `[[Prototype]]` of an existing object**.

There are some very complex, advanced techniques used deep in some frameworks that allow tricks like "subclassing" an `Array`, but this is commonly frowned on in general programming practice, as it usually leads to *much* harder to understand/maintain code.

Note: As of ES6, the `class` keyword will allow something that approximates "subclassing" of built-in's like `Array`. See Appendix A for discussion of the `class` syntax added in ES6.

The only other narrow exception (as mentioned earlier) would be setting the `[[Prototype]]` of a default function's `.prototype` object to reference some other object (besides `Object.prototype`). That would avoid replacing that default object entirely with a new linked object. Otherwise, **it's best to treat object `[[Prototype]]` linkage as a read-only characteristic** for ease of reading your code later.

Note: The JavaScript community unofficially coined a term for the double-underscore, specifically the leading one in properties like `__proto__`: "dunder". So, the "cool kids" in JavaScript would generally pronounce `__proto__` as "dunder proto".

Object Links

As we've now seen, the `[[Prototype]]` mechanism is an internal link that exists on one object which references some other object.

This linkage is (primarily) exercised when a property/method reference is made against the first object, and no such property/method exists. In that case, the `[[Prototype]]` linkage tells the engine to look for the property/method on the linked-to object. In turn, if that object cannot fulfill the look-up, its `[[Prototype]]` is followed, and so on. This series of links between objects forms what is called the "prototype chain".

`Create()`ing Links

We've thoroughly debunked why JavaScript's `[[Prototype]]` mechanism is **not** like *classes*, and we've seen how it instead creates **links** between proper objects.

What's the point of the `[[Prototype]]` mechanism? Why is it so common for JS developers to go to so much effort (emulating classes) in their code to wire up these linkages?

Remember we said much earlier in this chapter that `Object.create(..)` would be a hero? Now, we're ready to see how.

```
var foo = {
	something: function() {
		console.log( "Tell me something good..." );
	}
};

var bar = Object.create( foo );

bar.something(); // Tell me something good...
```

`Object.create(..)` creates a new object (`bar`) linked to the object we specified (`foo`), which gives us all the power (delegation) of the `[[Prototype]]` mechanism, but without any of the unnecessary complication of `new` functions acting as classes and constructor calls, confusing `.prototype` and `.constructor` references, or any of that extra stuff.

Note: `Object.create(null)` creates an object that has an empty (aka, `null`) `[[Prototype]]` linkage, and thus the object can't delegate anywhere. Since such an object has no prototype chain, the `instanceof` operator (explained earlier) has nothing to check, so it will always return `false` . These special empty- `[[Prototype]]` objects are often called "dictionaries" as they are typically used purely for storing data in properties, mostly because they have no possible surprise effects from any delegated properties/functions on the `[[Prototype]]` chain, and are thus purely flat data storage.

We don't *need* classes to create meaningful relationships between two objects. The only thing we should **really care about** is objects linked together for delegation, and `Object.create(..)` gives us that linkage without all the class cruft.

`Object.create()` Polyfilled

`Object.create(..)` was added in ES5. You may need to support pre-ES5 environments (like older IE's), so let's take a look at a simple **partial** polyfill for `Object.create(..)` that gives us the capability that we need even in those older JS environments:

```
if (!Object.create) {
	Object.create = function(o) {
		function F(){}
		F.prototype = o;
		return new F();
	};
}
```

This polyfill works by using a throw-away `F` function and overriding its `.prototype` property to point to the object we want to link to. Then we use `new F()` construction to make a new object that will be linked as we specified.

This usage of `Object.create(..)` is by far the most common usage, because it's the part that *can be* polyfilled. There's an additional set of functionality that the standard ES5 built-in `Object.create(..)` provides, which is **not polyfillable** for pre-ES5. As such, this capability is far-less commonly used. For completeness sake, let's look at that additional functionality:

```
var anotherObject = {
	a: 2
};

var myObject = Object.create( anotherObject, {
	b: {
		enumerable: false,
		writable: true,
		configurable: false,
		value: 3
	},
	c: {
		enumerable: true,
		writable: false,
		configurable: false,
		value: 4
	}
} );
```

```
myObject.hasOwnProperty( "a" ); // false
myObject.hasOwnProperty( "b" ); // true
myObject.hasOwnProperty( "c" ); // true

myObject.a; // 2
myObject.b; // 3
myObject.c; // 4
```

The second argument to `Object.create(..)` specifies property names to add to the newly created object, via declaring each new property's *property descriptor* (see Chapter 3). Because polyfilling property descriptors into pre-ES5 is not possible, this additional functionality on `Object.create(..)` also cannot be polyfilled.

The vast majority of usage of `Object.create(..)` uses the polyfill-safe subset of functionality, so most developers are fine with using the **partial polyfill** in pre-ES5 environments.

Some developers take a much stricter view, which is that no function should be polyfilled unless it can be *fully* polyfilled. Since `Object.create(..)` is one of those partial-polyfill'able utilities, this narrower perspective says that if you need to use any of the functionality of `Object.create(..)` in a pre-ES5 environment, instead of polyfilling, you should use a custom utility, and stay away from using the name `Object.create` entirely. You could instead define your own utility, like:

```
function createAndLinkObject(o) {
	function F(){}
	F.prototype = o;
	return new F();
}

var anotherObject = {
	a: 2
};

var myObject = createAndLinkObject( anotherObject );

myObject.a; // 2
```

I do not share this strict opinion. I fully endorse the common partial-polyfill of `Object.create(..)` as shown above, and using it in your code even in pre-ES5. I'll leave it to you to make your own decision.

Links As Fallbacks?

It may be tempting to think that these links between objects *primarily* provide a sort of fallback for "missing" properties or methods. While that may be an observed outcome, I don't think it represents the right way of thinking about `[[Prototype]]`.

Consider:

```
var anotherObject = {
	cool: function() {
		console.log( "cool!" );
	}
};

var myObject = Object.create( anotherObject );

myObject.cool(); // "cool!"
```

That code will work by virtue of `[[Prototype]]`, but if you wrote it that way so that `anotherObject` was acting as a fallback **just in case** `myObject` couldn't handle some property/method that some developer may try to call, odds are that your software is going to be a bit more "magical" and harder to understand and maintain.

That's not to say there aren't cases where fallbacks are an appropriate design pattern, but it's not very common or idiomatic in JS, so if you find yourself doing so, you might want to take a step back and reconsider if that's really appropriate and sensible design.

Note: In ES6, an advanced functionality called `Proxy` is introduced which can provide something of a "method not found" type of behavior. `Proxy` is beyond the scope of this book, but will be covered in detail in a later book in the "*You Don't Know JS*" series.

Don't miss an important but nuanced point here.

Designing software where you intend for a developer to, for instance, call `myObject.cool()` and have that work even though there is no `cool()` method on `myObject` introduces some "magic" into your API design that can be surprising for future developers who maintain your software.

You can however design your API with less "magic" to it, but still take advantage of the power of `[[Prototype]]` linkage.

```js
var anotherObject = {
	cool: function() {
		console.log( "cool!" );
	}
};

var myObject = Object.create( anotherObject );

myObject.doCool = function() {
	this.cool(); // internal delegation!
};

myObject.doCool(); // "cool!"
```

Here, we call `myObject.doCool()`, which is a method that *actually exists* on `myObject`, making our API design more explicit (less "magical"). *Internally*, our implementation follows the **delegation design pattern** (see Chapter 6), taking advantage of `[[Prototype]]` delegation to `anotherObject.cool()`.

In other words, delegation will tend to be less surprising/confusing if it's an internal implementation detail rather than plainly exposed in your API design. We will expound on **delegation** in great detail in the next chapter.

Review (TL;DR)

When attempting a property access on an object that doesn't have that property, the object's internal `[[Prototype]]` linkage defines where the `[[Get]]` operation (see Chapter 3) should look next. This cascading linkage from object to object essentially defines a "prototype chain" (somewhat similar to a nested scope chain) of objects to traverse for property resolution.

All normal objects have the built-in `Object.prototype` as the top of the prototype chain (like the global scope in scope look-up), where property resolution will stop if not found anywhere prior in the chain. `toString()`, `valueOf()`, and several other common utilities exist on this `Object.prototype` object, explaining how all objects in the language are able to access them.

The most common way to get two objects linked to each other is using the `new` keyword with a function call, which among its four steps (see Chapter 2), it creates a new object linked to another object.

The "another object" that the new object is linked to happens to be the object referenced by the arbitrarily named `.prototype` property of the function called with `new`. Functions called with `new` are often called "constructors", despite the fact that they are not actually instantiating a class as *constructors* do in traditional class-oriented languages.

While these JavaScript mechanisms can seem to resemble "class instantiation" and "class inheritance" from traditional class-oriented languages, the key distinction is that in JavaScript, no copies are made. Rather, objects end up linked to each other via an internal `[[Prototype]]` chain.

For a variety of reasons, not the least of which is terminology precedent, "inheritance" (and "prototypal inheritance") and all the other OO terms just do not make sense when considering how JavaScript *actually* works (not just applied to our forced mental models).

Instead, "delegation" is a more appropriate term, because these relationships are not *copies* but delegation **links**.

You Don't Know JS Yet: *this* & Object Prototypes - 2nd Edition

Chapter 6: Behavior Delegation

NOTE:
Work in progress

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In Chapter 5, we addressed the `[[Prototype]]` mechanism in detail, and *why* it's confusing and inappropriate (despite countless attempts for nearly two decades) to describe it as "class" or "inheritance". We trudged through not only the fairly verbose syntax (`.prototype` littering the code), but the various gotchas (like surprising `.constructor` resolution or ugly pseudo-polymorphic syntax). We explored variations of the "mixin" approach, which many people use to attempt to smooth over such rough areas.

It's a common reaction at this point to wonder why it has to be so complex to do something seemingly so simple. Now that we've pulled back the curtain and seen just how dirty it all gets, it's not a surprise that most JS developers never dive this deep, and instead relegate such mess to a "class" library to handle it for them.

I hope by now you're not content to just gloss over and leave such details to a "black box" library. Let's now dig into how we *could and should be* thinking about the object `[[Prototype]]` mechanism in JS, in a **much simpler and more straightforward way** than the confusion of classes.

As a brief review of our conclusions from Chapter 5, the `[[Prototype]]` mechanism is an internal link that exists on one object which references another object.

This linkage is exercised when a property/method reference is made against the first object, and no such property/method exists. In that case, the `[[Prototype]]` linkage tells the engine to look for the property/method on the linked-to object. In turn, if that object cannot fulfill the look-up, its `[[Prototype]]` is followed, and so on. This series of links between objects forms what is called the "prototype chain".

In other words, the actual mechanism, the essence of what's important to the functionality we can leverage in JavaScript, is **all about objects being linked to other objects.**

That single observation is fundamental and critical to understanding the motivations and approaches for the rest of this chapter!

Towards Delegation-Oriented Design

To properly focus our thoughts on how to use `[[Prototype]]` in the most straightforward way, we must recognize that it represents a fundamentally different design pattern from classes (see Chapter 4).

Note: *Some* principles of class-oriented design are still very valid, so don't toss out everything you know (just most of it!). For example, *encapsulation* is quite powerful, and is compatible (though not as common) with delegation.

We need to try to change our thinking from the class/inheritance design pattern to the behavior delegation design pattern. If you have done most or all of your programming in your education/career thinking in classes, this may be uncomfortable or feel unnatural. You may need to try this mental exercise quite a few times to get the hang of this very different way of thinking.

I'm going to walk you through some theoretical exercises first, then we'll look side-by-side at a more concrete example to give you practical context for your own code.

Class Theory

Let's say we have several similar tasks ("XYZ", "ABC", etc) that we need to model in our software.

With classes, the way you design the scenario is: define a general parent (base) class like `Task`, defining shared behavior for all the "alike" tasks. Then, you define child classes `XYZ` and `ABC`, both of which inherit from `Task`, and each of which adds specialized behavior to handle their respective tasks.

Importantly, the class design pattern will encourage you that to get the most out of inheritance, you will want to employ method overriding (and polymorphism), where you override the definition of some general `Task` method in your `XYZ` task, perhaps even making use of `super` to call to the base version of that method while adding more behavior to it. **You'll likely find quite a few places** where you can "abstract" out general behavior to the parent class and specialize (override) it in your child classes.

Here's some loose pseudo-code for that scenario:

```
class Task {
	id;

	// constructor `Task()`
	Task(ID) { id = ID; }
	outputTask() { output( id ); }
}

class XYZ inherits Task {
	label;

	// constructor `XYZ()`
	XYZ(ID,Label) { super( ID ); label = Label; }
	outputTask() { super(); output( label ); }
}

class ABC inherits Task {
	// ...
}
```

Now, you can instantiate one or more **copies** of the `XYZ` child class, and use those instance(s) to perform task "XYZ". These instances have **copies both** of the general `Task` defined behavior as well as the specific `XYZ` defined behavior. Likewise, instances of the `ABC` class would have copies of the `Task` behavior and the specific `ABC` behavior. After construction, you will generally only interact with these instances (and not the classes), as the instances each have copies of all the behavior you need to do the intended task.

Delegation Theory

But now let's try to think about the same problem domain, but using *behavior delegation* instead of *classes*.

You will first define an **object** (not a class, nor a `function` as most JS'rs would lead you to believe) called `Task`, and it will have concrete behavior on it that includes utility methods that various tasks can use (read: *delegate to*!). Then, for each task ("XYZ", "ABC"), you define an **object** to hold that task-specific data/behavior. You **link** your task-specific object(s) to the `Task` utility object, allowing them to delegate to it when they need to.

Basically, you think about performing task "XYZ" as needing behaviors from two sibling/peer objects (`XYZ` and `Task`) to accomplish it. But rather than needing to compose them together, via class copies, we can keep them in their separate objects, and we can allow `XYZ` object to **delegate to** `Task` when needed.

Here's some simple code to suggest how you accomplish that:

```
var Task = {
	setID: function(ID) { this.id = ID; },
	outputID: function() { console.log( this.id ); }
};
```

```
// make `XYZ` delegate to `Task`
var XYZ = Object.create( Task );

XYZ.prepareTask = function(ID,Label) {
        this.setID( ID );
        this.label = Label;
};

XYZ.outputTaskDetails = function() {
        this.outputID();
        console.log( this.label );
};

// ABC = Object.create( Task );
// ABC ... = ...
```

In this code, `Task` and `XYZ` are not classes (or functions), they're **just objects**. `XYZ` is set up via `Object.create(..)` to `[[Prototype]]` delegate to the `Task` object (see Chapter 5).

As compared to class-orientation (aka, OO -- object-oriented), I call this style of code **"OLOO"** (objects-linked-to-other-objects). All we *really* care about is that the `XYZ` object delegates to the `Task` object (as does the `ABC` object).

In JavaScript, the `[[Prototype]]` mechanism links **objects** to other **objects**. There are no abstract mechanisms like "classes", no matter how much you try to convince yourself otherwise. It's like paddling a canoe upstream: you *can* do it, but you're *choosing* to go against the natural current, so it's obviously **going to be harder to get where you're going.**

Some other differences to note with **OLOO style code**:

1. Both `id` and `label` data members from the previous class example are data properties directly on `XYZ` (neither is on `Task`). In general, with `[[Prototype]]` delegation involved, **you want state to be on the delegators** (`XYZ` , `ABC`), not on the delegate (`Task`).

2. With the class design pattern, we intentionally named `outputTask` the same on both parent (`Task`) and child (`XYZ`), so that we could take advantage of overriding (polymorphism). In behavior delegation, we do the opposite: **we avoid if at all possible naming things the same** at different levels of the `[[Prototype]]` chain (called shadowing -- see Chapter 5), because having those name collisions creates awkward/brittle syntax to disambiguate references (see Chapter 4), and we want to avoid that if we can.

   This design pattern calls for less of general method names which are prone to overriding and instead more of descriptive method names, *specific* to the type of behavior each object is doing. **This can actually create easier to understand/maintain code**, because the names of methods (not only at definition location but strewn throughout other code) are more obvious (self documenting).

3. `this.setID(ID);` inside of a method on the `XYZ` object first looks on `XYZ` for `setID(..)` , but since it doesn't find a method of that name on `XYZ` , `[[Prototype]]` *delegation* means it can follow the link to `Task` to look for `setID(..)` , which it of course finds. Moreover, because of implicit call-site `this` binding rules (see Chapter 2), when `setID(..)` runs, even though the method was found on `Task` , the `this` binding for that function call is `XYZ` exactly as we'd expect and want. We see the same thing with `this.outputID()` later in the code listing.

   In other words, the general utility methods that exist on `Task` are available to us while interacting with `XYZ` , because `XYZ` can delegate to `Task` .

Behavior Delegation means: let some object (`XYZ`) provide a delegation (to `Task`) for property or method references if not found on the object (`XYZ`).

This is an *extremely powerful* design pattern, very distinct from the idea of parent and child classes, inheritance, polymorphism, etc. Rather than organizing the objects in your mind vertically, with Parents flowing down to Children, think of objects side-by-side, as peers, with any direction of delegation links between the objects as necessary.

Note: Delegation is more properly used as an internal implementation detail rather than exposed directly in the API design. In the above example, we don't necessarily *intend* with our API design for developers to call `XYZ.setID()` (though we can, of course!). We sorta *hide* the delegation as an internal detail of our API, where `XYZ.prepareTask(..)` delegates to `Task.setID(..)` . See the "Links As Fallbacks?" discussion in Chapter 5 for more detail.

Mutual Delegation (Disallowed)

You cannot create a *cycle* where two or more objects are mutually delegated (bi-directionally) to each other. If you make `B` linked to `A`, and then try to link `A` to `B`, you will get an error.

It's a shame (not terribly surprising, but mildly annoying) that this is disallowed. If you made a reference to a property/method which didn't exist in either place, you'd have an infinite recursion on the `[[Prototype]]` loop. But if all references were strictly present, then `B` could delegate to `A`, and vice versa, and it *could* work. This would mean you could use either object to delegate to the other, for various tasks. There are a few niche use-cases where this might be helpful.

But it's disallowed because engine implementors have observed that it's more performant to check for (and reject!) the infinite circular reference once at set-time rather than needing to have the performance hit of that guard check every time you look-up a property on an object.

Debugged

We'll briefly cover a subtle detail that can be confusing to developers. In general, the JS specification does not control how browser developer tools should represent specific values/structures to a developer, so each browser/engine is free to interpret such things as they see fit. As such, browsers/tools *don't always agree*. Specifically, the behavior we will now examine is currently observed only in Chrome's Developer Tools.

Consider this traditional "class constructor" style JS code, as it would appear in the *console* of Chrome Developer Tools:

```
function Foo() {}

var a1 = new Foo();

a1; // Foo {}
```

Let's look at the last line of that snippet: the output of evaluating the `a1` expression, which prints `Foo {}`. If you try this same code in Firefox, you will likely see `Object {}`. Why the difference? What do these outputs mean?

Chrome is essentially saying "{} is an empty object that was constructed by a function with name 'Foo'". Firefox is saying "{} is an empty object of general construction from Object". The subtle difference is that Chrome is actively tracking, as an *internal property*, the name of the actual function that did the construction, whereas other browsers don't track that additional information.

It would be tempting to attempt to explain this with JavaScript mechanisms:

```js
function Foo() {}

var a1 = new Foo();

a1.constructor; // Foo(){}
a1.constructor.name; // "Foo"
```

So, is that how Chrome is outputting "Foo", by simply examining the object's `.constructor.name`? Confusingly, the answer is both "yes" and "no".

Consider this code:

```js
function Foo() {}

var a1 = new Foo();

Foo.prototype.constructor = function Gotcha(){};

a1.constructor; // Gotcha(){}
a1.constructor.name; // "Gotcha"

a1; // Foo {}
```

Even though we change `a1.constructor.name` to legitimately be something else ("Gotcha"), Chrome's console still uses the "Foo" name.

So, it would appear the answer to previous question (does it use `.constructor.name`?) is **no**, it must track it somewhere else, internally.

But, Not so fast! Let's see how this kind of behavior works with OLOO-style code:

```
var Foo = {};

var a1 = Object.create( Foo );

a1; // Object {}

Object.defineProperty( Foo, "constructor", {
        enumerable: false,
        value: function Gotcha(){}
});

a1; // Gotcha {}
```

Ah-ha! **Gotcha!** Here, Chrome's console **did** find and use the `.constructor.name`. Actually, while writing this book, this exact behavior was identified as a bug in Chrome, and by the time you're reading this, it may have already been fixed. So you may instead have seen the corrected `a1; // Object {}`.

Aside from that bug, the internal tracking (apparently only for debug output purposes) of the "constructor name" that Chrome does (shown in the earlier snippets) is an intentional Chrome-only extension of behavior beyond what the JS specification calls for.

If you don't use a "constructor" to make your objects, as we've discouraged with OLOO-style code here in this chapter, then you'll get objects that Chrome does *not* track an internal "constructor name" for, and such objects will correctly only be outputted as "Object {}", meaning "object generated from Object() construction".

Don't think this represents a drawback of OLOO-style coding. When you code with OLOO and behavior delegation as your design pattern, *who* "constructed" (that is, *which function* was called with `new`?) some object is an irrelevant detail. Chrome's specific internal "constructor name" tracking is really only useful if you're fully embracing "class-style" coding, but is moot if you're instead embracing OLOO delegation.

Mental Models Compared

Now that you can see a difference between "class" and "delegation" design patterns, at least theoretically, let's see the implications these design patterns have on the mental models we use to reason about our code.

We'll examine some more theoretical ("Foo", "Bar") code, and compare both ways (OO vs. OLOO) of implementing the code. The first snippet uses the classical ("prototypal") OO style:

```
function Foo(who) {
        this.me = who;
}
Foo.prototype.identify = function() {
        return "I am " + this.me;
};

function Bar(who) {
        Foo.call( this, who );
}
Bar.prototype = Object.create( Foo.prototype );

Bar.prototype.speak = function() {
        alert( "Hello, " + this.identify() + "." );
};

var b1 = new Bar( "b1" );
var b2 = new Bar( "b2" );

b1.speak();
b2.speak();
```

Parent class `Foo`, inherited by child class `Bar`, which is then instantiated twice as `b1` and `b2`. What we have is `b1` delegating to `Bar.prototype` which delegates to `Foo.prototype`. This should look fairly familiar to you, at this point. Nothing too ground-breaking going on.

