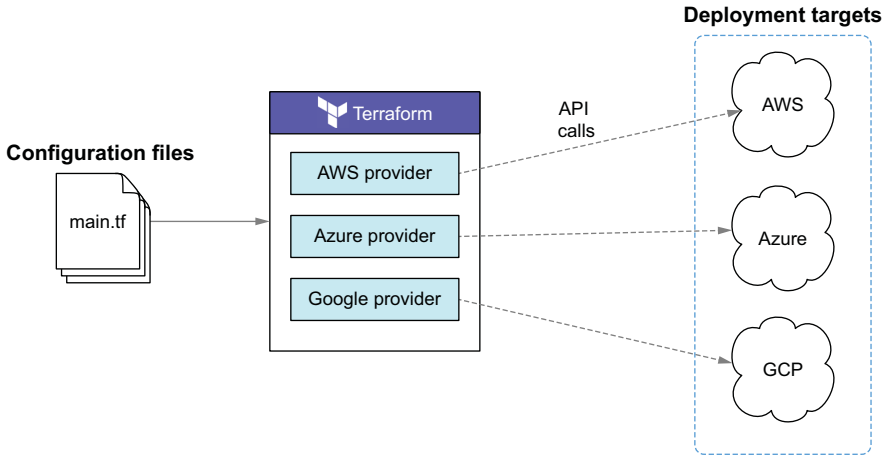
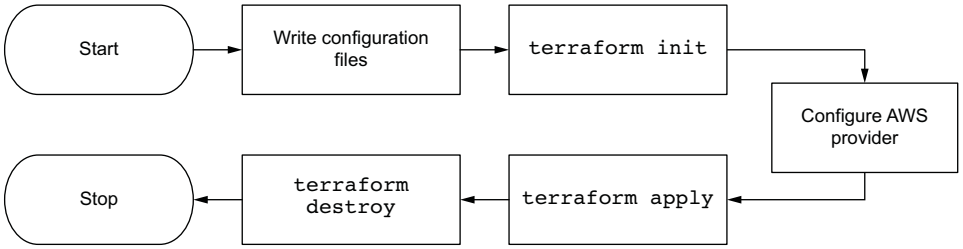
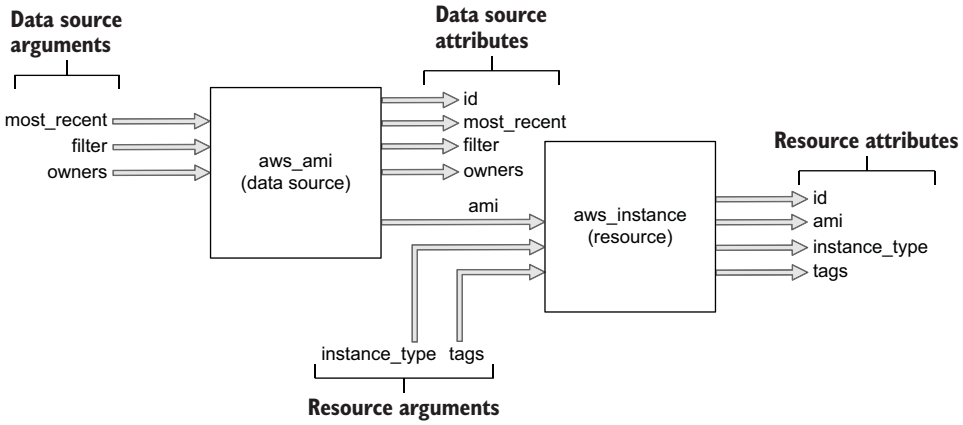
Terraform
IN ACTION



Deploying to multiple clouds concurrently with Terraform



Sequence diagram of "Hello Terraform!" deployment



How the output of the `aws_ami` data source will be chained to the input of the `aws_instance` resource

contents

Part 1

Terraform bootcamp

The pace of part 1 starts slowly but ramps up quickly. Think of these first few chapters as your personal bootcamp for using Terraform. By the end of chapter 4, you will have a solid grasp of the technology and be well prepared for the advanced topics coming in later chapters. Here's what's ahead.

Chapter 1 is a basic introduction to Terraform. We cover all the usual topics, such as why Terraform was created, what problems it solves, and how it compares to similar technologies. The chapter ends with a simple example of deploying an EC2 instance to AWS.

Chapter 2 is a deep dive into Terraform: resource lifecycle and state management. We examine how Terraform generates and applies execution plans to perform CRUD operations on managed resources and see how state plays a role in the process.

Chapter 3 is our first look at variables and functions. Although Terraform's expressiveness is inhibited by it being a declarative programming language, you can still do some pretty interesting things with `for` expressions and local values. Chapter 4 is the capstone project that brings together all the previous learning. We deploy a complete web server and database using Terraform and walk through how to structure Terraform configuration with nested modules.

1 Getting started with Terraform

This chapter covers

- Understanding the syntax of HCL
- Fundamental elements and building blocks of Terraform
- Setting up a Terraform workspace
- Configuring and deploying an Ubuntu virtual machine on AWS

Terraform is a deployment technology for anyone who wants to provision and manage their *infrastructure as code* (IaC). *Infrastructure* refers primarily to cloud-based infrastructure, although anything that could be controlled through an application programming interface (API) technically qualifies as infrastructure. *Infrastructure as code* is the process of managing and provisioning infrastructure through machine-readable definition files. We use IaC to automate processes that used to be done manually.

When we talk about *provisioning*, we mean the act of deploying infrastructure, as opposed to *configuration management*, which deals mostly with application delivery, particularly on virtual machines (VMs). Configuration management (CM) tools

like Ansible, Puppet, SaltStack, and Chef are extremely popular and have been around for many years. Terraform does not supplant these tools, at least not entirely, because infrastructure provisioning and configuration management are inherently different problems. That being said, Terraform does perform many of the functions once reserved by CM tools, and many companies find they do not need CM tools after adopting Terraform.

The basic principle of Terraform is that it allows you to write human-readable configuration code to define your IaC. With configuration code, you can deploy repeatable, ephemeral, consistent environments to vendors on the public, private, and hybrid clouds (see figure 1.1).

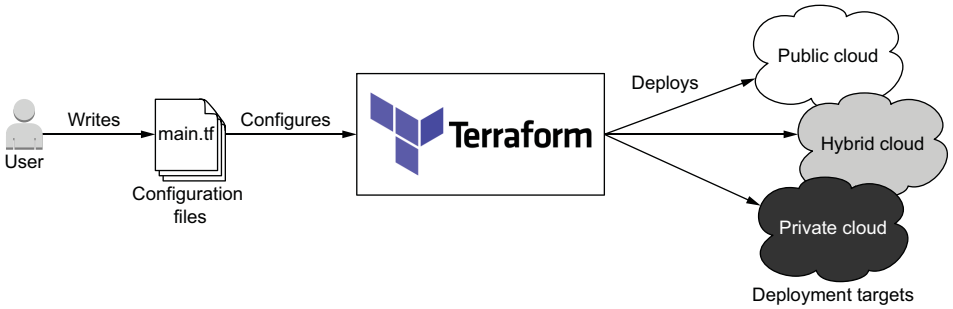


Figure 1.1 Terraform can deploy infrastructure to any cloud or combination of clouds.

In this chapter, we start by going over the distinguishing features of Terraform. We talk about the comparative advantages and disadvantages of Terraform in relation to other IaC technologies and what makes Terraform the clear winner. Finally, we look at the quintessential "Hello World!" of Terraform by deploying a single server to AWS and improving it by incorporating some of Terraform's more dynamic features.

1.1 What makes Terraform so great?

There's been a lot of hype about Terraform recently, but is any of it justified? Terraform isn't the only IaC technology on the block—plenty of other tools do the same thing. How is it that Terraform, a technology in the highly lucrative software deployment market space, can compete with the likes of Amazon, Microsoft, and Google? Six key characteristics make Terraform unique and give it a competitive advantage:

- *Provisioning tool*—Deploys infrastructure, not just applications.
- *Easy to use*—For all of us non-geniuses.
- *Free and open source*—Who doesn't like free?
- *Declarative*—Say what you want, not how to do it.
- *Cloud-agnostic*—Deploy to any cloud using the same tool.
- *Expressive and extendable*—You aren't limited by the language.

Table 1.1 compares Terraform and other IaC tools.