Now, let's implement **the exact same functionality** using *OLOO* style code:

```
var Foo = {
	init: function(who) {
		this.me = who;
	},
	identify: function() {
		return "I am " + this.me;
	}
};

var Bar = Object.create( Foo );

Bar.speak = function() {
	alert( "Hello, " + this.identify() + "." );
};

var b1 = Object.create( Bar );
b1.init( "b1" );
var b2 = Object.create( Bar );
b2.init( "b2" );

b1.speak();
b2.speak();
```

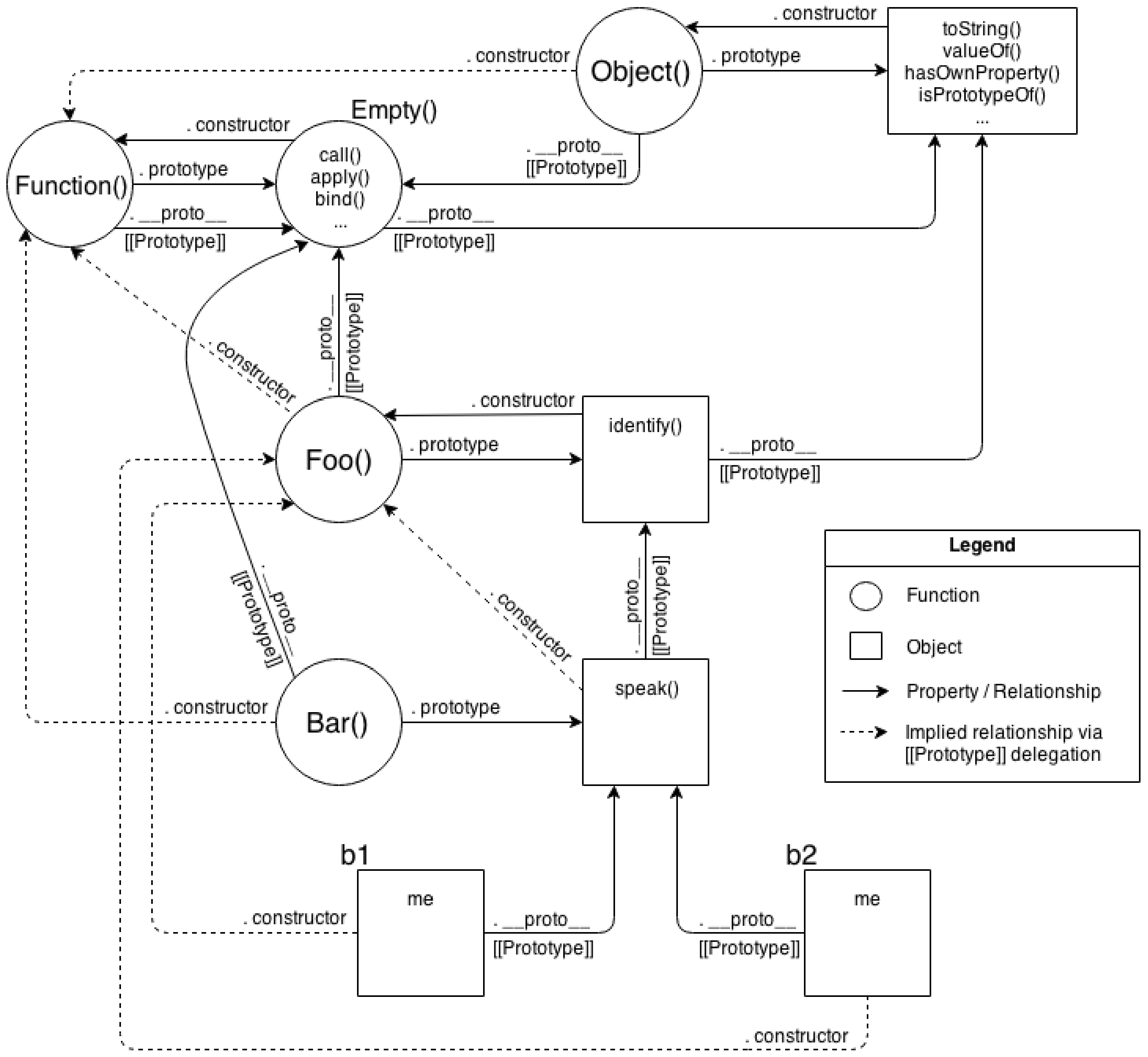
We take exactly the same advantage of `[[Prototype]]` delegation from `b1` to `Bar` to `Foo` as we did in the previous snippet between `b1`, `Bar.prototype`, and `Foo.prototype`. **We still have the same 3 objects linked together**.

But, importantly, we've greatly simplified *all the other stuff* going on, because now we just set up **objects** linked to each other, without needing all the cruft and confusion of things that look (but don't behave!) like classes, with constructors and prototypes and `new` calls.

Ask yourself: if I can get the same functionality with OLOO style code as I do with "class" style code, but OLOO is simpler and has less things to think about, **isn't OLOO better**?

Let's examine the mental models involved between these two snippets.

First, the class-style code snippet implies this mental model of entities and their relationships:

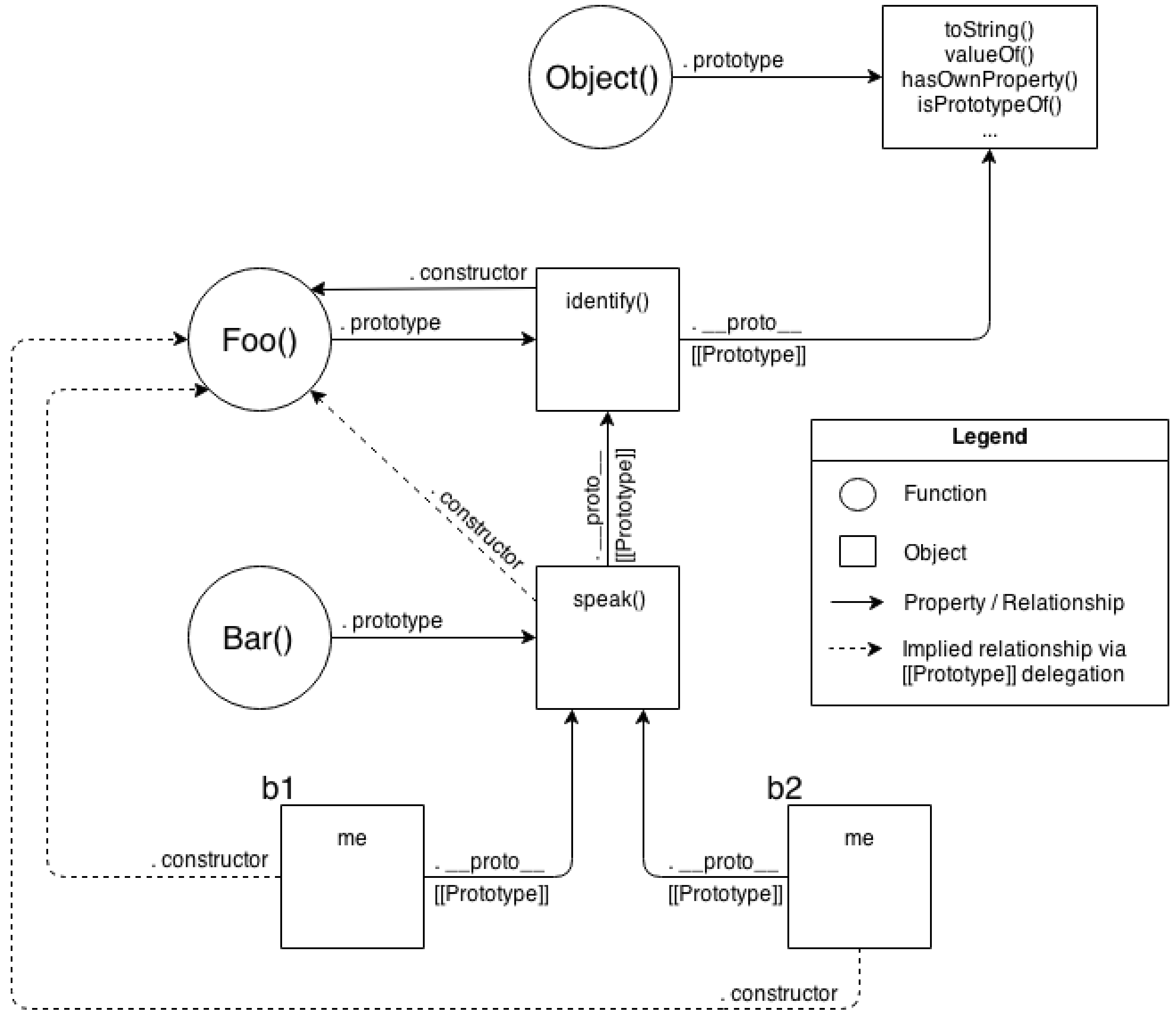


Object()
toString()
valueOf()
hasOwnProperty()
isPrototypeOf()
...
. constructor
. prototype
Function()
Empty()
call()
apply()
bind()
...
. __proto__
[[Prototype]]
Foo()
identify()
Bar()
speak()
b1
b2
me
Legend
Function
Object
Property / Relationship
Implied relationship via [[Prototype]] delegation

Actually, that's a little unfair/misleading, because it's showing a lot of extra detail that you don't *technically* need to know at all times (though you *do* need to understand it!). One take-away is that it's quite a complex series of relationships. But another take-away: if you spend the time to follow those relationship arrows around, **there's an amazing amount of internal consistency** in JS's mechanisms.

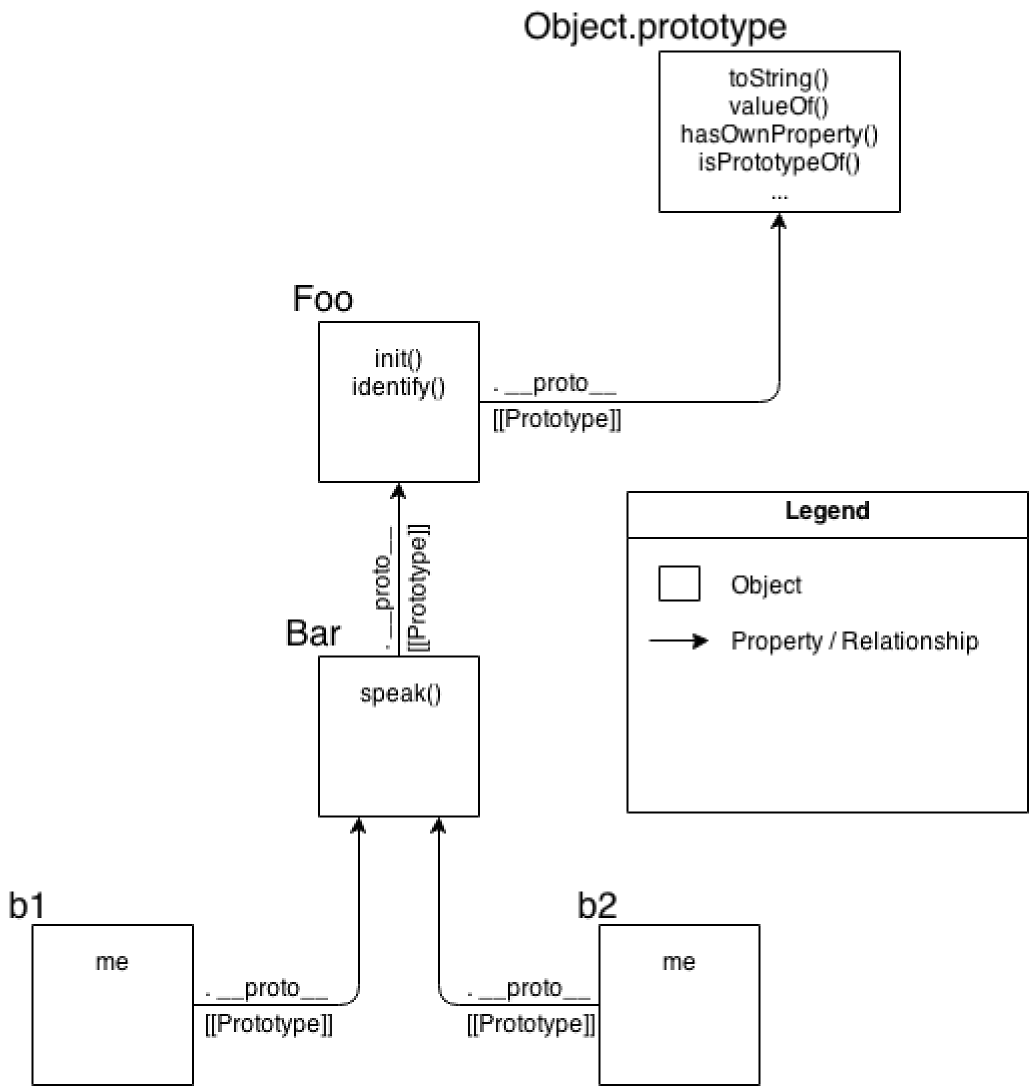
For instance, the ability of a JS function to access `call(..)`, `apply(..)`, and `bind(..)` (see Chapter 2) is because functions themselves are objects, and function-objects also have a `[[Prototype]]` linkage, to the `Function.prototype` object, which defines those default methods that any function-object can delegate to. JS can do those things, *and you can too!*.

OK, let's now look at a *slightly* simplified version of that diagram which is a little more "fair" for comparison -- it shows only the *relevant* entities and relationships.



Still pretty complex, eh? The dotted lines are depicting the implied relationships when you setup the "inheritance" between `Foo.prototype` and `Bar.prototype` and haven't yet *fixed* the **missing** `.constructor` property reference (see "Constructor Redux" in Chapter 5). Even with those dotted lines removed, the mental model is still an awful lot to juggle every time you work with object linkages.

Now, let's look at the mental model for OLOO-style code:



As you can see comparing them, it's quite obvious that OLOO-style code has *vastly less stuff* to worry about, because OLOO-style code embraces the **fact** that the only thing we ever really cared about was the **objects linked to other objects**.

All the other "class" cruft was a confusing and complex way of getting the same end result. Remove that stuff, and things get much simpler (without losing any capability).

Classes vs. Objects

We've just seen various theoretical explorations and mental models of "classes" vs. "behavior delegation". But, let's now look at more concrete code scenarios to show how'd you actually use these ideas.

We'll first examine a typical scenario in front-end web dev: creating UI widgets (buttons, drop-downs, etc).

Widget "Classes"

Because you're probably still so used to the OO design pattern, you'll likely immediately think of this problem domain in terms of a parent class (perhaps called `Widget`) with all the common base widget behavior, and then child derived classes for specific widget types (like `Button`).

Note: We're going to use jQuery here for DOM and CSS manipulation, only because it's a detail we don't really care about for the purposes of our current discussion. None of this code cares which JS framework (jQuery, Dojo, YUI, etc), if any, you might solve such mundane tasks with.

Let's examine how we'd implement the "class" design in classic-style pure JS without any "class" helper library or syntax:

```
// Parent class
function Widget(width,height) {
	this.width = width || 50;
	this.height = height || 50;
	this.$elem = null;
}

Widget.prototype.render = function($where){
	if (this.$elem) {
		this.$elem.css( {
```

```
                        width: this.width + "px",
                        height: this.height + "px"
                } ).appendTo( $where );
        }
};

// Child class
function Button(width,height,label) {
        // "super" constructor call
        Widget.call( this, width, height );
        this.label = label || "Default";

        this.$elem = $( "<button>" ).text( this.label );
}

// make `Button` "inherit" from `Widget`
Button.prototype = Object.create( Widget.prototype );

// override base "inherited" `render(..)`
Button.prototype.render = function($where) {
        // "super" call
        Widget.prototype.render.call( this, $where );
        this.$elem.click( this.onClick.bind( this ) );
};

Button.prototype.onClick = function(evt) {
        console.log( "Button '" + this.label + "' clicked!" );
};

$( document ).ready( function(){
        var $body = $( document.body );
        var btn1 = new Button( 125, 30, "Hello" );
        var btn2 = new Button( 150, 40, "World" );

        btn1.render( $body );
        btn2.render( $body );
} );
```

OO design patterns tell us to declare a base `render(..)` in the parent class, then override it in our child class, but not to replace it per se, rather to augment the base functionality with button-specific behavior.

Notice the ugliness of *explicit pseudo-polymorphism* (see Chapter 4) with `Widget.call` and `Widget.prototype.render.call` references for faking "super" calls from the child "class" methods back up to the "parent" class base methods. Yuck.

ES6 `class` sugar

We cover ES6 `class` syntax sugar in detail in Appendix A, but let's briefly demonstrate how we'd implement the same code using `class`:

```
class Widget {
	constructor(width,height) {
		this.width = width || 50;
		this.height = height || 50;
		this.$elem = null;
	}
	render($where){
		if (this.$elem) {
			this.$elem.css( {
				width: this.width + "px",
				height: this.height + "px"
			} ).appendTo( $where );
		}
	}
}

class Button extends Widget {
	constructor(width,height,label) {
		super( width, height );
		this.label = label || "Default";
		this.$elem = $( "<button>" ).text( this.label );
	}
	render($where) {
```

```
                super.render( $where );
                this.$elem.click( this.onClick.bind( this ) );
        }
        onClick(evt) {
                console.log( "Button '" + this.label + "' clicked!" );
        }
}

$( document ).ready( function(){
        var $body = $( document.body );
        var btn1 = new Button( 125, 30, "Hello" );
        var btn2 = new Button( 150, 40, "World" );

        btn1.render( $body );
        btn2.render( $body );
} );
```

Undoubtedly, a number of the syntax uglies of the previous classical approach have been smoothed over with ES6's `class`. The presence of a `super(..)` in particular seems quite nice (though when you dig into it, it's not all roses!).

Despite syntactic improvements, **these are not *real* classes**, as they still operate on top of the `[[Prototype]]` mechanism. They suffer from all the same mental-model mismatches we explored in Chapters 4, 5 and thus far in this chapter. Appendix A will expound on the ES6 `class` syntax and its implications in detail. We'll see why solving syntax hiccups doesn't substantially solve our class confusions in JS, though it makes a valiant effort masquerading as a solution!

Whether you use the classic prototypal syntax or the new ES6 sugar, you've still made a *choice* to model the problem domain (UI widgets) with "classes". And as the previous few chapters try to demonstrate, this *choice* in JavaScript is opting you into extra headaches and mental tax.

Delegating Widget Objects

Here's our simpler `Widget` / `Button` example, using **OLOO style delegation**:

```
var Widget = {
        init: function(width,height){
                this.width = width || 50;
                this.height = height || 50;
                this.$elem = null;
        },
        insert: function($where){
                if (this.$elem) {
                        this.$elem.css( {
                                width: this.width + "px",
                                height: this.height + "px"
                        } ).appendTo( $where );
                }
        }
};

var Button = Object.create( Widget );

Button.setup = function(width,height,label){
        // delegated call
        this.init( width, height );
        this.label = label || "Default";

        this.$elem = $( "<button>" ).text( this.label );
};
Button.build = function($where) {
        // delegated call
        this.insert( $where );
        this.$elem.click( this.onClick.bind( this ) );
};
Button.onClick = function(evt) {
        console.log( "Button '" + this.label + "' clicked!" );
};

$( document ).ready( function(){
        var $body = $( document.body );
```

```
	var btn1 = Object.create( Button );
	btn1.setup( 125, 30, "Hello" );

	var btn2 = Object.create( Button );
	btn2.setup( 150, 40, "World" );

	btn1.build( $body );
	btn2.build( $body );
} );
```

With this OLOO-style approach, we don't think of `Widget` as a parent and `Button` as a child. Rather, `Widget` **is just an object** and is sort of a utility collection that any specific type of widget might want to delegate to, and `Button` **is also just a stand-alone object** (with a delegation link to `Widget`, of course!).

From a design pattern perspective, we **didn't** share the same method name `render(..)` in both objects, the way classes suggest, but instead we chose different names (`insert(..)` and `build(..)`) that were more descriptive of what task each does specifically. The *initialization* methods are called `init(..)` and `setup(..)`, respectively, for the same reasons.

Not only does this delegation design pattern suggest different and more descriptive names (rather than shared and more generic names), but doing so with OLOO happens to avoid the ugliness of the explicit pseudo-polymorphic calls (`Widget.call` and `Widget.prototype.render.call`), as you can see by the simple, relative, delegated calls to `this.init(..)` and `this.insert(..)`.

Syntactically, we also don't have any constructors, `.prototype` or `new` present, as they are, in fact, just unnecessary cruft.

Now, if you're paying close attention, you may notice that what was previously just one call (`var btn1 = new Button(..)`) is now two calls (`var btn1 = Object.create(Button)` and `btn1.setup(..)`). Initially this may seem like a drawback (more code).

However, even this is something that's **a pro of OLOO style code** as compared to classical prototype style code. How?

With class constructors, you are "forced" (not really, but strongly suggested) to do both construction and initialization in the same step. However, there are many cases where being able to do these two steps separately (as you do with OLOO!) is more flexible.

For example, let's say you create all your instances in a pool at the beginning of your program, but you wait to initialize them with specific setup until they are pulled from the pool and used. We showed the two calls happening right next to each other, but of course they can happen at very different times and in very different parts of our code, as needed.

OLOO supports *better* the principle of separation of concerns, where creation and initialization are not necessarily conflated into the same operation.

Simpler Design

In addition to OLOO providing ostensibly simpler (and more flexible!) code, behavior delegation as a pattern can actually lead to simpler code architecture. Let's examine one last example that illustrates how OLOO simplifies your overall design.

The scenario we'll examine is two controller objects, one for handling the login form of a web page, and another for actually handling the authentication (communication) with the server.

We'll need a utility helper for making the Ajax communication to the server. We'll use jQuery (though any framework would do fine), since it handles not only the Ajax for us, but it returns a promise-like answer so that we can listen for the response in our calling code with `.then(..)`.

Note: We don't cover Promises here, but we will cover them in a future title of the "*You Don't Know JS*" series.

Following the typical class design pattern, we'll break up the task into base functionality in a class called `Controller`, and then we'll derive two child classes, `LoginController` and `AuthController`, which both inherit from `Controller` and specialize some of those base behaviors.

```
// Parent class
function Controller() {
        this.errors = [];
}
Controller.prototype.showDialog = function(title,msg) {
        // display title & message to user in dialog
};
Controller.prototype.success = function(msg) {
        this.showDialog( "Success", msg );
};
Controller.prototype.failure = function(err) {
        this.errors.push( err );
        this.showDialog( "Error", err );
};



// Child class
function LoginController() {
        Controller.call( this );
}
// Link child class to parent
LoginController.prototype = Object.create( Controller.prototype );
LoginController.prototype.getUser = function() {
        return document.getElementById( "login_username" ).value;
};
LoginController.prototype.getPassword = function() {
        return document.getElementById( "login_password" ).value;
};
LoginController.prototype.validateEntry = function(user,pw) {
        user = user || this.getUser();
        pw = pw || this.getPassword();

        if (!(user && pw)) {
                return this.failure( "Please enter a username & password!" );
        }
        else if (pw.length < 5) {
                return this.failure( "Password must be 5+ characters!" );
        }
        // got here? validated!
        return true;
};
// Override to extend base `failure()`
LoginController.prototype.failure = function(err) {
        // "super" call
        Controller.prototype.failure.call( this, "Login invalid: " + err );
};



// Child class
function AuthController(login) {
        Controller.call( this );
        // in addition to inheritance, we also need composition
        this.login = login;
}
// Link child class to parent
AuthController.prototype = Object.create( Controller.prototype );
AuthController.prototype.server = function(url,data) {
        return $.ajax( {
                url: url,
                data: data
        } );
};
AuthController.prototype.checkAuth = function() {
        var user = this.login.getUser();
        var pw = this.login.getPassword();

        if (this.login.validateEntry( user, pw )) {
                this.server( "/check-auth",{
                        user: user,
                        pw: pw
                } )
                .then( this.success.bind( this ) )
                .fail( this.failure.bind( this ) );
        }
};
```

```
// Override to extend base `success()`
AuthController.prototype.success = function() {
        // "super" call
        Controller.prototype.success.call( this, "Authenticated!" );
};
// Override to extend base `failure()`
AuthController.prototype.failure = function(err) {
        // "super" call
        Controller.prototype.failure.call( this, "Auth Failed: " + err );
};


var auth = new AuthController(
        // in addition to inheritance, we also need composition
        new LoginController()
);
auth.checkAuth();
```

We have base behaviors that all controllers share, which are `success(..)` , `failure(..)` and `showDialog(..)` . Our child classes `LoginController` and `AuthController` override `failure(..)` and `success(..)` to augment the default base class behavior. Also note that `AuthController` needs an instance of `LoginController` to interact with the login form, so that becomes a member data property.

The other thing to mention is that we chose some *composition* to sprinkle in on top of the inheritance. `AuthController` needs to know about `LoginController` , so we instantiate it (`new LoginController()`) and keep a class member property called `this.login` to reference it, so that `AuthController` can invoke behavior on `LoginController` .

Note: There *might* have been a slight temptation to make `AuthController` inherit from `LoginController` , or vice versa, such that we had *virtual composition* through the inheritance chain. But this is a strongly clear example of what's wrong with class inheritance as *the* model for the problem domain, because neither `AuthController` nor `LoginController` are specializing base behavior of the other, so inheritance between them makes little sense except if classes are your only design pattern. Instead, we layered in some simple *composition* and now they can cooperate, while still both benefiting from the inheritance from the parent base `Controller` .

If you're familiar with class-oriented (OO) design, this should all look pretty familiar and natural.

De-class-ified

But, **do we really need to model this problem** with a parent `Controller` class, two child classes, **and some composition**? Is there a way to take advantage of OLOO-style behavior delegation and have a *much* simpler design? **Yes!**

```
var LoginController = {
	errors: [],
	getUser: function() {
		return document.getElementById( "login_username" ).value;
	},
	getPassword: function() {
		return document.getElementById( "login_password" ).value;
	},
	validateEntry: function(user,pw) {
		user = user || this.getUser();
		pw = pw || this.getPassword();

		if (!(user && pw)) {
			return this.failure( "Please enter a username & password!" );
		}
		else if (pw.length < 5) {
			return this.failure( "Password must be 5+ characters!" );
		}

		// got here? validated!
		return true;
	},
	showDialog: function(title,msg) {
		// display success message to user in dialog
	},
	failure: function(err) {
		this.errors.push( err );
		this.showDialog( "Error", "Login invalid: " + err );
```

```
        }
};


// Link `AuthController` to delegate to `LoginController`
var AuthController = Object.create( LoginController );

AuthController.errors = [];
AuthController.checkAuth = function() {
        var user = this.getUser();
        var pw = this.getPassword();

        if (this.validateEntry( user, pw )) {
                this.server( "/check-auth",{
                        user: user,
                        pw: pw
                } )
                .then( this.accepted.bind( this ) )
                .fail( this.rejected.bind( this ) );
        }
};
AuthController.server = function(url,data) {
        return $.ajax( {
                url: url,
                data: data
        } );
};
AuthController.accepted = function() {
        this.showDialog( "Success", "Authenticated!" )
};
AuthController.rejected = function(err) {
        this.failure( "Auth Failed: " + err );
};
```

Since `AuthController` is just an object (so is `LoginController`), we don't need to instantiate (like `new AuthController()`) to perform our task. All we need to do is:

```
AuthController.checkAuth();
```

Of course, with OLOO, if you do need to create one or more additional objects in the delegation chain, that's easy, and still doesn't require anything like class instantiation:

```
var controller1 = Object.create( AuthController );
var controller2 = Object.create( AuthController );
```

With behavior delegation, `AuthController` and `LoginController` are **just objects**, *horizontal* peers of each other, and are not arranged or related as parents and children in class-orientation. We somewhat arbitrarily chose to have `AuthController` delegate to `LoginController` -- it would have been just as valid for the delegation to go the reverse direction.

The main takeaway from this second code listing is that we only have two entities (`LoginController` and `AuthController`), **not three** as before.

We didn't need a base `Controller` class to "share" behavior between the two, because delegation is a powerful enough mechanism to give us the functionality we need. We also, as noted before, don't need to instantiate our classes to work with them, because there are no classes, **just the objects themselves.** Furthermore, there's no need for *composition* as delegation gives the two objects the ability to cooperate *differentially* as needed.

Lastly, we avoided the polymorphism pitfalls of class-oriented design by not having the names `success(..)` and `failure(..)` be the same on both objects, which would have required ugly explicit pseudopolymorphism. Instead, we called them `accepted()` and `rejected(..)` on `AuthController` -- slightly more descriptive names for their specific tasks.

Bottom line: we end up with the same capability, but a (significantly) simpler design. That's the power of OLOO-style code and the power of the *behavior delegation* design pattern.

Nicer Syntax

One of the nicer things that makes ES6's `class` so deceptively attractive (see Appendix A on why to avoid it!) is the short-hand syntax for declaring class methods:

```
class Foo {
	methodName() { /* .. */ }
}
```

We get to drop the word `function` from the declaration, which makes JS developers everywhere cheer!

And you may have noticed and been frustrated that the suggested OLOO syntax above has lots of `function` appearances, which seems like a bit of a detractor to the goal of OLOO simplification. **But it doesn't have to be that way!**

As of ES6, we can use *concise method declarations* in any object literal, so an object in OLOO style can be declared this way (same short-hand sugar as with `class` body syntax):

```
var LoginController = {
	errors: [],
	getUser() { // Look ma, no `function`!
		// ...
	},
	getPassword() {
		// ...
	}
	// ...
};
```

About the only difference is that object literals will still require `,` comma separators between elements whereas `class` syntax doesn't. Pretty minor concession in the whole scheme of things.

Moreover, as of ES6, the clunkier syntax you use (like for the `AuthController` definition), where you're assigning properties individually and not using an object literal, can be re-written using an object literal (so that you can use concise methods), and you can just modify that object's `[[Prototype]]` with `Object.setPrototypeOf(..)`, like this:

```
// use nicer object literal syntax w/ concise methods!
var AuthController = {
        errors: [],
        checkAuth() {
                // ...
        },
        server(url,data) {
                // ...
        }
        // ...
};

// NOW, link `AuthController` to delegate to `LoginController`
Object.setPrototypeOf( AuthController, LoginController );
```

OLOO-style as of ES6, with concise methods, **is a lot friendlier** than it was before (and even then, it was much simpler and nicer than classical prototype-style code). **You don't have to opt for class** (complexity) to get nice clean object syntax!

Unlexical

There *is* one drawback to concise methods that's subtle but important to note. Consider this code:

```
var Foo = {
        bar() { /*..*/ },
        baz: function baz() { /*..*/ }
};
```

Here's the syntactic de-sugaring that expresses how that code will operate:

```
var Foo = {
	bar: function() { /*..*/ },
	baz: function baz() { /*..*/ }
};
```

See the difference? The `bar()` short-hand became an *anonymous function expression* (`function()..`) attached to the `bar` property, because the function object itself has no name identifier. Compare that to the manually specified *named function expression* (`function baz()..`) which has a lexical name identifier `baz` in addition to being attached to a `.baz` property.

So what? In the "*Scope & Closures*" title of this "*You Don't Know JS*" book series, we cover the three main downsides of *anonymous function expressions* in detail. We'll just briefly repeat them so we can compare to the concise method short-hand.

Lack of a `name` identifier on an anonymous function:

1. makes debugging stack traces harder
2. makes self-referencing (recursion, event (un)binding, etc) harder
3. makes code (a little bit) harder to understand

Items 1 and 3 don't apply to concise methods.

Even though the de-sugaring uses an *anonymous function expression* which normally would have no `name` in stack traces, concise methods are specified to set the internal `name` property of the function object accordingly, so stack traces should be able to use it (though that's implementation dependent so not guaranteed).

Item 2 is, unfortunately, **still a drawback to concise methods**. They will not have a lexical identifier to use as a self-reference. Consider:

```
var Foo = {
	bar: function(x) {
		if (x < 10) {
				return Foo.bar( x * 2 );
			}
			return x;
		},
		baz: function baz(x) {
			if (x < 10) {
				return baz( x * 2 );
			}
			return x;
		}
};
```

The manual `Foo.bar(x*2)` reference above kind of suffices in this example, but there are many cases where a function wouldn't necessarily be able to do that, such as cases where the function is being shared in delegation across different objects, using `this` binding, etc. You would want to use a real self-reference, and the function object's `name` identifier is the best way to accomplish that.

Just be aware of this caveat for concise methods, and if you run into such issues with lack of self-reference, make sure to forgo the concise method syntax **just for that declaration** in favor of the manual *named function expression* declaration form: `baz: function baz(){..}`.

Introspection

If you've spent much time with class oriented programming (either in JS or other languages), you're probably familiar with *type introspection*: inspecting an instance to find out what *kind* of object it is. The primary goal of *type introspection* with class instances is to reason about the structure/capabilities of the object based on *how it was created*.

Consider this code which uses `instanceof` (see Chapter 5) for introspecting on an object `a1` to infer its capability:

```
function Foo() {
	// ...
}
```

```
Foo.prototype.something = function(){
	// ...
}

var a1 = new Foo();

// later

if (a1 instanceof Foo) {
	a1.something();
}
```

Because `Foo.prototype` (not `Foo` !) is in the `[[Prototype]]` chain (see Chapter 5) of `a1` , the `instanceof` operator (confusingly) pretends to tell us that `a1` is an instance of the `Foo` "class". With this knowledge, we then assume that `a1` has the capabilities described by the `Foo` "class".

Of course, there is no `Foo` class, only a plain old normal function `Foo` , which happens to have a reference to an arbitrary object (`Foo.prototype`) that `a1` happens to be delegation-linked to. By its syntax, `instanceof` pretends to be inspecting the relationship between `a1` and `Foo` , but it's actually telling us whether `a1` and (the arbitrary object referenced by) `Foo.prototype` are related.

The semantic confusion (and indirection) of `instanceof` syntax means that to use `instanceof` -based introspection to ask if object `a1` is related to the capabilities object in question, you *have to* have a function that holds a reference to that object -- you can't just directly ask if the two objects are related.

Recall the abstract `Foo` / `Bar` / `b1` example from earlier in this chapter, which we'll abbreviate here:

```
function Foo() { /* .. */ }
Foo.prototype...

function Bar() { /* .. */ }
Bar.prototype = Object.create( Foo.prototype );
```

```
var b1 = new Bar( "b1" );
```

For *type introspection* purposes on the entities in that example, using `instanceof` and `.prototype` semantics, here are the various checks you might need to perform:

```
// relating `Foo` and `Bar` to each other
Bar.prototype instanceof Foo; // true
Object.getPrototypeOf( Bar.prototype ) === Foo.prototype; // true
Foo.prototype.isPrototypeOf( Bar.prototype ); // true

// relating `b1` to both `Foo` and `Bar`
b1 instanceof Foo; // true
b1 instanceof Bar; // true
Object.getPrototypeOf( b1 ) === Bar.prototype; // true
Foo.prototype.isPrototypeOf( b1 ); // true
Bar.prototype.isPrototypeOf( b1 ); // true
```

It's fair to say that some of that kinda sucks. For instance, intuitively (with classes) you might want to be able to say something like `Bar instanceof Foo` (because it's easy to mix up what "instance" means to think it includes "inheritance"), but that's not a sensible comparison in JS. You have to do `Bar.prototype instanceof Foo` instead.

Another common, but perhaps less robust, pattern for *type introspection*, which many devs seem to prefer over `instanceof`, is called "duck typing". This term comes from the adage, "if it looks like a duck, and it quacks like a duck, it must be a duck".

Example:

```
if (a1.something) {
        a1.something();
}
```

Rather than inspecting for a relationship between `a1` and an object that holds the delegatable `something()` function, we assume that the test for `a1.something` passing means `a1` has the capability to call `.something()` (regardless of if it found the method directly on `a1` or delegated to some other object). In and of itself, that assumption isn't so risky.

But "duck typing" is often extended to make **other assumptions about the object's capabilities** besides what's being tested, which of course introduces more risk (aka, brittle design) into the test.

One notable example of "duck typing" comes with ES6 Promises (which as an earlier note explained are not being covered in this book).

For various reasons, there's a need to determine if any arbitrary object reference *is a Promise*, but the way that test is done is to check if the object happens to have a `then()` function present on it. In other words, **if any object** happens to have a `then()` method, ES6 Promises will assume unconditionally that the object **is a "thenable"** and therefore will expect it to behave conformantly to all standard behaviors of Promises.

If you have any non-Promise object that happens for whatever reason to have a `then()` method on it, you are strongly advised to keep it far away from the ES6 Promise mechanism to avoid broken assumptions.

That example clearly illustrates the perils of "duck typing". You should only use such approaches sparingly and in controlled conditions.

Turning our attention once again back to OLOO-style code as presented here in this chapter, *type introspection* turns out to be much cleaner. Let's recall (and abbreviate) the `Foo` / `Bar` / `b1` OLOO example from earlier in the chapter:

```
var Foo = { /* .. */ };

var Bar = Object.create( Foo );
Bar...

var b1 = Object.create( Bar );
```

Using this OLOO approach, where all we have are plain objects that are related via `[[Prototype]]` delegation, here's the quite simplified *type introspection* we might use:

```js
// relating `Foo` and `Bar` to each other
Foo.isPrototypeOf( Bar ); // true
Object.getPrototypeOf( Bar ) === Foo; // true

// relating `b1` to both `Foo` and `Bar`
Foo.isPrototypeOf( b1 ); // true
Bar.isPrototypeOf( b1 ); // true
Object.getPrototypeOf( b1 ) === Bar; // true
```

We're not using `instanceof` anymore, because it's confusingly pretending to have something to do with classes. Now, we just ask the (informally stated) question, "are you *a* prototype of me?" There's no more indirection necessary with stuff like `Foo.prototype` or the painfully verbose `Foo.prototype.isPrototypeOf(..)`.

I think it's fair to say these checks are significantly less complicated/confusing than the previous set of introspection checks. **Yet again, we see that OLOO is simpler than (but with all the same power of) class-style coding in JavaScript.**

Review (TL;DR)

Classes and inheritance are a design pattern you can *choose*, or *not choose*, in your software architecture. Most developers take for granted that classes are the only (proper) way to organize code, but here we've seen there's another less-commonly talked about pattern that's actually quite powerful: **behavior delegation**.

Behavior delegation suggests objects as peers of each other, which delegate amongst themselves, rather than parent and child class relationships. JavaScript's `[[Prototype]]` mechanism is, by its very designed nature, a behavior delegation mechanism. That means we can either choose to struggle to implement class mechanics on top of JS (see Chapters 4 and 5), or we can just embrace the natural state of `[[Prototype]]` as a delegation mechanism.

When you design code with objects only, not only does it simplify the syntax you use, but it can actually lead to simpler code architecture design.

OLOO (objects-linked-to-other-objects) is a code style which creates and relates objects directly without the abstraction of classes. OLOO quite naturally implements `[[Prototype]]` -based behavior delegation.

You Don't Know JS Yet: *this* & Object Prototypes - 2nd Edition

Appendix A: ES6 `class`

NOTE:
Work in progress

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If there's any take-away message from the second half of this book (Chapters 4-6), it's that classes are an optional design pattern for code (not a necessary given), and that furthermore they are often quite awkward to implement in a `[[Prototype]]` language like JavaScript.

This awkwardness is *not* just about syntax, although that's a big part of it. Chapters 4 and 5 examined quite a bit of syntactic ugliness, from verbosity of `.prototype` references cluttering the code, to *explicit pseudo-polymorphism* (see Chapter 4) when you give methods the same name at different levels of the chain and try to implement a polymorphic reference from a lower-level method to a higher-level method. `.constructor` being wrongly interpreted as "was constructed by" and yet being unreliable for that definition is yet another syntactic ugly.

But the problems with class design are much deeper. Chapter 4 points out that classes in traditional class-oriented languages actually produce a *copy* action from parent to child to instance, whereas in `[[Prototype]]`, the action is **not** a copy, but rather the opposite -- a delegation link.

When compared to the simplicity of OLOO-style code and behavior delegation (see Chapter 6), which embrace `[[Prototype]]` rather than hide from it, classes stand out as a sore thumb in JS.

`class`

But we *don't* need to re-argue that case again. I re-mention those issues briefly only so that you keep them fresh in your mind now that we turn our attention to the ES6 `class` mechanism. We'll demonstrate here how it works, and look at whether or not `class` does anything substantial to address any of those "class" concerns.

Let's revisit the `Widget` / `Button` example from Chapter 6:

```
class Widget {
	constructor(width,height) {
		this.width = width || 50;
		this.height = height || 50;
		this.$elem = null;
	}
```

```
		render($where){
			if (this.$elem) {
				this.$elem.css( {
					width: this.width + "px",
					height: this.height + "px"
				} ).appendTo( $where );
			}
		}
	}

	class Button extends Widget {
		constructor(width,height,label) {
			super( width, height );
			this.label = label || "Default";
			this.$elem = $( "<button>" ).text( this.label );
		}
		render($where) {
			super.render( $where );
			this.$elem.click( this.onClick.bind( this ) );
		}
		onClick(evt) {
			console.log( "Button '" + this.label + "' clicked!" );
		}
	}
```

Beyond this syntax *looking* nicer, what problems does ES6 solve?

1. There's no more (well, sorta, see below!) references to `.prototype` cluttering the code.
2. `Button` is declared directly to "inherit from" (aka `extends`) `Widget`, instead of needing to use `Object.create(..)` to replace a `.prototype` object that's linked, or having to set with `.__proto__` or `Object.setPrototypeOf(..)`.
3. `super(..)` now gives us a very helpful **relative polymorphism** capability, so that any method at one level of the chain can refer relatively one level up the chain to a method of the same name. This includes a solution to the note from Chapter 4 about the weirdness of constructors not belonging to their class, and so being unrelated -- `super()` works inside constructors exactly as you'd expect.

4. `class` literal syntax has no affordance for specifying properties (only methods). This might seem limiting to some, but it's expected that the vast majority of cases where a property (state) exists elsewhere but the end-chain "instances", this is usually a mistake and surprising (as it's state that's implicitly "shared" among all "instances"). So, one *could* say the `class` syntax is protecting you from mistakes.
5. `extends` lets you extend even built-in object (sub)types, like `Array` or `RegExp`, in a very natural way. Doing so without `class .. extends` has long been an exceedingly complex and frustrating task, one that only the most adept of framework authors have ever been able to accurately tackle. Now, it will be rather trivial!

In all fairness, those are some substantial solutions to many of the most obvious (syntactic) issues and surprises people have with classical prototype-style code.

`class` Gotchas

It's not all bubblegum and roses, though. There are still some deep and profoundly troubling issues with using "classes" as a design pattern in JS.

Firstly, the `class` syntax may convince you a new "class" mechanism exists in JS as of ES6. **Not so.** `class` is, mostly, just syntactic sugar on top of the existing `[[Prototype]]` (delegation!) mechanism.

That means `class` is not actually copying definitions statically at declaration time the way it does in traditional class-oriented languages. If you change/replace a method (on purpose or by accident) on the parent "class", the child "class" and/or instances will still be "affected", in that they didn't get copies at declaration time, they are all still using the live-delegation model based on `[[Prototype]]`:

```
class C {
	constructor() {
		this.num = Math.random();
	}
	rand() {
		console.log( "Random: " + this.num );
	}
}

var c1 = new C();
c1.rand(); // "Random: 0.4324299..."

C.prototype.rand = function() {
        console.log( "Random: " + Math.round( this.num * 1000 ));
};

var c2 = new C();
c2.rand(); // "Random: 867"

c1.rand(); // "Random: 432" -- oops!!!
```

This only seems like reasonable behavior *if you already know* about the delegation nature of things, rather than expecting *copies* from "real classes". So the question to ask yourself is, why are you choosing `class` syntax for something fundamentally different from classes?