Table 1.1 A comparison of popular IaC tools

Name	Key features					
	Provisioning tool	Easy to use	Free and open source	Declarative	Cloud-agnostic	Expressive and extendable
Ansible (www.ansible.com)		X	X		X	X
Chef (www.chef.io)			X	X	X	X
Puppet (www.puppet.com)			X	X	X	X
SaltStack (www.saltstack.com)		X	X	X	X	X
Terraform (www.terraform.io)	X	X	X	X	X	X
Pulumi (www.pulumi.com)	X		X		X	X
AWS CloudFormation (https://aws.amazon.com/cloudformation)	X	X		X		
GCP Deployment Manager (https://cloud.google.com/deployment-manager)	X	X		X		
Azure Resource Manager (https://azure.microsoft.com/features/resource-manager)	X			X		

Tech comparison

Pulumi is technologically the most similar to Terraform, the only difference being that it's not declarative. The Pulumi team considers this an advantage over Terraform, but Terraform also has a cloud development kit (CDK) that allows you to do the same thing.

AWS CloudFormation was the original inspiration behind Terraform, and GCP Deployment Manager and Azure Resource Manager are cousins. These technologies, while decent, are neither cloud-agnostic nor open source. They only work for a particular cloud vendor and tend to be more verbose and less flexible than Terraform.

(continued)

Ansible, Chef, Puppet, and SaltStack are configuration management (CM) tools, as opposed to infrastructure provisioning tools. They solve a slightly different kind of problem than Terraform does, although there is some overlap.

1.1.1 Provisioning tool

Terraform is an infrastructure provisioning tool, not a CM tool. Provisioning tools deploy and manage infrastructure, whereas CM tools like Ansible, Puppet, SaltStack, and Chef deploy software onto existing servers. Some CM tools can also perform a degree of infrastructure provisioning, but not as well as Terraform, because this isn't the task they were originally designed to do.

The difference between CM and provisioning tools is a matter of philosophy. CM tools favor mutable infrastructure, whereas Terraform and other provisioning tools favor immutable infrastructure.

Mutable infrastructure means you perform software updates on existing servers. *Immutable infrastructure*, by contrast, doesn't care about existing servers—it treats infrastructure as a disposable commodity. The difference between the two paradigms can be summarized as a reusable versus disposable mentality.

1.1.2 Easy to use

The basics of Terraform are quick and easy to learn, even for non-programmers. By the end of chapter 4, you will have the skills necessary to call yourself an intermediate Terraform user, which is kind of shocking, when you think about it. Achieving mastery is another story, of course, but that's true for most skills.

The main reason Terraform is so easy to use is that the code is written in a domain-specific configuration language called *HashiCorp Configuration Language* (HCL). It's a language invented by HashiCorp as a substitute for more verbose configuration languages like JSON and XML. HCL attempts to strike a balance between human and machine readability and was influenced by earlier attempts in the field, such as libucl and Nginx configuration. HCL is fully compatible with JSON, which means HCL can be converted 1:1 to JSON and vice versa. This makes it easy to interoperate with systems outside of Terraform or generate configuration code on the fly.

1.1.3 Free and open source software

The engine that powers Terraform is called *Terraform core*, a free and open source software offered under the Mozilla Public License v2.0. This license stipulates that anyone is allowed to use, distribute, or modify the software for both private and commercial purposes. Being free is great because you never have to worry about incurring additional costs when using Terraform. In addition, you gain full transparency about the product and how it works.

There's no premium version of Terraform, but business and enterprise solutions are available for running Terraform at scale: *Terraform Cloud* and *Terraform Enterprise*. We'll go through what these are in chapter 6; and in chapter 12, we'll develop our own bootleg version of Terraform Enterprise.

1.1.4 Declarative programming

Declarative programming means you express the logic of a computation (the *what*) without describing the control flow (the *how*). Instead of writing step-by-step instructions, you describe what you want. Examples of declarative programming languages include database query languages (SQL), functional programming languages (Haskell, Clojure), configuration languages (XML, JSON), and most IaC tools (Ansible, Chef, Puppet).

Declarative programming is in contrast to imperative (or procedural) programming. Imperative programming languages use conditional branching, loops, and expressions to control system flow, save state, and execute commands. Nearly all traditional programming languages are imperative (Python, Java, C, etc.).

NOTE Declarative programming cares about the destination, not the journey. Imperative programming cares about the journey, not the destination.

1.1.5 Cloud-agnostic

Cloud-agnostic means being able to seamlessly run on any cloud platform using the same set of tools and workflows. Terraform is cloud-agnostic because you can deploy infrastructure to AWS just as easily as you could to GCP, Azure, or even a private datacenter (see figure 1.2). Being cloud-agnostic is important because it means you aren't locked in to a particular cloud vendor and don't have to learn a whole new technology every time you switch cloud vendors.

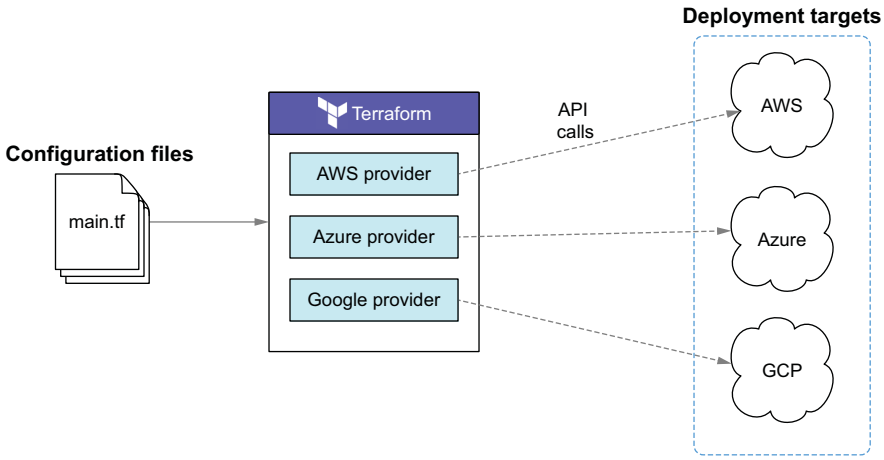


Figure 1.2 Deploying to multiple clouds concurrently with Terraform

Terraform integrates with different clouds through Terraform *providers*. Providers are plugins for Terraform that are designed to interface with external APIs. Each cloud vendor maintains its own Terraform provider, enabling Terraform to manage resources in that cloud. Providers are written in golang and distributed as binaries on the Terraform Registry (https://registry.terraform.io). They handle all the procedural logic for authenticating, making API requests, and handling timeouts and errors. There are hundreds of published providers on the registry that collectively enable you to manage thousands of different kinds of resources. You can even write your own Terraform provider, as we discuss in chapter 11.

1.1.6 Richly expressive and highly extensible

Terraform is richly expressive and highly extensible when compared to other declarative IaC tools. With conditionals, `for` expressions, directives, template files, dynamic blocks, variables, and many built-in functions, it's easy to write code to do exactly what you want. A tech comparison between Terraform and AWS CloudFormation (the technology that inspired Terraform) is shown in table 1.2.

Table 1.2 Tech comparison between the IaC tools in Terraform and AWS CloudFormation

Name	Language features				Other features		
	Intrinsic functions	Conditional statements	`for` Loops	Types	Pluggable	Modular	Wait conditions
Terraform	115	Yes	Yes	String, number, list, map, boolean, objects, complex types	Yes	Yes	No
AWS CloudFormation	11	Yes	No	String, number, list	Limited	Yes	Yes

1.2 "Hello Terraform!"

This section looks at a classical use case for Terraform: deploying a virtual machine (EC2 instance) onto AWS. We'll use the AWS provider for Terraform to make API calls on our behalf and deploy an EC2 instance. When we're done, we'll have Terraform take down the instance so we don't incur ongoing costs by keeping the server running. Figure 1.3 shows an architecture diagram for what we're doing.

As a prerequisite for this scenario, I expect that you have Terraform 0.15.X installed (see https://learn.hashicorp.com/terraform/getting-started/install.html) and that you have access credentials for AWS. The steps we'll take to deploy the project are as follows:

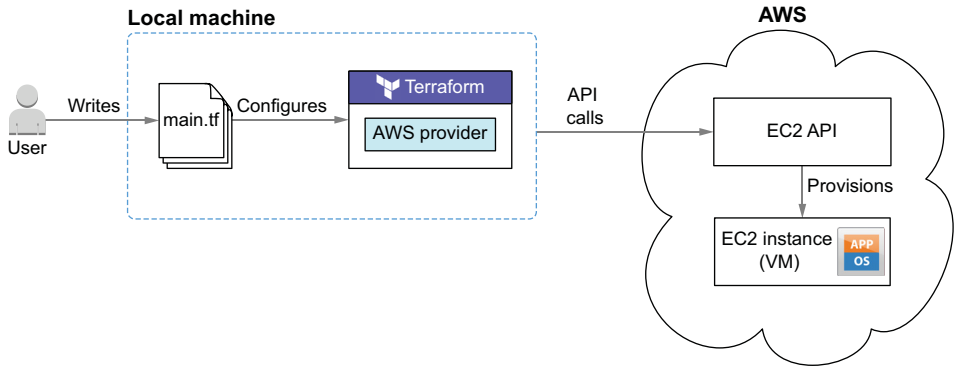


Figure 1.3 Using Terraform to deploy an EC2 instance to AWS

1. Write Terraform configuration files.
2. Configure the AWS provider.
3. Initialize Terraform with `terraform init`.
4. Deploy the EC2 instance with `terraform apply`.
5. Clean up with `terraform destroy`.