Doesn't the ES6 `class` syntax **just make it harder** to see and understand the difference between traditional classes and delegated objects?

`class` syntax *does not* provide a way to declare class member properties (only methods). So if you need to do that to track shared state among instances, then you end up going back to the ugly `.prototype` syntax, like this:

```
class C {
        constructor() {
                // make sure to modify the shared state,
                // not set a shadowed property on the
                // instances!
                C.prototype.count++;

                // here, `this.count` works as expected
                // via delegation
                console.log( "Hello: " + this.count );
```

```
		}
	}

	// add a property for shared state directly to
	// prototype object
	C.prototype.count = 0;

	var c1 = new C();
	// Hello: 1

	var c2 = new C();
	// Hello: 2

	c1.count === 2; // true
	c1.count === c2.count; // true
```

The biggest problem here is that it betrays the `class` syntax by exposing (leakage!) `.prototype` as an implementation detail.

But, we also still have the surprise gotcha that `this.count++` would implicitly create a separate shadowed `.count` property on both `c1` and `c2` objects, rather than updating the shared state. `class` offers us no consolation from that issue, except (presumably) to imply by lack of syntactic support that you shouldn't be doing that *at all*.

Moreover, accidental shadowing is still a hazard:

```
	class C {
		constructor(id) {
			// oops, gotcha, we're shadowing `id()` method
			// with a property value on the instance
			this.id = id;
		}
		id() {
			console.log( "Id: " + this.id );
		}
	}
```

```
var c1 = new C( "c1" );
c1.id(); // TypeError -- `c1.id` is now the string "c1"
```

There's also some very subtle nuanced issues with how `super` works. You might assume that `super` would be bound in an analogous way to how `this` gets bound (see Chapter 2), which is that `super` would always be bound to one level higher than whatever the current method's position in the `[[Prototype]]` chain is.

However, for performance reasons (`this` binding is already expensive), `super` is not bound dynamically. It's bound sort of "statically", as declaration time. No big deal, right?

Ehh... maybe, maybe not. If you, like most JS devs, start assigning functions around to different objects (which came from `class` definitions), in various different ways, you probably won't be very aware that in all those cases, the `super` mechanism under the covers is having to be re-bound each time.

And depending on what sorts of syntactic approaches you take to these assignments, there may very well be cases where the `super` can't be properly bound (at least, not where you suspect), so you may (at time of writing, TC39 discussion is ongoing on the topic) have to manually bind `super` with `toMethod(..)` (kinda like you have to do `bind(..)` for `this` -- see Chapter 2).

You're used to being able to assign around methods to different objects to *automatically* take advantage of the dynamism of `this` via the *implicit binding* rule (see Chapter 2). But the same will likely not be true with methods that use `super` .

Consider what `super` should do here (against `D` and `E`):

```
class P {
	foo() { console.log( "P.foo" ); }
}

class C extends P {
	foo() {
		super();
	}
}

var c1 = new C();
c1.foo(); // "P.foo"

var D = {
        foo: function() { console.log( "D.foo" ); }
};

var E = {
        foo: C.prototype.foo
};

// Link E to D for delegation
Object.setPrototypeOf( E, D );

E.foo(); // "P.foo"
```

If you were thinking (quite reasonably!) that `super` would be bound dynamically at call-time, you might expect that `super()` would automatically recognize that `E` delegates to `D`, so `E.foo()` using `super()` should call to `D.foo()`.

Not so. For performance pragmatism reasons, `super` is not *late bound* (aka, dynamically bound) like `this` is. Instead it's derived at call-time from `[[HomeObject]].[[Prototype]]`, where `[[HomeObject]]` is statically bound at creation time.

In this particular case, `super()` is still resolving to `P.foo()`, since the method's `[[HomeObject]]` is still `C` and `C.[[Prototype]]` is `P`.

There will *probably* be ways to manually address such gotchas. Using `toMethod(..)` to bind/rebind a method's `[[HomeObject]]` (along with setting the `[[Prototype]]` of that object!) appears to work in this scenario:

```
var D = {
        foo: function() { console.log( "D.foo" ); }
};
```

```
// Link E to D for delegation
var E = Object.create( D );

// manually bind `foo`s `[[HomeObject]]` as
// `E`, and `E.[[Prototype]]` is `D`, so thus
// `super()` is `D.foo()`
E.foo = C.prototype.foo.toMethod( E, "foo" );

E.foo(); // "D.foo"
```

Note: `toMethod(..)` clones the method, and takes `homeObject` as its first parameter (which is why we pass `E`), and the second parameter (optionally) sets a `name` for the new method (which keep at "foo").

It remains to be seen if there are other corner case gotchas that devs will run into beyond this scenario. Regardless, you will have to be diligent and stay aware of which places the engine automatically figures out `super` for you, and which places you have to manually take care of it. **Ugh!**

Static > Dynamic?

But the biggest problem of all about ES6 `class` is that all these various gotchas mean `class` sorta opts you into a syntax which seems to imply (like traditional classes) that once you declare a `class`, it's a static definition of a (future instantiated) thing. You completely lose sight of the fact that `C` is an object, a concrete thing, which you can directly interact with.

In traditional class-oriented languages, you never adjust the definition of a class later, so the class design pattern doesn't suggest such capabilities. But **one of the most powerful parts** of JS is that it *is* dynamic, and the definition of any object is (unless you make it immutable) a fluid and mutable *thing*.

`class` seems to imply you shouldn't do such things, by forcing you into the uglier `.prototype` syntax to do so, or forcing you to think about `super` gotchas, etc. It also offers *very little* support for any of the pitfalls that this dynamism can bring.

In other words, it's as if `class` is telling you: "dynamic is too hard, so it's probably not a good idea. Here's a static-looking syntax, so code your stuff statically."

What a sad commentary on JavaScript: **dynamic is too hard, let's pretend to be (but not actually be!) static**.

These are the reasons why ES6 `class` is masquerading as a nice solution to syntactic headaches, but it's actually muddying the waters further and making things worse for JS and for clear and concise understanding.

Note: If you use the `.bind(..)` utility to make a hard-bound function (see Chapter 2), the function created is not subclassable with ES6 `extend` like normal functions are.

Review (TL;DR)

`class` does a very good job of pretending to fix the problems with the class/inheritance design pattern in JS. But it actually does the opposite: **it hides many of the problems, and introduces other subtle but dangerous ones**.

`class` contributes to the ongoing confusion of "class" in JavaScript which has plagued the language for nearly two decades. In some respects, it asks more questions than it answers, and it feels in totality like a very unnatural fit on top of the elegant simplicity of the `[[Prototype]]` mechanism.

Bottom line: if ES6 `class` makes it harder to robustly leverage `[[Prototype]]`, and hides the most important nature of the JS object mechanism -- **the live delegation links between objects** -- shouldn't we see `class` as creating more troubles than it solves, and just relegate it to an anti-pattern?

I can't really answer that question for you. But I hope this book has fully explored the issue at a deeper level than you've ever gone before, and has given you the information you need *to answer it yourself*.

You Don't Know JS Yet: Types & Grammar - 2nd Edition

NOTE:

NOTE:
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Foreword

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You Don't Know JS Yet - 2nd Edition

Preface

Welcome to the 2nd edition of the widely-acclaimed *You Don't Know JS* (**YDKJS**) book series: *You Don't Know JS* ***Yet*** (**YDKJSY**).

If you've read any of the 1st edition of the books, you can expect a refreshed approach in these new books, with plenty of new coverage of what's changed in JS over the last five years. But what I hope and believe you'll still *get* is the same committment to respecting JS and digging into what really makes it tick.

If this is your first time to read these books, I'm glad you're here. Prepare for a deep and extensive journey into all the corners of JavaScript.

The Parts

These books approach JavaScript intentionally the opposite of *The Good Parts*. No, not *the bad parts*, but rather, focused on **all the parts**.

You may have been told, or felt yourself, that JS is a deeply flawed language that was poorly designed and inconsistently implemented. Many have asserted that it's the worst most popular language in the world; that nobody writes JS because they want to, only because they have to given its place at the center of the web. That's a ridiculous, unhealthy, and wholly condescending claim.

Millions of developers write JavaScript every day, and many of them appreciate and respect the language.

Like any great language, it has its brilliant parts and it has its scars. Even the creator of JavaScript himself, Brendan Eich, laments some of those parts as mistakes. But he's wrong: they weren't mistakes at all. JS is what it is today -- the world's most ubiquitous and thus most influential programming language -- precisely because of *all those parts*.

Don't buy the lie that you should only learn and use a small collection of *good parts* while avoiding all the bad stuff. Don't buy the "X is the new Y" snake oil, that some new feature of the language instantly relegates all usage of a previous feature as obsolete and ignorant. Don't listen when someone says your code isn't "modern" because it isn't yet using a stage-0 feature that was only proposed a few weeks ago!

Every part of JS is useful. Some parts are more useful than others. Some parts require you to be more careful and intentional.

I find it absurd to try to be a truly effective JavaScript developer while only using a small sliver of what the language has to offer. Can you imagine a construction worker with a toolbox full of tools, who only uses his hammer and scoffs at the screwdriver or tape measure as inferior? That's just silly.

My unreserved claim is that you should go about learning all parts of JavaScript, and where appropriate, use them! And if I may be so bold as to suggest: it's time to discard any other JS books which tell you otherwise.

The Title?

So what's the title of the series all about?

I'm not trying to insult you with criticism about your current lack of knowledge or understanding of JavaScript. I'm not suggesting you can't or won't be able to learn JavaScript. I'm not boasting about secret advanced insider wisdom that I and only a select few possess.

Seriously, all those were real reactions to the original series title before folks even read the books. And they're baseless.

The primary point of the title "You Don't Know JS Yet" is to point out that most JS developers don't take the time to really understand how the code that they write, works. They know that it works -- that it produces a desired outcome. But they either don't understand exactly *how*, or worse, they have an inaccurate mental model for the *how* that falters on closer scrutiny.

I'm presenting a gentle but earnest challenge to you the reader, to set aside the assumptions you have about JS, and approach it with fresh eyes and an invigorated curiosity that leads you to ask *why* for every line of code you write. Why does it do what it does? Why is one way better or more appropriate than the other half dozen ways you could have accomplished it? Why do all the "popular kids" say to do X with your code, but it turns out that Y might be a better choice?

I added "Yet" to the title, not only because it's the second edition, but because ultimately I want these books to challenge you in a hopeful rather than discouraging way.

But let me be clear: I don't think it's possible to ever fully *know* JS. That's not an achievement to be obtained, but a goal to strive after. You don't finish knowing everything about JS, you just keep learning more and more as you spend more time with the language. And the deeper you go, the more you revisit what you *knew* before, and you re-learn it from that more experienced perspective.

I encourage you to adopt a mindset around JavaScript, and indeed all of software development, that you will never fully have mastered it, but that you can and should keep working to get closer to that end, a journey that will stretch for the entirety of your software development career, and beyond.

You can always know JS better than you currently do. That's what I hope these YDKJSY books represent.

The Mission

The case doesn't really need to be made for why developers should take JS seriously -- I think it's already more than proven worthy of first class status among the world's programming languages.

But a different, more important case still needs to be made, and these books rise to that challenge.

I've taught more than 5,000 developers from teams and companies all over the world, in more than 25 countries and six continents. And what I've seen is that far too often, what *counts* is generally just the result of the program, not how the program is written or how/why it works.

My experience not only as a developer but in teaching many other developers tells me: you will always be more effective in your development work if you more completely understand how your code works, than you are solely *just* getting it to produce a desired outcome.

In other words, *good enough to work* is not *good enough*.

All developers regularly struggle with some piece of code not working correctly, and they can't figure out why. But far too often, JS developers will blame this on the language rather than admitting it's their own understanding that is falling short. These books serve as both the question and answer: why did it do *this*, and here's how to get it to do *that* instead.

My mission with YDKJSY is to empower every single JavaScript developer to fully own the JS they write, to understand it and to write with intention and clarity.

The Path

Some of you have started reading this book with the goal of completing all six books, back-to-back.

I would like to caution you to consider changing that plan.

It is not my intention that YDKJSY be read straight through. The material in these books is dense, because JavaScript is powerful, sophisticated, and in parts rather complex. Nobody can really hope to *download* all this information to their brains in a single pass and retain any significant amount of it. That's unreasonable, and it's foolish to try.

My suggestion is you take your time going through YDKJSY. Take one chapter, read it completely through start to finish, and then go back and re-read it section by section. Stop in between each section, and practice the code or ideas from that section. For larger concepts, it probably is a good idea to expect to spend several days digesting, re-reading, practicing, then digesting some more.

You could spend a week or two on each chapter, and a month or two on each book, and a year or more on the whole series, and you would still not be squeezing every ounce of YDKJSY out.

Don't binge these books; be patient and spread out your reading. Interleave reading with lots of practice on real code in your job or on projects you participate in. Wrestle with the opinions I've presented along the way, debate with others, and most of all, disagree with me! Run a study group or book club. Teach mini-workshops at your office. Write blog posts on what you've learned. Speak about these topics at local JS meetups.

It's never my goal to convince you to agree with my opinion, but to own and be able to defend your opinions. You can't get *there* with an expedient read through of these books. That's something that takes a long while to emerge, little by little, as you study and ponder and re-visit.

These books are meant to be a field-guide on your wanderings through JavaScript, from wherever you currently are with the language, to a place of deeper understanding. And the deeper you understand JS, the more questions you will ask and the more you will have to explore! That's what I find so exciting!

I'm so glad you're embarking on this journey, and I am so honored you would consider and consult these books along the way. It's time to start *getting to know JS*.

You Don't Know JS Yet: Types & Grammar - 2nd Edition

Chapter 1: Types

NOTE:
Work in progress

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Most developers would say that a dynamic language (like JS) does not have *types*. Let's see what the ES5.1 specification (http://www.ecma-international.org/ecma-262/5.1/) has to say on the topic:

> Algorithms within this specification manipulate values each of which has an associated type. The possible value types are exactly those defined in this clause. Types are further sub classified into ECMAScript language types and specification types.
>
> An ECMAScript language type corresponds to values that are directly manipulated by an ECMAScript programmer using the ECMAScript language. The ECMAScript language types are Undefined, Null, Boolean, String, Number, and Object.

Now, if you're a fan of strongly typed (statically typed) languages, you may object to this usage of the word "type." In those languages, "type" means a whole lot *more* than it does here in JS.

Some people say JS shouldn't claim to have "types," and they should instead be called "tags" or perhaps "subtypes".

Bah! We're going to use this rough definition (the same one that seems to drive the wording of the spec): a *type* is an intrinsic, built-in set of characteristics that uniquely identifies the behavior of a particular value and distinguishes it from other values, both to the engine **and to the developer**.

In other words, if both the engine and the developer treat value `42` (the number) differently than they treat value `"42"` (the string), then those two values have different *types* -- `number` and `string`, respectively. When you use `42`, you are *intending* to do something numeric, like math. But when you use `"42"`, you are *intending* to do something string'ish, like outputting to the page, etc. **These two values have different types.**

That's by no means a perfect definition. But it's good enough for this discussion. And it's consistent with how JS describes itself.

A Type By Any Other Name...

Beyond academic definition disagreements, why does it matter if JavaScript has *types* or not?

Having a proper understanding of each *type* and its intrinsic behavior is absolutely essential to understanding how to properly and accurately convert values to different types (see Coercion, Chapter 4). Nearly every JS program ever written will need to handle value coercion in some shape or form, so it's important you do so responsibly and with confidence.

If you have the `number` value `42`, but you want to treat it like a `string`, such as pulling out the `"2"` as a character in position `1`, you obviously must first convert (coerce) the value from `number` to `string`.

That seems simple enough.

But there are many different ways that such coercion can happen. Some of these ways are explicit, easy to reason about, and reliable. But if you're not careful, coercion can happen in very strange and surprising ways.

Coercion confusion is perhaps one of the most profound frustrations for JavaScript developers. It has often been criticized as being so *dangerous* as to be considered a flaw in the design of the language, to be shunned and avoided.

Armed with a full understanding of JavaScript types, we're aiming to illustrate why coercion's *bad reputation* is largely overhyped and somewhat undeserved -- to flip your perspective, to seeing coercion's power and usefulness. But first, we have to get a much better grip on values and types.

Built-in Types

JavaScript defines seven built-in types:

- `null`
- `undefined`
- `boolean`
- `number`
- `string`
- `object`
- `symbol` -- added in ES6!

Note: All of these types except `object` are called "primitives".

The `typeof` operator inspects the type of the given value, and always returns one of seven string values -- surprisingly, there's not an exact 1-to-1 match with the seven built-in types we just listed.

```
typeof undefined     === "undefined"; // true
typeof true          === "boolean";   // true
typeof 42            === "number";    // true
typeof "42"           === "string";    // true
typeof { life: 42 }  === "object";    // true

// added in ES6!
typeof Symbol()       === "symbol";    // true
```

These six listed types have values of the corresponding type and return a string value of the same name, as shown. `Symbol` is a new data type as of ES6, and will be covered in Chapter 3.

As you may have noticed, I excluded `null` from the above listing. It's *special* -- special in the sense that it's buggy when combined with the `typeof` operator:

```
typeof null === "object"; // true
```

It would have been nice (and correct!) if it returned `"null"`, but this original bug in JS has persisted for nearly two decades, and will likely never be fixed because there's too much existing web content that relies on its buggy behavior that "fixing" the bug would *create* more "bugs" and break a lot of web software.

If you want to test for a `null` value using its type, you need a compound condition:

```
var a = null;

(!a && typeof a === "object"); // true
```

`null` is the only primitive value that is "falsy" (aka false-like; see Chapter 4) but that also returns `"object"` from the `typeof` check.

So what's the seventh string value that `typeof` can return?

```
typeof function a(){ /* .. */ } === "function"; // true
```

It's easy to think that `function` would be a top-level built-in type in JS, especially given this behavior of the `typeof` operator. However, if you read the spec, you'll see it's actually a "subtype" of object. Specifically, a function is referred to as a "callable object" -- an object that has an internal `[[Call]]` property that allows it to be invoked.

The fact that functions are actually objects is quite useful. Most importantly, they can have properties. For example:

```
function a(b,c) {
	/* .. */
}
```

The function object has a `length` property set to the number of formal parameters it is declared with.

```
a.length; // 2
```

Since you declared the function with two formal named parameters (`b` and `c`), the "length of the function" is `2` .

What about arrays? They're native to JS, so are they a special type?

```
typeof [1,2,3] === "object"; // true
```

Nope, just objects. It's most appropriate to think of them also as a "subtype" of object (see Chapter 3), in this case with the additional characteristics of being numerically indexed (as opposed to just being string-keyed like plain objects) and maintaining an automatically updated `.length` property.

Values as Types

In JavaScript, variables don't have types -- **values have types**. Variables can hold any value, at any time.

Another way to think about JS types is that JS doesn't have "type enforcement," in that the engine doesn't insist that a *variable* always holds values of the *same initial type* that it starts out with. A variable can, in one assignment statement, hold a `string`, and in the next hold a `number`, and so on.

The *value* `42` has an intrinsic type of `number`, and its *type* cannot be changed. Another value, like `"42"` with the `string` type, can be created *from* the `number` value `42` through a process called **coercion** (see Chapter 4).

If you use `typeof` against a variable, it's not asking "what's the type of the variable?" as it may seem, since JS variables have no types. Instead, it's asking "what's the type of the value *in* the variable?"

```
var a = 42;
typeof a; // "number"

a = true;
typeof a; // "boolean"
```

The `typeof` operator always returns a string. So:

```
typeof typeof 42; // "string"
```

The first `typeof 42` returns `"number"`, and `typeof "number"` is `"string"`.

`undefined` vs "undeclared"

Variables that have no value *currently*, actually have the `undefined` value. Calling `typeof` against such variables will return `"undefined"`:

```
var a;

typeof a; // "undefined"
```

```
var b = 42;
var c;

// later
b = c;

typeof b; // "undefined"
typeof c; // "undefined"
```

It's tempting for most developers to think of the word "undefined" and think of it as a synonym for "undeclared." However, in JS, these two concepts are quite different.

An "undefined" variable is one that has been declared in the accessible scope, but *at the moment* has no other value in it. By contrast, an "undeclared" variable is one that has not been formally declared in the accessible scope.

Consider:

```
var a;

a; // undefined
b; // ReferenceError: b is not defined
```

An annoying confusion is the error message that browsers assign to this condition. As you can see, the message is "b is not defined," which is of course very easy and reasonable to confuse with "b is undefined." Yet again, "undefined" and "is not defined" are very different things. It'd be nice if the browsers said something like "b is not found" or "b is not declared," to reduce the confusion!

There's also a special behavior associated with `typeof` as it relates to undeclared variables that even further reinforces the confusion. Consider:

```
var a;
```

```
typeof a; // "undefined"

typeof b; // "undefined"
```

The `typeof` operator returns `"undefined"` even for "undeclared" (or "not defined") variables. Notice that there was no error thrown when we executed `typeof b`, even though `b` is an undeclared variable. This is a special safety guard in the behavior of `typeof`.

Similar to above, it would have been nice if `typeof` used with an undeclared variable returned "undeclared" instead of conflating the result value with the different "undefined" case.

`typeof` Undeclared

Nevertheless, this safety guard is a useful feature when dealing with JavaScript in the browser, where multiple script files can load variables into the shared global namespace.

Note: Many developers believe there should never be any variables in the global namespace, and that everything should be contained in modules and private/separate namespaces. This is great in theory but nearly impossible in practicality; still it's a good goal to strive toward! Fortunately, ES6 added first-class support for modules, which will eventually make that much more practical.

As a simple example, imagine having a "debug mode" in your program that is controlled by a global variable (flag) called `DEBUG`. You'd want to check if that variable was declared before performing a debug task like logging a message to the console. A top-level global `var DEBUG = true` declaration would only be included in a "debug.js" file, which you only load into the browser when you're in development/testing, but not in production.

However, you have to take care in how you check for the global `DEBUG` variable in the rest of your application code, so that you don't throw a `ReferenceError`. The safety guard on `typeof` is our friend in this case.

```
// oops, this would throw an error!
if (DEBUG) {
		console.log( "Debugging is starting" );
}

// this is a safe existence check
if (typeof DEBUG !== "undefined") {
		console.log( "Debugging is starting" );
}
```

This sort of check is useful even if you're not dealing with user-defined variables (like `DEBUG`). If you are doing a feature check for a built-in API, you may also find it helpful to check without throwing an error:

```
if (typeof atob === "undefined") {
		atob = function() { /*..*/ };
}
```

Note: If you're defining a "polyfill" for a feature if it doesn't already exist, you probably want to avoid using `var` to make the `atob` declaration. If you declare `var atob` inside the `if` statement, this declaration is hoisted (see the *Scope & Closures* title of this series) to the top of the scope, even if the `if` condition doesn't pass (because the global `atob` already exists!). In some browsers and for some special types of global built-in variables (often called "host objects"), this duplicate declaration may throw an error. Omitting the `var` prevents this hoisted declaration.

Another way of doing these checks against global variables but without the safety guard feature of `typeof` is to observe that all global variables are also properties of the global object, which in the browser is basically the `window` object. So, the above checks could have been done (quite safely) as:

```
if (window.DEBUG) {
		// ..
}

if (!window.atob) {
		// ..
}
```

Unlike referencing undeclared variables, there is no `ReferenceError` thrown if you try to access an object property (even on the global `window` object) that doesn't exist.

On the other hand, manually referencing the global variable with a `window` reference is something some developers prefer to avoid, especially if your code needs to run in multiple JS environments (not just browsers, but server-side node.js, for instance), where the global object may not always be called `window`.

Technically, this safety guard on `typeof` is useful even if you're not using global variables, though these circumstances are less common, and some developers may find this design approach less desirable. Imagine a utility function that you want others to copy-and-paste into their programs or modules, in which you want to check to see if the including program has defined a certain variable (so that you can use it) or not:

```
function doSomethingCool() {
	var helper =
		(typeof FeatureXYZ !== "undefined") ?
		FeatureXYZ :
		function() { /*.. default feature ..*/ };

	var val = helper();
	// ..
}
```

`doSomethingCool()` tests for a variable called `FeatureXYZ`, and if found, uses it, but if not, uses its own. Now, if someone includes this utility in their module/program, it safely checks if they've defined `FeatureXYZ` or not:

```
// an IIFE (see "Immediately Invoked Function Expressions"
// discussion in the *Scope & Closures* title of this series)
(function(){
	function FeatureXYZ() { /*.. my XYZ feature ..*/ }

	// include `doSomethingCool(..)`
```

```
		function doSomethingCool() {
			var helper =
				(typeof FeatureXYZ !== "undefined") ?
				FeatureXYZ :
				function() { /*.. default feature ..*/ };

			var val = helper();
			// ..
		}

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

Here, `FeatureXYZ` is not at all a global variable, but we're still using the safety guard of `typeof` to make it safe to check for. And importantly, here there is *no* object we can use (like we did for global variables with `window.___`) to make the check, so `typeof` is quite helpful.

Other developers would prefer a design pattern called "dependency injection," where instead of `doSomethingCool()` inspecting implicitly for `FeatureXYZ` to be defined outside/around it, it would need to have the dependency explicitly passed in, like:

```
	function doSomethingCool(FeatureXYZ) {
		var helper = FeatureXYZ ||
			function() { /*.. default feature ..*/ };

		var val = helper();
		// ..
	}
```

There are lots of options when designing such functionality. No one pattern here is "correct" or "wrong" -- there are various tradeoffs to each approach. But overall, it's nice that the `typeof` undeclared safety guard gives us more options.

Review

JavaScript has seven built-in *types*: `null` , `undefined` , `boolean` , `number` , `string` , `object` , `symbol` . They can be identified by the `typeof` operator.

Variables don't have types, but the values in them do. These types define intrinsic behavior of the values.

Many developers will assume "undefined" and "undeclared" are roughly the same thing, but in JavaScript, they're quite different. `undefined` is a value that a declared variable can hold. "Undeclared" means a variable has never been declared.

JavaScript unfortunately kind of conflates these two terms, not only in its error messages ("ReferenceError: a is not defined") but also in the return values of `typeof` , which is `"undefined"` for both cases.

However, the safety guard (preventing an error) on `typeof` when used against an undeclared variable can be helpful in certain cases.

You Don't Know JS Yet: Types & Grammar - 2nd Edition

Chapter 2: Values

NOTE:
Work in progress

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`array` s, `string` s, and `number` s are the most basic building-blocks of any program, but JavaScript has some unique characteristics with these types that may either delight or confound you.

Let's look at several of the built-in value types in JS, and explore how we can more fully understand and correctly leverage their behaviors.

Arrays

As compared to other type-enforced languages, JavaScript `array` s are just containers for any type of value, from `string` to `number` to `object` to even another `array` (which is how you get multidimensional `array` s).

```
var a = [ 1, "2", [3] ];

a.length;               // 3
a[0] === 1;             // true
a[2][0] === 3;   // true
```

You don't need to presize your `array` s (see "Arrays" in Chapter 3), you can just declare them and add values as you see fit:

```
var a = [ ];

a.length;       // 0
```

```
a[0] = 1;
a[1] = "2";
a[2] = [ 3 ];

a.length;       // 3
```

Warning: Using `delete` on an `array` value will remove that slot from the `array`, but even if you remove the final element, it does **not** update the `length` property, so be careful! We'll cover the `delete` operator itself in more detail in Chapter 5.

Be careful about creating "sparse" `array`s (leaving or creating empty/missing slots):

```
var a = [ ];

a[0] = 1;
// no `a[1]` slot set here
a[2] = [ 3 ];

a[1];           // undefined

a.length;       // 3
```

While that works, it can lead to some confusing behavior with the "empty slots" you leave in between. While the slot appears to have the `undefined` value in it, it will not behave the same as if the slot is explicitly set (`a[1] = undefined`). See "Arrays" in Chapter 3 for more information.

`array`s are numerically indexed (as you'd expect), but the tricky thing is that they also are objects that can have `string` keys/properties added to them (but which don't count toward the `length` of the `array`):

```
var a = [ ];

a[0] = 1;
a["foobar"] = 2;
```

```
a.length;                // 1
a["foobar"];     // 2
a.foobar;                // 2
```

However, a gotcha to be aware of is that if a `string` value intended as a key can be coerced to a standard base-10 `number`, then it is assumed that you wanted to use it as a `number` index rather than as a `string` key!

```
var a = [ ];

a["13"] = 42;

a.length; // 14
```

Generally, it's not a great idea to add `string` keys/properties to `array` s. Use `object` s for holding values in keys/properties, and save `array` s for strictly numerically indexed values.

Array-Likes

There will be occasions where you need to convert an `array` -like value (a numerically indexed collection of values) into a true `array`, usually so you can call array utilities (like `indexOf(..)`, `concat(..)`, `forEach(..)`, etc.) against the collection of values.

For example, various DOM query operations return lists of DOM elements that are not true `array` s but are `array` -like enough for our conversion purposes. Another common example is when functions expose the `arguments` (`array` -like) object (as of ES6, deprecated) to access the arguments as a list.

One very common way to make such a conversion is to borrow the `slice(..)` utility against the value:

```
function foo() {
        var arr = Array.prototype.slice.call( arguments );
        arr.push( "bam" );
        console.log( arr );
}

foo( "bar", "baz" ); // ["bar","baz","bam"]
```

If `slice()` is called without any other parameters, as it effectively is in the above snippet, the default values for its parameters have the effect of duplicating the `array` (or, in this case, `array` -like).

As of ES6, there's also a built-in utility called `Array.from(..)` that can do the same task:

```
...
var arr = Array.from( arguments );
...
```

Note: `Array.from(..)` has several powerful capabilities, and will be covered in detail in the *ES6 & Beyond* title of this series.

Strings

It's a very common belief that `string` s are essentially just `array` s of characters. While the implementation under the covers may or may not use `array` s, it's important to realize that JavaScript `string` s are really not the same as `array` s of characters. The similarity is mostly just skin-deep.

For example, let's consider these two values:

```
var a = "foo";
var b = ["f","o","o"];
```

Strings do have a shallow resemblance to `array` s -- `array` -likes, as above -- for instance, both of them having a `length` property, an `indexOf(..)` method (`array` version only as of ES5), and a `concat(..)` method:

```
a.length;                                                   // 3
b.length;                                                   // 3

a.indexOf( "o" );                                   // 1
b.indexOf( "o" );                                   // 1

var c = a.concat( "bar" );                  // "foobar"
var d = b.concat( ["b","a","r"] );      // ["f","o","o","b","a","r"]

a === c;                                                    // false
b === d;                                                    // false

a;                                                                  // "foo"
b;                                                                  // ["f","o","o"]
```

So, they're both basically just "arrays of characters", right? **Not exactly**:

```
a[1] = "O";
b[1] = "O";

a; // "foo"
b; // ["f","O","o"]
```

JavaScript `string` s are immutable, while `array` s are quite mutable. Moreover, the `a[1]` character position access form was not always widely valid JavaScript. Older versions of IE did not allow that syntax (but now they do). Instead, the *correct* approach has been `a.charAt(1)` .

A further consequence of immutable `string` s is that none of the `string` methods that alter its contents can modify in-place, but rather must create and return new `string` s. By contrast, many of the methods that change `array` contents actually *do* modify in-place.

```
c = a.toUpperCase();
a === c;        // false
a;                      // "foo"
c;                      // "FOO"

b.push( "!" );
b;                      // ["f","O","o","!"]
```

Also, many of the `array` methods that could be helpful when dealing with `string`s are not actually available for them, but we can "borrow" non-mutation `array` methods against our `string`:

```
a.join;                 // undefined
a.map;                  // undefined

var c = Array.prototype.join.call( a, "-" );
var d = Array.prototype.map.call( a, function(v){
        return v.toUpperCase() + ".";
} ).join( "" );

c;                              // "f-o-o"
d;                              // "F.O.O."
```

Let's take another example: reversing a `string` (incidentally, a common JavaScript interview trivia question!). `array`s have a `reverse()` in-place mutator method, but `string`s do not:

```
a.reverse;              // undefined

b.reverse();    // ["!","o","O","f"]
b;                              // ["!","o","O","f"]
```

Unfortunately, this "borrowing" doesn't work with `array` mutators, because `string` s are immutable and thus can't be modified in place:

```
Array.prototype.reverse.call( a );
// still returns a String object wrapper (see Chapter 3)
// for "foo" :(
```

Another workaround (aka hack) is to convert the `string` into an `array`, perform the desired operation, then convert it back to a `string`.

```
var c = a
        // split `a` into an array of characters
        .split( "" )
        // reverse the array of characters
        .reverse()
        // join the array of characters back to a string
        .join( "" );

c; // "oof"
```

If that feels ugly, it is. Nevertheless, *it works* for simple `string` s, so if you need something quick-n-dirty, often such an approach gets the job done.

Warning: Be careful! This approach **doesn't work** for `string` s with complex (unicode) characters in them (astral symbols, multibyte characters, etc.). You need more sophisticated library utilities that are unicode-aware for such operations to be handled accurately. Consult Mathias Bynens' work on the subject: *Esrever* (https://github.com/mathiasbynens/esrever).

The other way to look at this is: if you are more commonly doing tasks on your "strings" that treat them as basically *arrays of characters*, perhaps it's better to just actually store them as `array` s rather than as `string` s. You'll probably save yourself a lot of hassle of converting from `string` to `array` each time. You can always call `join("")` on the `array` *of characters* whenever you actually need the `string` representation.

Numbers

JavaScript has just one numeric type: `number`. This type includes both "integer" values and fractional decimal numbers. I say "integer" in quotes because it's long been a criticism of JS that there are not true integers, as there are in other languages. That may change at some point in the future, but for now, we just have `number`s for everything.

So, in JS, an "integer" is just a value that has no fractional decimal value. That is, `42.0` is as much an "integer" as `42`.

Like most modern languages, including practically all scripting languages, the implementation of JavaScript's `number`s is based on the "IEEE 754" standard, often called "floating-point." JavaScript specifically uses the "double precision" format (aka "64-bit binary") of the standard.

There are many great write-ups on the Web about the nitty-gritty details of how binary floating-point numbers are stored in memory, and the implications of those choices. Because understanding bit patterns in memory is not strictly necessary to understand how to correctly use `number`s in JS, we'll leave it as an exercise for the interested reader if you'd like to dig further into IEEE 754 details.

Numeric Syntax

Number literals are expressed in JavaScript generally as base-10 decimal literals. For example:

```
var a = 42;
var b = 42.3;
```

The leading portion of a decimal value, if `0`, is optional:

```
var a = 0.42;
var b = .42;
```

Similarly, the trailing portion (the fractional) of a decimal value after the `.`, if `0`, is optional:

```
var a = 42.0;
var b = 42.;
```

Warning: `42.` is pretty uncommon, and probably not a great idea if you're trying to avoid confusion when other people read your code. But it is, nevertheless, valid.

By default, most `number` s will be outputted as base-10 decimals, with trailing fractional `0` s removed. So:

```
var a = 42.300;
var b = 42.0;

a; // 42.3
b; // 42
```

Very large or very small `number` s will by default be outputted in exponent form, the same as the output of the `toExponential()` method, like:

```
var a = 5E10;
a;                                      // 50000000000
a.toExponential();      // "5e+10"

var b = a * a;
b;                                      // 2.5e+21

var c = 1 / a;
c;                                      // 2e-11
```

Because `number` values can be boxed with the `Number` object wrapper (see Chapter 3), `number` values can access methods that are built into the `Number.prototype` (see Chapter 3). For example, the `toFixed(..)` method allows you to specify how many fractional decimal places you'd like the value to be represented with:

```
var a = 42.59;

a.toFixed( 0 ); // "43"
a.toFixed( 1 ); // "42.6"
a.toFixed( 2 ); // "42.59"
a.toFixed( 3 ); // "42.590"
a.toFixed( 4 ); // "42.5900"
```

Notice that the output is actually a `string` representation of the `number`, and that the value is `0`-padded on the right-hand side if you ask for more decimals than the value holds.

`toPrecision(..)` is similar, but specifies how many *significant digits* should be used to represent the value:

```
var a = 42.59;

a.toPrecision( 1 ); // "4e+1"
a.toPrecision( 2 ); // "43"
a.toPrecision( 3 ); // "42.6"
a.toPrecision( 4 ); // "42.59"
a.toPrecision( 5 ); // "42.590"
a.toPrecision( 6 ); // "42.5900"
```

You don't have to use a variable with the value in it to access these methods; you can access these methods directly on `number` literals. But you have to be careful with the `.` operator. Since `.` is a valid numeric character, it will first be interpreted as part of the `number` literal, if possible, instead of being interpreted as a property accessor.

```
// invalid syntax:
42.toFixed( 3 );        // SyntaxError

// these are all valid:
(42).toFixed( 3 );      // "42.000"
```

```
0.42.toFixed( 3 );      // "0.420"
42..toFixed( 3 );       // "42.000"
```

`42.toFixed(3)` is invalid syntax, because the `.` is swallowed up as part of the `42.` literal (which is valid -- see above!), and so then there's no `.` property operator present to make the `.toFixed` access.

`42..toFixed(3)` works because the first `.` is part of the `number` and the second `.` is the property operator. But it probably looks strange, and indeed it's very rare to see something like that in actual JavaScript code. In fact, it's pretty uncommon to access methods directly on any of the primitive values. Uncommon doesn't mean *bad* or *wrong*.

Note: There are libraries that extend the built-in `Number.prototype` (see Chapter 3) to provide extra operations on/with `number` s, and so in those cases, it's perfectly valid to use something like `10..makeItRain()` to set off a 10-second money raining animation, or something else silly like that.

This is also technically valid (notice the space):

```
42 .toFixed(3); // "42.000"
```

However, with the `number` literal specifically, **this is particularly confusing coding style** and will serve no other purpose but to confuse other developers (and your future self). Avoid it.

`number` s can also be specified in exponent form, which is common when representing larger `number` s, such as:

```
var onethousand = 1E3;                                  // means 1 * 10^3
var onemilliononehundredthousand = 1.1E6;       // means 1.1 * 10^6
```

`number` literals can also be expressed in other bases, like binary, octal, and hexadecimal.

These formats work in current versions of JavaScript:

```
0xf3; // hexadecimal for: 243
0Xf3; // ditto

0363; // octal for: 243
```

Note: Starting with ES6 + `strict` mode, the `0363` form of octal literals is no longer allowed (see below for the new form). The `0363` form is still allowed in non-`strict` mode, but you should stop using it anyway, to be future-friendly (and because you should be using `strict` mode by now!).

As of ES6, the following new forms are also valid:

```
0o363;          // octal for: 243
0O363;          // ditto

0b11110011;     // binary for: 243
0B11110011; // ditto
```

Please do your fellow developers a favor: never use the `0O363` form. `0` next to capital `O` is just asking for confusion. Always use the lowercase predicates `0x` , `0b` , and `0o` .

Small Decimal Values

The most (in)famous side effect of using binary floating-point numbers (which, remember, is true of **all** languages that use IEEE 754 -- not *just* JavaScript as many assume/pretend) is:

```
0.1 + 0.2 === 0.3; // false
```

Mathematically, we know that statement should be `true` . Why is it `false` ?

Simply put, the representations for `0.1` and `0.2` in binary floating-point are not exact, so when they are added, the result is not exactly `0.3`. It's **really** close: `0.30000000000000004`, but if your comparison fails, "close" is irrelevant.

Note: Should JavaScript switch to a different `number` implementation that has exact representations for all values? Some think so. There have been many alternatives presented over the years. None of them have been accepted yet, and perhaps never will. As easy as it may seem to just wave a hand and say, "fix that bug already!", it's not nearly that easy. If it were, it most definitely would have been changed a long time ago.

Now, the question is, if some `number`s can't be *trusted* to be exact, does that mean we can't use `number`s at all? **Of course not.**

There are some applications where you need to be more careful, especially when dealing with fractional decimal values. There are also plenty of (maybe most?) applications that only deal with whole numbers ("integers"), and moreover, only deal with numbers in the millions or trillions at maximum. These applications have been, and always will be, **perfectly safe** to use numeric operations in JS.

What if we *did* need to compare two `number`s, like `0.1 + 0.2` to `0.3`, knowing that the simple equality test fails?

The most commonly accepted practice is to use a tiny "rounding error" value as the *tolerance* for comparison. This tiny value is often called "machine epsilon," which is commonly `2^-52` (`2.220446049250313e-16`) for the kind of `number`s in JavaScript.

As of ES6, `Number.EPSILON` is predefined with this tolerance value, so you'd want to use it, but you can safely polyfill the definition for pre-ES6:

```
if (!Number.EPSILON) {
	Number.EPSILON = Math.pow(2,-52);
}
```

We can use this `Number.EPSILON` to compare two `number`s for "equality" (within the rounding error tolerance):

```
function numbersCloseEnoughToEqual(n1,n2) {
        return Math.abs( n1 - n2 ) < Number.EPSILON;
}

var a = 0.1 + 0.2;
var b = 0.3;

numbersCloseEnoughToEqual( a, b );                                    // true
numbersCloseEnoughToEqual( 0.0000001, 0.0000002 );      // false
```

The maximum floating-point value that can be represented is roughly `1.798e+308` (which is really, really, really huge!), predefined for you as `Number.MAX_VALUE`. On the small end, `Number.MIN_VALUE` is roughly `5e-324`, which isn't negative but is really close to zero!

Safe Integer Ranges

Because of how `number`s are represented, there is a range of "safe" values for the whole `number` "integers", and it's significantly less than `Number.MAX_VALUE`.

The maximum integer that can "safely" be represented (that is, there's a guarantee that the requested value is actually representable unambiguously) is `2^53 - 1`, which is `9007199254740991`. If you insert your commas, you'll see that this is just over 9 quadrillion. So that's pretty darn big for `number`s to range up to.

This value is actually automatically predefined in ES6, as `Number.MAX_SAFE_INTEGER`. Unsurprisingly, there's a minimum value, `-9007199254740991`, and it's defined in ES6 as `Number.MIN_SAFE_INTEGER`.

The main way that JS programs are confronted with dealing with such large numbers is when dealing with 64-bit IDs from databases, etc. 64-bit numbers cannot be represented accurately with the `number` type, so must be stored in (and transmitted to/from) JavaScript using `string` representation.

Numeric operations on such large ID `number` values (besides comparison, which will be fine with `string` s) aren't all that common, thankfully. But if you *do* need to perform math on these very large values, for now you'll need to use a *big number* utility. Big numbers may get official support in a future version of JavaScript.

Testing for Integers

To test if a value is an integer, you can use the ES6-specified `Number.isInteger(..)` :

```
Number.isInteger( 42 );         // true
Number.isInteger( 42.000 );     // true
Number.isInteger( 42.3 );       // false
```

To polyfill `Number.isInteger(..)` for pre-ES6:

```
if (!Number.isInteger) {
        Number.isInteger = function(num) {
                return typeof num == "number" && num % 1 == 0;
        };
}
```

To test if a value is a *safe integer*, use the ES6-specified `Number.isSafeInteger(..)` :

```
Number.isSafeInteger( Number.MAX_SAFE_INTEGER );        // true
Number.isSafeInteger( Math.pow( 2, 53 ) );                      // false
Number.isSafeInteger( Math.pow( 2, 53 ) - 1 );          // true
```

To polyfill `Number.isSafeInteger(..)` in pre-ES6 browsers:

```
if (!Number.isSafeInteger) {
        Number.isSafeInteger = function(num) {
                return Number.isInteger( num ) &&
                    Math.abs( num ) <= Number.MAX_SAFE_INTEGER;
            };
    }
```

32-bit (Signed) Integers

While integers can range up to roughly 9 quadrillion safely (53 bits), there are some numeric operations (like the bitwise operators) that are only defined for 32-bit `number` s, so the "safe range" for `number` s used in that way must be much smaller.

The range then is `Math.pow(-2,31)` (`-2147483648` , about -2.1 billion) up to `Math.pow(2,31)-1` (`2147483647` , about +2.1 billion).

To force a `number` value in `a` to a 32-bit signed integer value, use `a | 0` . This works because the `|` bitwise operator only works for 32-bit integer values (meaning it can only pay attention to 32 bits and any other bits will be lost). Then, "or'ing" with zero is essentially a no-op bitwise speaking.

Note: Certain special values (which we will cover in the next section) such as `NaN` and `Infinity` are not "32-bit safe," in that those values when passed to a bitwise operator will pass through the abstract operation `ToInt32` (see Chapter 4) and become simply the `+0` value for the purpose of that bitwise operation.

Special Values

There are several special values spread across the various types that the *alert* JS developer needs to be aware of, and use properly.

The Non-value Values

For the `undefined` type, there is one and only one value: `undefined` . For the `null` type, there is one and only one value: `null` . So for both of them, the label is both its type and its value.

Both `undefined` and `null` are often taken to be interchangeable as either "empty" values or "non" values. Other developers prefer to distinguish between them with nuance. For example:

- `null` is an empty value
- `undefined` is a missing value

Or:

- `undefined` hasn't had a value yet
- `null` had a value and doesn't anymore

Regardless of how you choose to "define" and use these two values, `null` is a special keyword, not an identifier, and thus you cannot treat it as a variable to assign to (why would you!?). However, `undefined` *is* (unfortunately) an identifier. Uh oh.

Undefined

In non-`strict` mode, it's actually possible (though incredibly ill-advised!) to assign a value to the globally provided `undefined` identifier:

```
function foo() {
        undefined = 2; // really bad idea!
}

foo();
```

```
function foo() {
        "use strict";
        undefined = 2; // TypeError!
}

foo();
```

In both non- `strict` mode and `strict` mode, however, you can create a local variable of the name `undefined` . But again, this is a terrible idea!