Figure 1.4 illustrates this flow.

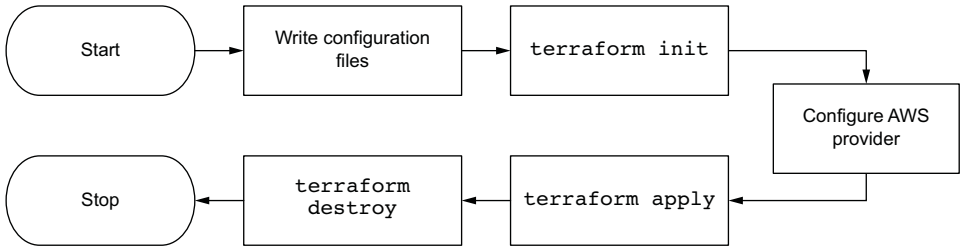


Figure 1.4 Sequence diagram of "Hello Terraform!" deployment

1.2.1 Writing the Terraform configuration

Terraform reads from configuration files to deploy infrastructure. To tell Terraform we want it to deploy an EC2 instance, we need to declare an EC2 instance as code. Let's do that now. Start by creating a new file named main.tf with the contents from the following listing. The .tf extension signifies that it's a Terraform configuration file. When Terraform runs, it will read all files in the working directory that have a .tf extension and concatenate them together.

Listing 1.1 Contents of main.tf

```
resource "aws_instance" "helloworld" {
  ami           = "ami-09dd2e08d601bff67"
  instance_type = "t2.micro"
  tags = {
    Name = "HelloWorld"
  }
}
```

Attributes for the EC2 instance

Declares an aws_instance resource with name "HelloWorld"

NOTE This Amazon Machine Image (AMI) is only valid for the us-west-2 region.

The code in listing 1.1 declares that we want Terraform to provision a `t2.micro` AWS EC2 instance with an Ubuntu AMI and a name tag. Compare this to the following equivalent CloudFormation code, and you can see how much clearer and more concise Terraform is:

```
{
    "Resources": {
        "Example": {
            "Type": "AWS::EC2::Instance",
            "Properties": {
                "ImageId": "ami-09dd2e08d601bff67",
                "InstanceType": "t2.micro",
                "Tags": [
                    {
                        "Key": "Name",
                        "Value": "HelloWorld"
                    }
                ]
            }
        }
    }
}
```

This EC2 code block is an example of a Terraform *resource*. Terraform resources are the most important elements in Terraform, as they provision infrastructure such as VMs, load balancers, NAT gateways, and so forth. Resources are declared as HCL objects with type `resource` and exactly two labels. The first label specifies the type of resource you want to create, and the second is the resource name. The name has no special significance and is only used to reference the resource within a given module scope (we talk about module scope in chapter 4). Together, the type and name make up the resource identifier, which is unique for each resource. Figure 1.5 shows the syntax of a resource block in Terraform.

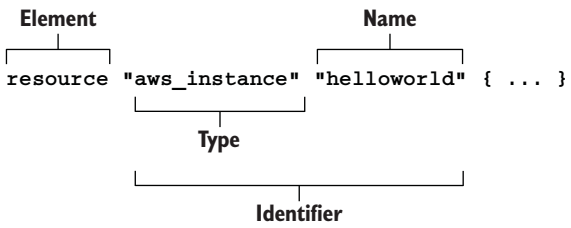


Figure 1.5 Syntax of a resource block

Each resource has inputs and outputs. Inputs are called *arguments*, and outputs are called *attributes*. Arguments are passed through the resource and are also available as resource attributes. There are also *computed attributes* that are only available after the resource has been created. Computed attributes contain calculated information about the managed resource. Figure 1.6 shows sample arguments, attributes, and computed attributes for an `aws_instance` resource.