```
function foo() {
        "use strict";
        var undefined = 2;
        console.log( undefined ); // 2
}

foo();
```

Friends don't let friends override `undefined` . Ever.

`void` Operator

While `undefined` is a built-in identifier that holds (unless modified -- see above!) the built-in `undefined` value, another way to get this value is the `void` operator.

The expression `void ___` "voids" out any value, so that the result of the expression is always the `undefined` value. It doesn't modify the existing value; it just ensures that no value comes back from the operator expression.

```
var a = 42;

console.log( void a, a ); // undefined 42
```

By convention (mostly from C-language programming), to represent the `undefined` value stand-alone by using `void` , you'd use `void 0` (though clearly even `void true` or any other `void` expression does the same thing). There's no practical difference between `void 0` , `void 1` , and `undefined` .

But the `void` operator can be useful in a few other circumstances, if you need to ensure that an expression has no result value (even if it has side effects).

For example:

```
function doSomething() {
	// note: `APP.ready` is provided by our application
	if (!APP.ready) {
		// try again later
		return void setTimeout( doSomething, 100 );
	}

	var result;

	// do some other stuff
	return result;
}

// were we able to do it right away?
if (doSomething()) {
	// handle next tasks right away
}
```

Here, the `setTimeout(..)` function returns a numeric value (the unique identifier of the timer interval, if you wanted to cancel it), but we want to `void` that out so that the return value of our function doesn't give a false-positive with the `if` statement.

Many devs prefer to just do these actions separately, which works the same but doesn't use the `void` operator:

```
if (!APP.ready) {
	// try again later
	setTimeout( doSomething, 100 );
	return;
}
```

In general, if there's ever a place where a value exists (from some expression) and you'd find it useful for the value to be `undefined` instead, use the `void` operator. That probably won't be terribly common in your programs, but in the rare cases you do need it, it can be quite helpful.

Special Numbers

The `number` type includes several special values. We'll take a look at each in detail.

The Not Number, Number

Any mathematic operation you perform without both operands being `number`s (or values that can be interpreted as regular `number`s in base 10 or base 16) will result in the operation failing to produce a valid `number`, in which case you will get the `NaN` value.

`NaN` literally stands for "not a `number`", though this label/description is very poor and misleading, as we'll see shortly. It would be much more accurate to think of `NaN` as being "invalid number," "failed number," or even "bad number," than to think of it as "not a number."

For example:

```
var a = 2 / "foo";              // NaN

typeof a === "number";  // true
```

In other words: "the type of not-a-number is 'number'!" Hooray for confusing names and semantics.

`NaN` is a kind of "sentinel value" (an otherwise normal value that's assigned a special meaning) that represents a special kind of error condition within the `number` set. The error condition is, in essence: "I tried to perform a mathematic operation but failed, so here's the failed `number` result instead."

So, if you have a value in some variable and want to test to see if it's this special failed-number `NaN`, you might think you could directly compare to `NaN` itself, as you can with any other value, like `null` or `undefined`. Nope.

```
var a = 2 / "foo";

a == NaN;       // false
a === NaN;      // false
```

`NaN` is a very special value in that it's never equal to another `NaN` value (i.e., it's never equal to itself). It's the only value, in fact, that is not reflexive (without the Identity characteristic `x === x`). So, `NaN !== NaN`. A bit strange, huh?

So how *do* we test for it, if we can't compare to `NaN` (since that comparison would always fail)?

```
var a = 2 / "foo";

isNaN( a ); // true
```

Easy enough, right? We use the built-in global utility called `isNaN(..)` and it tells us if the value is `NaN` or not. Problem solved!

Not so fast.

The `isNaN(..)` utility has a fatal flaw. It appears it tried to take the meaning of `NaN` ("Not a Number") too literally -- that its job is basically: "test if the thing passed in is either not a `number` or is a `number`." But that's not quite accurate.

```
var a = 2 / "foo";
var b = "foo";

a; // NaN
b; // "foo"
```

```
window.isNaN( a ); // true
window.isNaN( b ); // true -- ouch!
```

Clearly, `"foo"` is literally *not a `number`*, but it's definitely not the `NaN` value either! This bug has been in JS since the very beginning (over 19 years of *ouch*).

As of ES6, finally a replacement utility has been provided: `Number.isNaN(..)`. A simple polyfill for it so that you can safely check `NaN` values *now* even in pre-ES6 browsers is:

```
if (!Number.isNaN) {
	Number.isNaN = function(n) {
		return (
			typeof n === "number" &&
			window.isNaN( n )
		);
	};
}

var a = 2 / "foo";
var b = "foo";

Number.isNaN( a ); // true
Number.isNaN( b ); // false -- phew!
```

Actually, we can implement a `Number.isNaN(..)` polyfill even easier, by taking advantage of that peculiar fact that `NaN` isn't equal to itself. `NaN` is the *only* value in the whole language where that's true; every other value is always **equal to itself**.

So:

```
if (!Number.isNaN) {
	Number.isNaN = function(n) {
		return n !== n;
```

```
        };
}
```

Weird, huh? But it works!

`NaN` s are probably a reality in a lot of real-world JS programs, either on purpose or by accident. It's a really good idea to use a reliable test, like `Number.isNaN(..)` as provided (or polyfilled), to recognize them properly.

If you're currently using just `isNaN(..)` in a program, the sad reality is your program *has a bug*, even if you haven't been bitten by it yet!

Infinities

Developers from traditional compiled languages like C are probably used to seeing either a compiler error or runtime exception, like "Divide by zero," for an operation like:

```
var a = 1 / 0;
```

However, in JS, this operation is well-defined and results in the value `Infinity` (aka `Number.POSITIVE_INFINITY`). Unsurprisingly:

```
var a = 1 / 0;  // Infinity
var b = -1 / 0; // -Infinity
```

As you can see, `-Infinity` (aka `Number.NEGATIVE_INFINITY`) results from a divide-by-zero where either (but not both!) of the divide operands is negative.

JS uses finite numeric representations (IEEE 754 floating-point, which we covered earlier), so contrary to pure mathematics, it seems it *is* possible to overflow even with an operation like addition or subtraction, in which case you'd get `Infinity` or `-Infinity` .

For example:

```
var a = Number.MAX_VALUE;        // 1.7976931348623157e+308
a + a;                                          // Infinity
a + Math.pow( 2, 970 );          // Infinity
a + Math.pow( 2, 969 );          // 1.7976931348623157e+308
```

According to the specification, if an operation like addition results in a value that's too big to represent, the IEEE 754 "round-to-nearest" mode specifies what the result should be. So, in a crude sense, `Number.MAX_VALUE + Math.pow( 2, 969 )` is closer to `Number.MAX_VALUE` than to `Infinity`, so it "rounds down," whereas `Number.MAX_VALUE + Math.pow( 2, 970 )` is closer to `Infinity` so it "rounds up".

If you think too much about that, it's going to make your head hurt. So don't. Seriously, stop!

Once you overflow to either one of the *infinities*, however, there's no going back. In other words, in an almost poetic sense, you can go from finite to infinite but not from infinite back to finite.

It's almost philosophical to ask: "What is infinity divided by infinity". Our naive brains would likely say "1" or maybe "infinity." Turns out neither is true. Both mathematically and in JavaScript, `Infinity / Infinity` is not a defined operation. In JS, this results in `NaN`.

But what about any positive finite `number` divided by `Infinity`? That's easy! `0`. And what about a negative finite `number` divided by `Infinity`? Keep reading!

Zeros

While it may confuse the mathematics-minded reader, JavaScript has both a normal zero `0` (otherwise known as a positive zero `+0`) *and* a negative zero `-0`. Before we explain why the `-0` exists, we should examine how JS handles it, because it can be quite confusing.

Besides being specified literally as `-0`, negative zero also results from certain mathematic operations. For example:

```
var a = 0 / -3; // -0
var b = 0 * -3; // -0
```

Addition and subtraction cannot result in a negative zero.

A negative zero when examined in the developer console will usually reveal `-0`, though that was not the common case until fairly recently, so some older browsers you encounter may still report it as `0`.

However, if you try to stringify a negative zero value, it will always be reported as `"0"`, according to the spec.

```
var a = 0 / -3;

// (some browser) consoles at least get it right
a;                                                      // -0

// but the spec insists on lying to you!
a.toString();                               // "0"
a + "";                                             // "0"
String( a );                                // "0"

// strangely, even JSON gets in on the deception
JSON.stringify( a );                // "0"
```

Interestingly, the reverse operations (going from `string` to `number`) don't lie:

```
+"-0";                              // -0
Number( "-0" );             // -0
JSON.parse( "-0" );         // -0
```

Warning: The `JSON.stringify( -0 )` behavior of `"0"` is particularly strange when you observe that it's inconsistent with the reverse: `JSON.parse( "-0" )` reports `-0` as you'd correctly expect.

In addition to stringification of negative zero being deceptive to hide its true value, the comparison operators are also (intentionally) configured to *lie*.

```
var a = 0;
var b = 0 / -3;

a == b;         // true
-0 == 0;        // true

a === b;        // true
-0 === 0;       // true

0 > -0;         // false
a > b;          // false
```

Clearly, if you want to distinguish a `-0` from a `0` in your code, you can't just rely on what the developer console outputs, so you're going to have to be a bit more clever:

```
function isNegZero(n) {
        n = Number( n );
        return (n === 0) && (1 / n === -Infinity);
}

isNegZero( -0 );                // true
isNegZero( 0 / -3 );    // true
isNegZero( 0 );                 // false
```

Now, why do we need a negative zero, besides academic trivia?

There are certain applications where developers use the magnitude of a value to represent one piece of information (like speed of movement per animation frame) and the sign of that `number` to represent another piece of information (like the direction of that movement).

In those applications, as one example, if a variable arrives at zero and it loses its sign, then you would lose the information of what direction it was moving in before it arrived at zero. Preserving the sign of the zero prevents potentially unwanted information loss.

Special Equality

As we saw above, the `NaN` value and the `-0` value have special behavior when it comes to equality comparison. `NaN` is never equal to itself, so you have to use ES6's `Number.isNaN(..)` (or a polyfill). Similarly, `-0` lies and pretends that it's equal (even `===` strict equal -- see Chapter 4) to regular positive `0`, so you have to use the somewhat hackish `isNegZero(..)` utility we suggested above.

As of ES6, there's a new utility that can be used to test two values for absolute equality, without any of these exceptions. It's called `Object.is(..)`:

```
var a = 2 / "foo";
var b = -3 * 0;

Object.is( a, NaN );	// true
Object.is( b, -0 );		// true

Object.is( b, 0 );		// false
```

There's a pretty simple polyfill for `Object.is(..)` for pre-ES6 environments:

```
if (!Object.is) {
	Object.is = function(v1, v2) {
		// test for `-0`
		if (v1 === 0 && v2 === 0) {
			return 1 / v1 === 1 / v2;
		}
		// test for `NaN`
		if (v1 !== v1) {
```

```
                return v2 !== v2;
            }
            // everything else
            return v1 === v2;
        };
}
```

`Object.is(..)` probably shouldn't be used in cases where `==` or `===` are known to be *safe* (see Chapter 4 "Coercion"), as the operators are likely much more efficient and certainly are more idiomatic/common. `Object.is(..)` is mostly for these special cases of equality.

Value vs. Reference

In many other languages, values can either be assigned/passed by value-copy or by reference-copy depending on the syntax you use.

For example, in C++ if you want to pass a `number` variable into a function and have that variable's value updated, you can declare the function parameter like `int& myNum`, and when you pass in a variable like `x`, `myNum` will be a **reference to `x`**; references are like a special form of pointers, where you obtain a pointer to another variable (like an *alias*). If you don't declare a reference parameter, the value passed in will *always* be copied, even if it's a complex object.

In JavaScript, there are no pointers, and references work a bit differently. You cannot have a reference from one JS variable to another variable. That's just not possible.

A reference in JS points at a (shared) **value**, so if you have 10 different references, they are all always distinct references to a single shared value; **none of them are references/pointers to each other.**

Moreover, in JavaScript, there are no syntactic hints that control value vs. reference assignment/passing. Instead, the *type* of the value *solely* controls whether that value will be assigned by value-copy or by reference-copy.

Let's illustrate:

```js
var a = 2;
var b = a; // `b` is always a copy of the value in `a`
b++;
a; // 2
b; // 3

var c = [1,2,3];
var d = c; // `d` is a reference to the shared `[1,2,3]` value
d.push( 4 );
c; // [1,2,3,4]
d; // [1,2,3,4]
```

Simple values (aka scalar primitives) are *always* assigned/passed by value-copy: `null` , `undefined` , `string` , `number` , `boolean` , and ES6's `symbol` .

Compound values -- `object` s (including `array` s, and all boxed object wrappers -- see Chapter 3) and `function` s -- *always* create a copy of the reference on assignment or passing.

In the above snippet, because `2` is a scalar primitive, `a` holds one initial copy of that value, and `b` is assigned another *copy* of the value. When changing `b` , you are in no way changing the value in `a` .

But **both `c` and `d`** are separate references to the same shared value `[1,2,3]` , which is a compound value. It's important to note that neither `c` nor `d` more "owns" the `[1,2,3]` value -- both are just equal peer references to the value. So, when using either reference to modify (`.push(4)`) the actual shared `array` value itself, it's affecting just the one shared value, and both references will reference the newly modified value `[1,2,3,4]` .

Since references point to the values themselves and not to the variables, you cannot use one reference to change where another reference is pointed:

```js
var a = [1,2,3];
var b = a;
a; // [1,2,3]
```

```
b; // [1,2,3]

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

When we make the assignment `b = [4,5,6]`, we are doing absolutely nothing to affect *where* `a` is still referencing (`[1,2,3]`). To do that, `b` would have to be a pointer to `a` rather than a reference to the `array` -- but no such capability exists in JS!

The most common way such confusion happens is with function parameters:

```
function foo(x) {
        x.push( 4 );
        x; // [1,2,3,4]

        // later
        x = [4,5,6];
        x.push( 7 );
        x; // [4,5,6,7]
}

var a = [1,2,3];

foo( a );

a; // [1,2,3,4]  not  [4,5,6,7]
```

When we pass in the argument `a`, it assigns a copy of the `a` reference to `x`. `x` and `a` are separate references pointing at the same `[1,2,3]` value. Now, inside the function, we can use that reference to mutate the value itself (`push(4)`). But when we make the assignment `x = [4,5,6]`, this is in no way affecting where the initial reference `a` is pointing -- still points at the (now modified) `[1,2,3,4]` value.

There is no way to use the `x` reference to change where `a` is pointing. We could only modify the contents of the shared value that both `a` and `x` are pointing to.

To accomplish changing `a` to have the `[4,5,6,7]` value contents, you can't create a new `array` and assign -- you must modify the existing `array` value:

```
function foo(x) {
        x.push( 4 );
        x; // [1,2,3,4]

        // later
        x.length = 0; // empty existing array in-place
        x.push( 4, 5, 6, 7 );
        x; // [4,5,6,7]
}

var a = [1,2,3];

foo( a );

a; // [4,5,6,7]  not  [1,2,3,4]
```

As you can see, `x.length = 0` and `x.push(4,5,6,7)` were not creating a new `array`, but modifying the existing shared `array`. So of course, `a` references the new `[4,5,6,7]` contents.

Remember: you cannot directly control/override value-copy vs. reference -- those semantics are controlled entirely by the type of the underlying value.

To effectively pass a compound value (like an `array`) by value-copy, you need to manually make a copy of it, so that the reference passed doesn't still point to the original. For example:

```
foo( a.slice() );
```

`slice(..)` with no parameters by default makes an entirely new (shallow) copy of the `array`. So, we pass in a reference only to the copied `array`, and thus `foo(..)` cannot affect the contents of `a`.

To do the reverse -- pass a scalar primitive value in a way where its value updates can be seen, kinda like a reference -- you have to wrap the value in another compound value (`object`, `array`, etc) that *can* be passed by reference-copy:

```
function foo(wrapper) {
	wrapper.a = 42;
}

var obj = {
	a: 2
};

foo( obj );

obj.a; // 42
```

Here, `obj` acts as a wrapper for the scalar primitive property `a`. When passed to `foo(..)`, a copy of the `obj` reference is passed in and set to the `wrapper` parameter. We now can use the `wrapper` reference to access the shared object, and update its property. After the function finishes, `obj.a` will see the updated value `42`.

It may occur to you that if you wanted to pass in a reference to a scalar primitive value like `2`, you could just box the value in its `Number` object wrapper (see Chapter 3).

It *is* true a copy of the reference to this `Number` object *will* be passed to the function, but unfortunately, having a reference to the shared object is not going to give you the ability to modify the shared primitive value, like you may expect:

```
function foo(x) {
	x = x + 1;
	x; // 3
}
```

```
var a = 2;
var b = new Number( a ); // or equivalently `Object(a)`

foo( b );
console.log( b ); // 2, not 3
```

The problem is that the underlying scalar primitive value is *not mutable* (same goes for `String` and `Boolean`). If a `Number` object holds the scalar primitive value `2` , that exact `Number` object can never be changed to hold another value; you can only create a whole new `Number` object with a different value.

When `x` is used in the expression `x + 1` , the underlying scalar primitive value `2` is unboxed (extracted) from the `Number` object automatically, so the line `x = x + 1` very subtly changes `x` from being a shared reference to the `Number` object, to just holding the scalar primitive value `3` as a result of the addition operation `2 + 1` . Therefore, `b` on the outside still references the original unmodified/immutable `Number` object holding the value `2` .

You *can* add properties on top of the `Number` object (just not change its inner primitive value), so you could exchange information indirectly via those additional properties.

This is not all that common, however; it probably would not be considered a good practice by most developers.

Instead of using the wrapper object `Number` in this way, it's probably much better to use the manual object wrapper (`obj`) approach in the earlier snippet. That's not to say that there's no clever uses for the boxed object wrappers like `Number` -- just that you should probably prefer the scalar primitive value form in most cases.

References are quite powerful, but sometimes they get in your way, and sometimes you need them where they don't exist. The only control you have over reference vs. value-copy behavior is the type of the value itself, so you must indirectly influence the assignment/passing behavior by which value types you choose to use.

Review

In JavaScript, `array` s are simply numerically indexed collections of any value-type. `string` s are somewhat " `array` -like", but they have distinct behaviors and care must be taken if you want to treat them as `array` s. Numbers in JavaScript include both "integers" and floating-point values.

Several special values are defined within the primitive types.

The `null` type has just one value: `null` , and likewise the `undefined` type has just the `undefined` value. `undefined` is basically the default value in any variable or property if no other value is present. The `void` operator lets you create the `undefined` value from any other value.

`number` s include several special values, like `NaN` (supposedly "Not a Number", but really more appropriately "invalid number"); `+Infinity` and `-Infinity` ; and `-0` .

Simple scalar primitives (`string` s, `number` s, etc.) are assigned/passed by value-copy, but compound values (`object` s, etc.) are assigned/passed by reference-copy. References are not like references/pointers in other languages -- they're never pointed at other variables/references, only at the underlying values.

You Don't Know JS Yet: Types & Grammar - 2nd Edition

Chapter 3: Natives

NOTE:
Work in progress

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Several times in Chapters 1 and 2, we alluded to various built-ins, usually called "natives," like `String` and `Number` . Let's examine those in detail now.

Here's a list of the most commonly used natives:

- `String()`
- `Number()`
- `Boolean()`
- `Array()`
- `Object()`
- `Function()`
- `RegExp()`
- `Date()`
- `Error()`
- `Symbol()` -- added in ES6!

As you can see, these natives are actually built-in functions.

If you're coming to JS from a language like Java, JavaScript's `String()` will look like the `String(..)` constructor you're used to for creating string values. So, you'll quickly observe that you can do things like:

```
var s = new String( "Hello World!" );

console.log( s.toString() ); // "Hello World!"
```

It *is* true that each of these natives can be used as a native constructor. But what's being constructed may be different than you think.

```
var a = new String( "abc" );

typeof a; // "object" ... not "String"

a instanceof String; // true

Object.prototype.toString.call( a ); // "[object String]"
```

The result of the constructor form of value creation (`new String("abc")`) is an object wrapper around the primitive (`"abc"`) value.

Importantly, `typeof` shows that these objects are not their own special *types*, but more appropriately they are subtypes of the `object` type.

This object wrapper can further be observed with:

```
console.log( a );
```

The output of that statement varies depending on your browser, as developer consoles are free to choose however they feel it's appropriate to serialize the object for developer inspection.

Note: At the time of writing, the latest Chrome prints something like this: `String {0: "a", 1: "b", 2: "c", length: 3, [[PrimitiveValue]]: "abc"}` . But older versions of Chrome used to just print this: `String {0: "a", 1: "b", 2: "c"}` . The latest Firefox currently prints `String ["a","b","c"]` , but used to print `"abc"` in italics, which was clickable to open the object inspector. Of course, these results are subject to rapid change and your experience may vary.

The point is, `new String("abc")` creates a string wrapper object around `"abc"` , not just the primitive `"abc"` value itself.

Internal `[[Class]]`

Values that are `typeof` `"object"` (such as an array) are additionally tagged with an internal `[[Class]]` property (think of this more as an internal *class*ification rather than related to classes from traditional class-oriented coding). This property cannot be accessed directly, but can generally be revealed indirectly by borrowing the default `Object.prototype.toString(..)` method called against the value. For example:

```
Object.prototype.toString.call( [1,2,3] );                      // "[object Array]"

Object.prototype.toString.call( /regex-literal/i );     // "[object RegExp]"
```

So, for the array in this example, the internal `[[Class]]` value is `"Array"` , and for the regular expression, it's `"RegExp"` . In most cases, this internal `[[Class]]` value corresponds to the built-in native constructor (see below) that's related to the value, but that's not always the case.

What about primitive values? First, `null` and `undefined` :

```
Object.prototype.toString.call( null );                 // "[object Null]"
Object.prototype.toString.call( undefined );    // "[object Undefined]"
```

You'll note that there are no `Null()` or `Undefined()` native constructors, but nevertheless the `"Null"` and `"Undefined"` are the internal `[[Class]]` values exposed.

But for the other simple primitives like `string`, `number`, and `boolean`, another behavior actually kicks in, which is usually called "boxing" (see "Boxing Wrappers" section next):

```
Object.prototype.toString.call( "abc" );        // "[object String]"
Object.prototype.toString.call( 42 );           // "[object Number]"
Object.prototype.toString.call( true );         // "[object Boolean]"
```

In this snippet, each of the simple primitives are automatically boxed by their respective object wrappers, which is why `"String"`, `"Number"`, and `"Boolean"` are revealed as the respective internal `[[Class]]` values.

Note: The behavior of `toString()` and `[[Class]]` as illustrated here has changed a bit from ES5 to ES6, but we cover those details in the *ES6 & Beyond* title of this series.

Boxing Wrappers

These object wrappers serve a very important purpose. Primitive values don't have properties or methods, so to access `.length` or `.toString()` you need an object wrapper around the value. Thankfully, JS will automatically *box* (aka wrap) the primitive value to fulfill such accesses.

```
var a = "abc";

a.length; // 3
a.toUpperCase(); // "ABC"
```

So, if you're going to be accessing these properties/methods on your string values regularly, like a `i < a.length` condition in a `for` loop for instance, it might seem to make sense to just have the object form of the value from the start, so the JS engine doesn't need to implicitly create it for you.

But it turns out that's a bad idea. Browsers long ago performance-optimized the common cases like `.length`, which means your program will *actually go slower* if you try to "preoptimize" by directly using the object form (which isn't on the optimized path).

In general, there's basically no reason to use the object form directly. It's better to just let the boxing happen implicitly where necessary. In other words, never do things like `new String("abc")`, `new Number(42)`, etc -- always prefer using the literal primitive values `"abc"` and `42`.

Object Wrapper Gotchas

There are some gotchas with using the object wrappers directly that you should be aware of if you *do* choose to ever use them.

For example, consider `Boolean` wrapped values:

```
var a = new Boolean( false );

if (!a) {
        console.log( "Oops" ); // never runs
}
```

The problem is that you've created an object wrapper around the `false` value, but objects themselves are "truthy" (see Chapter 4), so using the object behaves oppositely to using the underlying `false` value itself, which is quite contrary to normal expectation.

If you want to manually box a primitive value, you can use the `Object(..)` function (no `new` keyword):

```
var a = "abc";
var b = new String( a );
var c = Object( a );

typeof a; // "string"
typeof b; // "object"
typeof c; // "object"

b instanceof String; // true
c instanceof String; // true

Object.prototype.toString.call( b ); // "[object String]"
Object.prototype.toString.call( c ); // "[object String]"
```

Again, using the boxed object wrapper directly (like `b` and `c` above) is usually discouraged, but there may be some rare occasions you'll run into where they may be useful.

Unboxing

If you have an object wrapper and you want to get the underlying primitive value out, you can use the `valueOf()` method:

```
var a = new String( "abc" );
var b = new Number( 42 );
var c = new Boolean( true );

a.valueOf(); // "abc"
b.valueOf(); // 42
c.valueOf(); // true
```

Unboxing can also happen implicitly, when using an object wrapper value in a way that requires the primitive value. This process (coercion) will be covered in more detail in Chapter 4, but briefly:

```
var a = new String( "abc" );
var b = a + ""; // `b` has the unboxed primitive value "abc"

typeof a; // "object"
typeof b; // "string"
```

Natives as Constructors

For `array` , `object` , `function` , and regular-expression values, it's almost universally preferred that you use the literal form for creating the values, but the literal form creates the same sort of object as the constructor form does (that is, there is no nonwrapped value).

Just as we've seen above with the other natives, these constructor forms should generally be avoided, unless you really know you need them, mostly because they introduce exceptions and gotchas that you probably don't really *want* to deal with.

`Array(..)`

```
var a = new Array( 1, 2, 3 );
a; // [1, 2, 3]

var b = [1, 2, 3];
b; // [1, 2, 3]
```

Note: The `Array(..)` constructor does not require the `new` keyword in front of it. If you omit it, it will behave as if you have used it anyway. So `Array(1,2,3)` is the same outcome as `new Array(1,2,3)` .

The `Array` constructor has a special form where if only one `number` argument is passed, instead of providing that value as *contents* of the array, it's taken as a length to "presize the array" (well, sorta).

This is a terrible idea. Firstly, you can trip over that form accidentally, as it's easy to forget.

But more importantly, there's no such thing as actually presizing the array. Instead, what you're creating is an otherwise empty array, but setting the `length` property of the array to the numeric value specified.

An array that has no explicit values in its slots, but has a `length` property that *implies* the slots exist, is a weird exotic type of data structure in JS with some very strange and confusing behavior. The capability to create such a value comes purely from old, deprecated, historical functionalities ("array-like objects" like the `arguments` object).

Note: An array with at least one "empty slot" in it is often called a "sparse array."

It doesn't help matters that this is yet another example where browser developer consoles vary on how they represent such an object, which breeds more confusion.

For example:

```
var a = new Array( 3 );

a.length; // 3
a;
```

The serialization of `a` in Chrome is (at the time of writing): `[ undefined x 3 ]`. **This is really unfortunate.** It implies that there are three `undefined` values in the slots of this array, when in fact the slots do not exist (so-called "empty slots" -- also a bad name!).

To visualize the difference, try this:

```
var a = new Array( 3 );
var b = [ undefined, undefined, undefined ];
var c = [];
c.length = 3;

a;
b;
c;
```

Note: As you can see with `c` in this example, empty slots in an array can happen after creation of the array. Changing the `length` of an array to go beyond its number of actually-defined slot values, you implicitly introduce empty slots. In fact, you could even call `delete b[1]` in the above snippet, and it would introduce an empty slot into the middle of `b`.

For `b` (in Chrome, currently), you'll find `[ undefined, undefined, undefined ]` as the serialization, as opposed to `[ undefined x 3 ]` for `a` and `c`. Confused? Yeah, so is everyone else.

Worse than that, at the time of writing, Firefox reports `[ , , , ]` for `a` and `c`. Did you catch why that's so confusing? Look closely. Three commas implies four slots, not three slots like we'd expect.

What!? Firefox puts an extra `,` on the end of their serialization here because as of ES5, trailing commas in lists (array values, property lists, etc.) are allowed (and thus dropped and ignored). So if you were to type in a `[ , , , ]` value into your program or the console, you'd actually get the underlying value that's like `[ , , ]` (that is, an array with three empty slots). This choice, while confusing if reading the developer console, is defended as instead making copy-n-paste behavior accurate.

If you're shaking your head or rolling your eyes about now, you're not alone! Shrugs.

Unfortunately, it gets worse. More than just confusing console output, `a` and `b` from the above code snippet actually behave the same in some cases **but differently in others**:

```
a.join( "-" ); // "--"
b.join( "-" ); // "--"

a.map(function(v,i){ return i; }); // [ undefined x 3 ]
b.map(function(v,i){ return i; }); // [ 0, 1, 2 ]
```

Ugh.

The `a.map(..)` call *fails* because the slots don't actually exist, so `map(..)` has nothing to iterate over. `join(..)` works differently. Basically, we can think of it implemented sort of like this:

```
function fakeJoin(arr,connector) {
        var str = "";
        for (var i = 0; i < arr.length; i++) {
                if (i > 0) {
                        str += connector;
                }
                if (arr[i] !== undefined) {
                        str += arr[i];
                }
        }
        return str;
}

var a = new Array( 3 );
fakeJoin( a, "-" ); // "--"
```

As you can see, `join(..)` works by just *assuming* the slots exist and looping up to the `length` value. Whatever `map(..)` does internally, it (apparently) doesn't make such an assumption, so the result from the strange "empty slots" array is unexpected and likely to cause failure.

So, if you wanted to *actually* create an array of actual `undefined` values (not just "empty slots"), how could you do it (besides manually)?

```
var a = Array.apply( null, { length: 3 } );
a; // [ undefined, undefined, undefined ]
```

Confused? Yeah. Here's roughly how it works.

`apply(..)` is a utility available to all functions, which calls the function it's used with but in a special way.

The first argument is a `this` object binding (covered in the *this & Object Prototypes* title of this series), which we don't care about here, so we set it to `null`. The second argument is supposed to be an array (or something *like* an array -- aka an "array-like object"). The contents of this "array" are "spread" out as arguments to the function in question.

So, `Array.apply(..)` is calling the `Array(..)` function and spreading out the values (of the `{ length: 3 }` object value) as its arguments.

Inside of `apply(..)`, we can envision there's another `for` loop (kinda like `join(..)` from above) that goes from `0` up to, but not including, `length` (`3` in our case).

For each index, it retrieves that key from the object. So if the array-object parameter was named `arr` internally inside of the `apply(..)` function, the property access would effectively be `arr[0]`, `arr[1]`, and `arr[2]`. Of course, none of those properties exist on the `{ length: 3 }` object value, so all three of those property accesses would return the value `undefined`.

In other words, it ends up calling `Array(..)` basically like this: `Array(undefined,undefined,undefined)`, which is how we end up with an array filled with `undefined` values, and not just those (crazy) empty slots.

While `Array.apply( null, { length: 3 } )` is a strange and verbose way to create an array filled with `undefined` values, it's **vastly** better and more reliable than what you get with the footgun'ish `Array(3)` empty slots.

Bottom line: **never ever, under any circumstances**, should you intentionally create and use these exotic empty-slot arrays. Just don't do it. They're nuts.

`Object(..)`, `Function(..)`, and `RegExp(..)`

The `Object(..)` / `Function(..)` / `RegExp(..)` constructors are also generally optional (and thus should usually be avoided unless specifically called for):

```
var c = new Object();
c.foo = "bar";
c; // { foo: "bar" }
```

```
var d = { foo: "bar" };
d; // { foo: "bar" }

var e = new Function( "a", "return a * 2;" );
var f = function(a) { return a * 2; };
function g(a) { return a * 2; }

var h = new RegExp( "^a*b+", "g" );
var i = /^a*b+/g;
```

There's practically no reason to ever use the `new Object()` constructor form, especially since it forces you to add properties one-by-one instead of many at once in the object literal form.

The `Function` constructor is helpful only in the rarest of cases, where you need to dynamically define a function's parameters and/or its function body. **Do not just treat `Function(..)` as an alternate form of `eval(..)`**. You will almost never need to dynamically define a function in this way.

Regular expressions defined in the literal form (`/^a*b+/g`) are strongly preferred, not just for ease of syntax but for performance reasons -- the JS engine precompiles and caches them before code execution. Unlike the other constructor forms we've seen so far, `RegExp(..)` has some reasonable utility: to dynamically define the pattern for a regular expression.

```
var name = "Kyle";
var namePattern = new RegExp( "\\b(?:" + name + ")+\\b", "ig" );

var matches = someText.match( namePattern );
```

This kind of scenario legitimately occurs in JS programs from time to time, so you'd need to use the `new RegExp("pattern","flags")` form.

`Date(..)` and `Error(..)`

The `Date(..)` and `Error(..)` native constructors are much more useful than the other natives, because there is no literal form for either.

To create a date object value, you must use `new Date()`. The `Date(..)` constructor accepts optional arguments to specify the date/time to use, but if omitted, the current date/time is assumed.

By far the most common reason you construct a date object is to get the current timestamp value (a signed integer number of milliseconds since Jan 1, 1970). You can do this by calling `getTime()` on a date object instance.

But an even easier way is to just call the static helper function defined as of ES5: `Date.now()`. And to polyfill that for pre-ES5 is pretty easy:

```
if (!Date.now) {
	Date.now = function(){
		return (new Date()).getTime();
	};
}
```

Note: If you call `Date()` without `new`, you'll get back a string representation of the date/time at that moment. The exact form of this representation is not specified in the language spec, though browsers tend to agree on something close to: `"Fri Jul 18 2014 00:31:02 GMT-0500 (CDT)"`.

The `Error(..)` constructor (much like `Array()` above) behaves the same with the `new` keyword present or omitted.

The main reason you'd want to create an error object is that it captures the current execution stack context into the object (in most JS engines, revealed as a read-only `.stack` property once constructed). This stack context includes the function call-stack and the line-number where the error object was created, which makes debugging that error much easier.

You would typically use such an error object with the `throw` operator:

```
function foo(x) {
	if (!x) {
```

```
                throw new Error( "x wasn't provided" );
            }
            // ..
    }
```

Error object instances generally have at least a `message` property, and sometimes other properties (which you should treat as read-only), like `type`. However, other than inspecting the above-mentioned `stack` property, it's usually best to just call `toString()` on the error object (either explicitly, or implicitly through coercion -- see Chapter 4) to get a friendly-formatted error message.

Tip: Technically, in addition to the general `Error(..)` native, there are several other specific-error-type natives: `EvalError(..)`, `RangeError(..)`, `ReferenceError(..)`, `SyntaxError(..)`, `TypeError(..)`, and `URIError(..)`. But it's very rare to manually use these specific error natives. They are automatically used if your program actually suffers from a real exception (such as referencing an undeclared variable and getting a `ReferenceError` error).

`Symbol(..)`

New as of ES6, an additional primitive value type has been added, called "Symbol". Symbols are special "unique" (not strictly guaranteed!) values that can be used as properties on objects with little fear of any collision. They're primarily designed for special built-in behaviors of ES6 constructs, but you can also define your own symbols.

Symbols can be used as property names, but you cannot see or access the actual value of a symbol from your program, nor from the developer console. If you evaluate a symbol in the developer console, what's shown looks like `Symbol(Symbol.create)`, for example.

There are several predefined symbols in ES6, accessed as static properties of the `Symbol` function object, like `Symbol.create`, `Symbol.iterator`, etc. To use them, do something like:

```
obj[Symbol.iterator] = function(){ /*..*/ };
```

To define your own custom symbols, use the `Symbol(..)` native. The `Symbol(..)` native "constructor" is unique in that you're not allowed to use `new` with it, as doing so will throw an error.

```
var mysym = Symbol( "my own symbol" );
mysym;                          // Symbol(my own symbol)
mysym.toString();       // "Symbol(my own symbol)"
typeof mysym;           // "symbol"

var a = { };
a[mysym] = "foobar";

Object.getOwnPropertySymbols( a );
// [ Symbol(my own symbol) ]
```

While symbols are not actually private (`Object.getOwnPropertySymbols(..)` reflects on the object and reveals the symbols quite publicly), using them for private or special properties is likely their primary use-case. For most developers, they may take the place of property names with `_` underscore prefixes, which are almost always by convention signals to say, "hey, this is a private/special/internal property, so leave it alone!"

Note: `Symbol` s are *not* `object` s, they are simple scalar primitives.

Native Prototypes

Each of the built-in native constructors has its own `.prototype` object -- `Array.prototype` , `String.prototype` , etc.

These objects contain behavior unique to their particular object subtype.

For example, all string objects, and by extension (via boxing) `string` primitives, have access to default behavior as methods defined on the `String.prototype` object.

Note: By documentation convention, `String.prototype.XYZ` is shortened to `String#XYZ` , and likewise for all the other `.prototype` s.

- `String#indexOf(..)` : find the position in the string of another substring
- `String#charAt(..)` : access the character at a position in the string
- `String#substr(..)` , `String#substring(..)` , and `String#slice(..)` : extract a portion of the string as a new string
- `String#toUpperCase()` and `String#toLowerCase()` : create a new string that's converted to either uppercase or lowercase
- `String#trim()` : create a new string that's stripped of any trailing or leading whitespace

None of the methods modify the string *in place*. Modifications (like case conversion or trimming) create a new value from the existing value.

By virtue of prototype delegation (see the *this & Object Prototypes* title in this series), any string value can access these methods:

```
var a = " abc ";

a.indexOf( "c" ); // 3
a.toUpperCase(); // " ABC "
a.trim(); // "abc"
```

The other constructor prototypes contain behaviors appropriate to their types, such as `Number#toFixed(..)` (stringifying a number with a fixed number of decimal digits) and `Array#concat(..)` (merging arrays). All functions have access to `apply(..)` , `call(..)` , and `bind(..)` because `Function.prototype` defines them.

But, some of the native prototypes aren't *just* plain objects:

```
typeof Function.prototype;                      // "function"
Function.prototype();                           // it's an empty function!

RegExp.prototype.toString();            // "/(?:)/" -- empty regex
"abc".match( RegExp.prototype );        // [""]
```

A particularly bad idea, you can even modify these native prototypes (not just adding properties as you're probably familiar with):

```
Array.isArray( Array.prototype );       // true
Array.prototype.push( 1, 2, 3 );        // 3
Array.prototype;                                        // [1,2,3]

// don't leave it that way, though, or expect weirdness!
// reset the `Array.prototype` to empty
Array.prototype.length = 0;
```

As you can see, `Function.prototype` is a function, `RegExp.prototype` is a regular expression, and `Array.prototype` is an array. Interesting and cool, huh?

Prototypes As Defaults

`Function.prototype` being an empty function, `RegExp.prototype` being an "empty" (e.g., non-matching) regex, and `Array.prototype` being an empty array, make them all nice "default" values to assign to variables if those variables wouldn't already have had a value of the proper type.

For example:

```
function isThisCool(vals,fn,rx) {
        vals = vals || Array.prototype;
        fn = fn || Function.prototype;
        rx = rx || RegExp.prototype;

        return rx.test(
                vals.map( fn ).join( "" )
        );
}

isThisCool();           // true
isThisCool(
        ["a","b","c"],
        function(v){ return v.toUpperCase(); },
        /D/
);                                      // false
```

Note: As of ES6, we don't need to use the `vals = vals || ..` default value syntax trick (see Chapter 4) anymore, because default values can be set for parameters via native syntax in the function declaration (see Chapter 5).

One minor side-benefit of this approach is that the `.prototype` s are already created and built-in, thus created *only once*. By contrast, using `[]` , `function(){}` , and `/(?:)/` values themselves for those defaults would (likely, depending on engine implementations) be recreating those values (and probably garbage-collecting them later) for *each call* of `isThisCool(..)` . That could be memory/CPU wasteful.

Also, be very careful not to use `Array.prototype` as a default value **that will subsequently be modified**. In this example, `vals` is used read-only, but if you were to instead make in-place changes to `vals` , you would actually be modifying `Array.prototype` itself, which would lead to the gotchas mentioned earlier!

Note: While we're pointing out these native prototypes and some usefulness, be cautious of relying on them and even more wary of modifying them in any way. See Appendix A "Native Prototypes" for more discussion.

Review

JavaScript provides object wrappers around primitive values, known as natives (`String` , `Number` , `Boolean` , etc). These object wrappers give the values access to behaviors appropriate for each object subtype (`String#trim()` and `Array#concat(..)`).

If you have a simple scalar primitive value like `"abc"` and you access its `length` property or some `String.prototype` method, JS automatically "boxes" the value (wraps it in its respective object wrapper) so that the property/method accesses can be fulfilled.

You Don't Know JS Yet: Types & Grammar - 2nd Edition

Chapter 4: Coercion

NOTE:
Work in progress

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Now that we much more fully understand JavaScript's types and values, we turn our attention to a very controversial topic: coercion.

As we mentioned in Chapter 1, the debates over whether coercion is a useful feature or a flaw in the design of the language (or somewhere in between!) have raged since day one. If you've read other popular books on JS, you know that the overwhelmingly prevalent *message* out there is that coercion is magical, evil, confusing, and just downright a bad idea.

In the same overall spirit of this book series, rather than running away from coercion because everyone else does, or because you get bitten by some quirk, I think you should run toward that which you don't understand and seek to *get it* more fully.

Our goal is to fully explore the pros and cons (yes, there *are* pros!) of coercion, so that you can make an informed decision on its appropriateness in your program.

Converting Values

Converting a value from one type to another is often called "type casting," when done explicitly, and "coercion" when done implicitly (forced by the rules of how a value is used).

Note: It may not be obvious, but JavaScript coercions always result in one of the scalar primitive (see Chapter 2) values, like `string`, `number`, or `boolean`. There is no coercion that results in a complex value like `object` or `function`. Chapter 3 covers "boxing," which wraps scalar primitive values in their `object` counterparts, but this is not really coercion in an accurate sense.

Another way these terms are often distinguished is as follows: "type casting" (or "type conversion") occur in statically typed languages at compile time, while "type coercion" is a runtime conversion for dynamically typed languages.

However, in JavaScript, most people refer to all these types of conversions as *coercion*, so the way I prefer to distinguish is to say "implicit coercion" vs. "explicit coercion."

The difference should be obvious: "explicit coercion" is when it is obvious from looking at the code that a type conversion is intentionally occurring, whereas "implicit coercion" is when the type conversion will occur as a less obvious side effect of some other intentional operation.

For example, consider these two approaches to coercion:

```
var a = 42;

var b = a + "";                 // implicit coercion
var c = String( a );    // explicit coercion
```

For `b`, the coercion that occurs happens implicitly, because the `+` operator combined with one of the operands being a `string` value (`""`) will insist on the operation being a `string` concatenation (adding two strings together), which *as a (hidden) side effect* will force the `42` value in `a` to be coerced to its `string` equivalent: `"42"`.

By contrast, the `String(..)` function makes it pretty obvious that it's explicitly taking the value in `a` and coercing it to a `string` representation.

Both approaches accomplish the same effect: `"42"` comes from `42`. But it's the *how* that is at the heart of the heated debates over JavaScript coercion.

Note: Technically, there's some nuanced behavioral difference here beyond the stylistic difference. We cover that in more detail later in the chapter, in the "Implicitly: Strings <--> Numbers" section.

The terms "explicit" and "implicit," or "obvious" and "hidden side effect," are *relative*.

If you know exactly what `a + ""` is doing and you're intentionally doing that to coerce to a `string`, you might feel the operation is sufficiently "explicit." Conversely, if you've never seen the `String(..)` function used for `string` coercion, its behavior might seem hidden enough as to feel "implicit" to you.

But we're having this discussion of "explicit" vs. "implicit" based on the likely opinions of an *average, reasonably informed, but not expert or JS specification devotee* developer. To whatever extent you do or do not find yourself fitting neatly in that bucket, you will need to adjust your perspective on our observations here accordingly.

Just remember: it's often rare that we write our code and are the only ones who ever read it. Even if you're an expert on all the ins and outs of JS, consider how a less experienced teammate of yours will feel when they read your code. Will it be "explicit" or "implicit" to them in the same way it is for you?

Abstract Value Operations

Before we can explore *explicit* vs *implicit* coercion, we need to learn the basic rules that govern how values *become* either a `string`, `number`, or `boolean`. The ES5 spec in section 9 defines several "abstract operations" (fancy spec-speak for "internal-only operation") with the rules of value conversion. We will specifically pay attention to: `ToString`, `ToNumber`, and `ToBoolean`, and to a lesser extent, `ToPrimitive`.

`ToString`

When any non-`string` value is coerced to a `string` representation, the conversion is handled by the `ToString` abstract operation in section 9.8 of the specification.

Built-in primitive values have natural stringification: `null` becomes `"null"`, `undefined` becomes `"undefined"` and `true` becomes `"true"`. `number`s are generally expressed in the natural way you'd expect, but as we discussed in Chapter 2, very small or very large `numbers` are represented in exponent form:

```
// multiplying `1.07` by `1000`, seven times over
var a = 1.07 * 1000 * 1000 * 1000 * 1000 * 1000 * 1000 * 1000;

// seven times three digits => 21 digits
a.toString(); // "1.07e21"
```

For regular objects, unless you specify your own, the default `toString()` (located in `Object.prototype.toString()`) will return the *internal* `[[Class]]` (see Chapter 3), like for instance `"[object Object]"`.

But as shown earlier, if an object has its own `toString()` method on it, and you use that object in a `string`-like way, its `toString()` will automatically be called, and the `string` result of that call will be used instead.

Note: The way an object is coerced to a `string` technically goes through the `ToPrimitive` abstract operation (ES5 spec, section 9.1), but those nuanced details are covered in more detail in the `ToNumber` section later in this chapter, so we will skip over them here.

Arrays have an overridden default `toString()` that stringifies as the (string) concatenation of all its values (each stringified themselves), with `","` in between each value:

```
var a = [1,2,3];

a.toString(); // "1,2,3"
```

Again, `toString()` can either be called explicitly, or it will automatically be called if a non- `string` is used in a `string` context.

JSON Stringification

Another task that seems awfully related to `ToString` is when you use the `JSON.stringify(..)` utility to serialize a value to a JSON-compatible `string` value.

It's important to note that this stringification is not exactly the same thing as coercion. But since it's related to the `ToString` rules above, we'll take a slight diversion to cover JSON stringification behaviors here.

For most simple values, JSON stringification behaves basically the same as `toString()` conversions, except that the serialization result is *always a* `string` :

```
JSON.stringify( 42 );   // "42"
JSON.stringify( "42" ); // ""42"" (a string with a quoted string value in it)
JSON.stringify( null ); // "null"
JSON.stringify( true ); // "true"
```

Any *JSON-safe* value can be stringified by `JSON.stringify(..)` . But what is *JSON-safe*? Any value that can be represented validly in a JSON representation.

It may be easier to consider values that are **not** JSON-safe. Some examples: `undefined`s, `function`s, (ES6+) `symbol`s, and `object`s with circular references (where property references in an object structure create a never-ending cycle through each other). These are all illegal values for a standard JSON structure, mostly because they aren't portable to other languages that consume JSON values.

The `JSON.stringify(..)` utility will automatically omit `undefined`, `function`, and `symbol` values when it comes across them. If such a value is found in an `array`, that value is replaced by `null` (so that the array position information isn't altered). If found as a property of an `object`, that property will simply be excluded.

Consider:

```
JSON.stringify( undefined );                                    // undefined
JSON.stringify( function(){} );                                 // undefined

JSON.stringify( [1,undefined,function(){},4] ); // "[1,null,null,4]"
JSON.stringify( { a:2, b:function(){} } );              // "{"a":2}"
```

But if you try to `JSON.stringify(..)` an `object` with circular reference(s) in it, an error will be thrown.

JSON stringification has the special behavior that if an `object` value has a `toJSON()` method defined, this method will be called first to get a value to use for serialization.

If you intend to JSON stringify an object that may contain illegal JSON value(s), or if you just have values in the `object` that aren't appropriate for the serialization, you should define a `toJSON()` method for it that returns a *JSON-safe* version of the `object`.

For example:

```
var o = { };

var a = {
        b: 42,
		c: o,
		d: function(){}
};

// create a circular reference inside `a`
o.e = a;

// would throw an error on the circular reference
// JSON.stringify( a );

// define a custom JSON value serialization
a.toJSON = function() {
		// only include the `b` property for serialization
		return { b: this.b };
};

JSON.stringify( a ); // "{"b":42}"
```

It's a very common misconception that `toJSON()` should return a JSON stringification representation. That's probably incorrect, unless you're wanting to actually stringify the `string` itself (usually not!). `toJSON()` should return the actual regular value (of whatever type) that's appropriate, and `JSON.stringify(..)` itself will handle the stringification.

In other words, `toJSON()` should be interpreted as "to a JSON-safe value suitable for stringification," not "to a JSON string" as many developers mistakenly assume.

Consider:

```
var a = {
		val: [1,2,3],

		// probably correct!
		toJSON: function(){
				return this.val.slice( 1 );
		}
};
```

```
var b = {
	val: [1,2,3],

	// probably incorrect!
	toJSON: function(){
		return "[" +
			this.val.slice( 1 ).join() +
		"]";
	}
};

JSON.stringify( a ); // "[2,3]"

JSON.stringify( b ); // ""[2,3]""
```

In the second call, we stringified the returned `string` rather than the `array` itself, which was probably not what we wanted to do.

While we're talking about `JSON.stringify(..)`, let's discuss some lesser-known functionalities that can still be very useful.

An optional second argument can be passed to `JSON.stringify(..)` that is called *replacer*. This argument can either be an `array` or a `function`. It's used to customize the recursive serialization of an `object` by providing a filtering mechanism for which properties should and should not be included, in a similar way to how `toJSON()` can prepare a value for serialization.

If *replacer* is an `array`, it should be an `array` of `string`s, each of which will specify a property name that is allowed to be included in the serialization of the `object`. If a property exists that isn't in this list, it will be skipped.

If *replacer* is a `function`, it will be called once for the `object` itself, and then once for each property in the `object`, and each time is passed two arguments, *key* and *value*. To skip a *key* in the serialization, return `undefined`. Otherwise, return the *value* provided.

```
var a = {
	b: 42,
        c: "42",
        d: [1,2,3]
};

JSON.stringify( a, ["b","c"] ); // "{"b":42,"c":"42"}"

JSON.stringify( a, function(k,v){
        if (k !== "c") return v;
} );
// "{"b":42,"d":[1,2,3]}"
```

Note: In the `function` *replacer* case, the key argument `k` is `undefined` for the first call (where the `a` object itself is being passed in). The `if` statement **filters out** the property named `"c"`. Stringification is recursive, so the `[1,2,3]` array has each of its values (`1` , `2` , and `3`) passed as `v` to *replacer*, with indexes (`0` , `1` , and `2`) as `k` .

A third optional argument can also be passed to `JSON.stringify(..)` , called *space*, which is used as indentation for prettier human-friendly output. *space* can be a positive integer to indicate how many space characters should be used at each indentation level. Or, *space* can be a `string` , in which case up to the first ten characters of its value will be used for each indentation level.

```
var a = {
        b: 42,
        c: "42",
        d: [1,2,3]
};

JSON.stringify( a, null, 3 );
// "{
//    "b": 42,
//    "c": "42",
//    "d": [
//       1,
//       2,
//       3
//     ]
// }"

JSON.stringify( a, null, "-----" );
// "{
// -----"b": 42,
// -----"c": "42",
// -----"d": [
// ----------1,
// ----------2,
// ----------3
// -----]
// }"
```

Remember, `JSON.stringify(..)` is not directly a form of coercion. We covered it here, however, for two reasons that relate its behavior to `ToString` coercion:

1. `string`, `number`, `boolean`, and `null` values all stringify for JSON basically the same as how they coerce to `string` values via the rules of the `ToString` abstract operation.
2. If you pass an `object` value to `JSON.stringify(..)`, and that `object` has a `toJSON()` method on it, `toJSON()` is automatically called to (sort of) "coerce" the value to be *JSON-safe* before stringification.

`ToNumber`

If any non-`number` value is used in a way that requires it to be a `number`, such as a mathematical operation, the ES5 spec defines the `ToNumber` abstract operation in section 9.3.

For example, `true` becomes `1` and `false` becomes `0`. `undefined` becomes `NaN`, but (curiously) `null` becomes `0`.

`ToNumber` for a `string` value essentially works for the most part like the rules/syntax for numeric literals (see Chapter 3). If it fails, the result is `NaN` (instead of a syntax error as with `number` literals). One example difference is that `0`-prefixed octal numbers are not handled as octals (just as normal base-10 decimals) in this operation, though such octals are valid as `number` literals (see Chapter 2).

Note: The differences between `number` literal grammar and `ToNumber` on a `string` value are subtle and highly nuanced, and thus will not be covered further here. Consult section 9.3.1 of the ES5 spec for more information.

Objects (and arrays) will first be converted to their primitive value equivalent, and the resulting value (if a primitive but not already a `number`) is coerced to a `number` according to the `ToNumber` rules just mentioned.

To convert to this primitive value equivalent, the `ToPrimitive` abstract operation (ES5 spec, section 9.1) will consult the value (using the internal `DefaultValue` operation -- ES5 spec, section 8.12.8) in question to see if it has a `valueOf()` method. If `valueOf()` is available and it returns a primitive value, *that* value is used for the coercion. If not, but `toString()` is available, it will provide the value for the coercion.

If neither operation can provide a primitive value, a `TypeError` is thrown.

As of ES5, you can create such a noncoercible object -- one without `valueOf()` and `toString()` -- if it has a `null` value for its `[[Prototype]]` , typically created with `Object.create(null)` . See the *this & Object Prototypes* title of this series for more information on `[[Prototype]]` s.

Note: We cover how to coerce to `number` s later in this chapter in detail, but for this next code snippet, just assume the `Number(..)` function does so.

Consider:

```
var a = {
        valueOf: function(){
                return "42";
        }
};

var b = {
        toString: function(){
                return "42";
        }
};
```

```
var c = [4,2];
c.toString = function(){
        return this.join( "" ); // "42"
};

Number( a );                    // 42
Number( b );                    // 42
Number( c );                    // 42
Number( "" );                   // 0
Number( [] );                   // 0
Number( [ "abc" ] );    // NaN
```

`ToBoolean`

Next, let's have a little chat about how `boolean` s behave in JS. There's **lots of confusion and misconception** floating out there around this topic, so pay close attention!

First and foremost, JS has actual keywords `true` and `false` , and they behave exactly as you'd expect of `boolean` values. It's a common misconception that the values `1` and `0` are identical to `true` / `false` . While that may be true in other languages, in JS the `number` s are `number` s and the `boolean` s are `boolean` s. You can coerce `1` to `true` (and vice versa) or `0` to `false` (and vice versa). But they're not the same.

Falsy Values

But that's not the end of the story. We need to discuss how values other than the two `boolean` s behave whenever you coerce *to* their `boolean` equivalent.

All of JavaScript's values can be divided into two categories:

1. values that will become `false` if coerced to `boolean`
2. everything else (which will obviously become `true`)

I'm not just being facetious. The JS spec defines a specific, narrow list of values that will coerce to `false` when coerced to a `boolean` value.

How do we know what the list of values is? In the ES5 spec, section 9.2 defines a `ToBoolean` abstract operation, which says exactly what happens for all the possible values when you try to coerce them "to boolean."

From that table, we get the following as the so-called "falsy" values list:

- `undefined`
- `null`
- `false`
- `+0`, `-0`, and `NaN`
- `""`

That's it. If a value is on that list, it's a "falsy" value, and it will coerce to `false` if you force a `boolean` coercion on it.

By logical conclusion, if a value is *not* on that list, it must be on *another list*, which we call the "truthy" values list. But JS doesn't really define a "truthy" list per se. It gives some examples, such as saying explicitly that all objects are truthy, but mostly the spec just implies: **anything not explicitly on the falsy list is therefore truthy.**

Falsy Objects

Wait a minute, that section title even sounds contradictory. I literally *just said* the spec calls all objects truthy, right? There should be no such thing as a "falsy object."

What could that possibly even mean?

You might be tempted to think it means an object wrapper (see Chapter 3) around a falsy value (such as `""`, `0` or `false`). But don't fall into that *trap*.

Note: That's a subtle specification joke some of you may get.

Consider:

```
var a = new Boolean( false );
var b = new Number( 0 );
var c = new String( "" );
```

We know all three values here are objects (see Chapter 3) wrapped around obviously falsy values. But do these objects behave as `true` or as `false`? That's easy to answer:

```
var d = Boolean( a && b && c );

d; // true
```

So, all three behave as `true`, as that's the only way `d` could end up as `true`.

Tip: Notice the `Boolean( .. )` wrapped around the `a && b && c` expression -- you might wonder why that's there. We'll come back to that later in this chapter, so make a mental note of it. For a sneak-peek (trivia-wise), try for yourself what `d` will be if you just do `d = a && b && c` without the `Boolean( .. )` call!

So, if "falsy objects" are **not just objects wrapped around falsy values**, what the heck are they?

The tricky part is that they can show up in your JS program, but they're not actually part of JavaScript itself.

What!?

There are certain cases where browsers have created their own sort of *exotic* values behavior, namely this idea of "falsy objects," on top of regular JS semantics.

A "falsy object" is a value that looks and acts like a normal object (properties, etc.), but when you coerce it to a `boolean`, it coerces to a `false` value.

Why!?

The most well-known case is `document.all` : an array-like (object) provided to your JS program *by the DOM* (not the JS engine itself), which exposes elements in your page to your JS program. It *used* to behave like a normal object--it would act truthy. But not anymore.

`document.all` itself was never really "standard" and has long since been deprecated/abandoned.

"Can't they just remove it, then?" Sorry, nice try. Wish they could. But there's far too many legacy JS code bases out there that rely on using it.

So, why make it act falsy? Because coercions of `document.all` to `boolean` (like in `if` statements) were almost always used as a means of detecting old, nonstandard IE.

IE has long since come up to standards compliance, and in many cases is pushing the web forward as much or more than any other browser. But all that old `if (document.all) { /* it's IE */ }` code is still out there, and much of it is probably never going away. All this legacy code is still assuming it's running in decade-old IE, which just leads to bad browsing experience for IE users.

So, we can't remove `document.all` completely, but IE doesn't want `if (document.all) { .. }` code to work anymore, so that users in modern IE get new, standards-compliant code logic.

"What should we do?" **"I've got it! Let's bastardize the JS type system and pretend that `document.all` is falsy!"

Ugh. That sucks. It's a crazy gotcha that most JS developers don't understand. But the alternative (doing nothing about the above no-win problems) sucks *just a little bit more*.

So... that's what we've got: crazy, nonstandard "falsy objects" added to JavaScript by the browsers. Yay!

Truthy Values

Back to the truthy list. What exactly are the truthy values? Remember: **a value is truthy if it's not on the falsy list.**

Consider:

```
var a = "false";
var b = "0";
var c = "''";

var d = Boolean( a && b && c );

d;
```

What value do you expect `d` to have here? It's gotta be either `true` or `false`.

It's `true`. Why? Because despite the contents of those `string` values looking like falsy values, the `string` values themselves are all truthy, because `""` is the only `string` value on the falsy list.

What about these?

```
var a = [];                             // empty array -- truthy or falsy?
var b = {};                             // empty object -- truthy or falsy?
var c = function(){};   // empty function -- truthy or falsy?

var d = Boolean( a && b && c );

d;
```

Yep, you guessed it, `d` is still `true` here. Why? Same reason as before. Despite what it may seem like, `[]`, `{}`, and `function(){}` are *not* on the falsy list, and thus are truthy values.

In other words, the truthy list is infinitely long. It's impossible to make such a list. You can only make a finite falsy list and consult *it*.

Take five minutes, write the falsy list on a post-it note for your computer monitor, or memorize it if you prefer. Either way, you'll easily be able to construct a virtual truthy list whenever you need it by simply asking if it's on the falsy list or not.

The importance of truthy and falsy is in understanding how a value will behave if you coerce it (either explicitly or implicitly) to a `boolean` value. Now that you have those two lists in mind, we can dive into coercion examples themselves.

Explicit Coercion

Explicit coercion refers to type conversions that are obvious and explicit. There's a wide range of type conversion usage that clearly falls under the *explicit* coercion category for most developers.

The goal here is to identify patterns in our code where we can make it clear and obvious that we're converting a value from one type to another, so as to not leave potholes for future developers to trip into. The more explicit we are, the more likely someone later will be able to read our code and understand without undue effort what our intent was.

It would be hard to find any salient disagreements with *explicit* coercion, as it most closely aligns with how the commonly accepted practice of type conversion works in statically typed languages. As such, we'll take for granted (for now) that *explicit* coercion can be agreed upon to not be evil or controversial. We'll revisit this later, though.

Explicitly: Strings <--> Numbers

We'll start with the simplest and perhaps most common coercion operation: coercing values between `string` and `number` representation.

To coerce between `string` s and `number` s, we use the built-in `String(..)` and `Number(..)` functions (which we referred to as "native constructors" in Chapter 3), but **very importantly**, we do not use the `new` keyword in front of them. As such, we're not creating object wrappers.

Instead, we're actually *explicitly coercing* between the two types:

```
var a = 42;
var b = String( a );

var c = "3.14";
var d = Number( c );

b; // "42"
d; // 3.14
```

`String(..)` coerces from any other value to a primitive `string` value, using the rules of the `ToString` operation discussed earlier. `Number(..)` coerces from any other value to a primitive `number` value, using the rules of the `ToNumber` operation discussed earlier.

I call this *explicit* coercion because in general, it's pretty obvious to most developers that the end result of these operations is the applicable type conversion.

In fact, this usage actually looks a lot like it does in some other statically typed languages.

For example, in C/C++, you can say either `(int)x` or `int(x)`, and both will convert the value in `x` to an integer. Both forms are valid, but many prefer the latter, which kinda looks like a function call. In JavaScript, when you say `Number(x)`, it looks awfully similar. Does it matter that it's *actually* a function call in JS? Not really.

Besides `String(..)` and `Number(..)`, there are other ways to "explicitly" convert these values between `string` and `number`:

```
var a = 42;
var b = a.toString();

var c = "3.14";
var d = +c;

b; // "42"
d; // 3.14
```

Calling `a.toString()` is ostensibly explicit (pretty clear that "toString" means "to a string"), but there's some hidden implicitness here. `toString()` cannot be called on a *primitive* value like `42`. So JS automatically "boxes" (see Chapter 3) `42` in an object wrapper, so that `toString()` can be called against the object. In other words, you might call it "explicitly implicit."

`+c` here is showing the *unary operator* form (operator with only one operand) of the `+` operator. Instead of performing mathematic addition (or string concatenation -- see below), the unary `+` explicitly coerces its operand (`c`) to a `number` value.

Is `+c` *explicit* coercion? Depends on your experience and perspective. If you know (which you do, now!) that unary `+` is explicitly intended for `number` coercion, then it's pretty explicit and obvious. However, if you've never seen it before, it can seem awfully confusing, implicit, with hidden side effects, etc.

Note: The generally accepted perspective in the open-source JS community is that unary `+` is an accepted form of *explicit* coercion.

Even if you really like the `+c` form, there are definitely places where it can look awfully confusing. Consider:

```
var c = "3.14";
var d = 5+ +c;

d; // 8.14
```