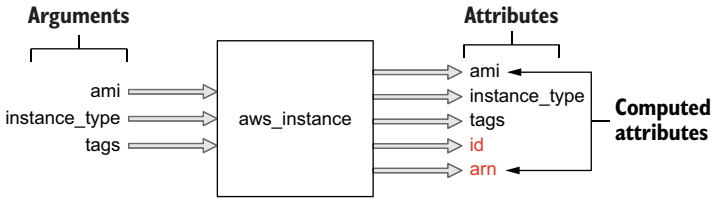


Figure 1.6 Sample inputs and outputs for an `aws_instance` resource

1.2.2 Configuring the AWS provider

Next, we need to configure the AWS provider. The AWS provider is responsible for understanding API interactions, making authenticated requests, and exposing resources to Terraform. Let's configure the AWS provider by adding a `provider` block. Update your code in main.tf as shown next.

Listing 1.2 main.tf

```
provider "aws" {
  region  = "us-west-2"
}

resource "aws_instance" "helloworld" {
  ami           = "ami-09dd2e08d601bff67"
  instance_type = "t2.micro"
  tags = {
    Name = "HelloWorld"
  }
}
```

Configures a deployment region

Declares the AWS provider

> **NOTE** You will need to obtain AWS credentials before you can provision infrastructure. These can be stored either in the credentials file or as environment variables. Refer to appendix A for a guide.

Unlike resources, providers have only one label: `Name`. This is the official name of the provider as published in the Terraform Registry (e.g. "aws" for AWS, "google" for GCP, and "azurerm" for Azure). The syntax for a provider block is shown in figure 1.7.

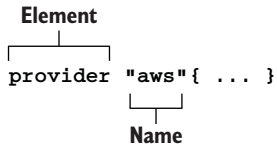


Figure 1.7 Syntax of a provider block

> **NOTE** The Terraform Registry is a global store for sharing versioned provider binaries. When Terraform initializes, it automatically looks up and downloads any required providers from the registry.

Providers don't have outputs—only inputs. You configure a provider by passing inputs, or *configuration arguments*, to the provider block. Configuration arguments are things like the service endpoint URL, region, and provider version and any credentials needed to authenticate against the API. This process is illustrated in figure 1.8.

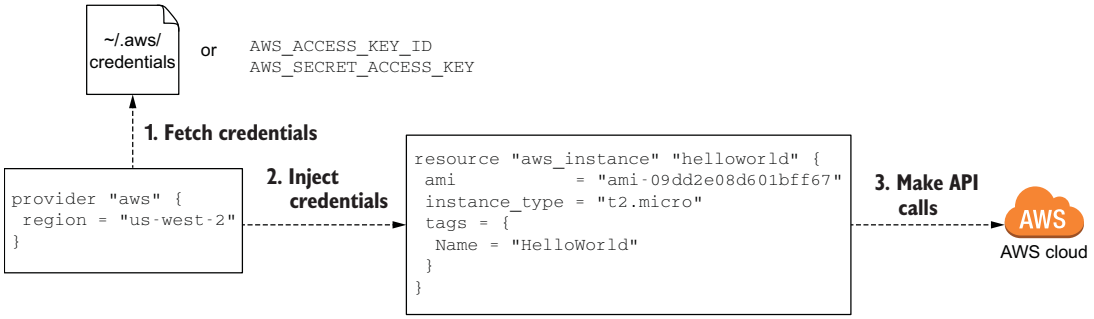


Figure 1.8 How the configured provider injects credentials into `aws_instance` when making API calls

Usually, you don't want to pass secrets into the provider as plaintext, especially when this code will later be checked into version control, so many providers allow you to read secrets from environment variables or shared credential files. If you are interested in secrets management, I recommend reading chapter 13, where we cover this topic in greater detail.

1.2.3 Initializing Terraform

Before we have Terraform deploy our EC2 instance, we first have to initialize the workspace. Even though we have declared the AWS provider, Terraform still needs to download and install the binary from the Terraform Registry. Initialization is required at least once for all workspaces.

You can initialize Terraform by running the command `terraform init`. When you do this, you will see the following output:

```
$ terraform init

Initializing the backend...

Initializing provider plugins...
- Finding latest version of hashicorp/aws...
- Installing hashicorp/aws v3.28.0...
- Installed hashicorp/aws v3.28.0 (signed by HashiCorp)
```

Terraform fetches the latest version of the AWS provider.

```
Terraform has created a lock file .terraform.lock.hcl to record the
provider selections it made above. Include this file in your version
control repository so that Terraform can guarantee to make the same
selections by default when you run "terraform init" in the future.

Terraform has been successfully initialized!
```

The only thing we really care about

```
You may now begin working with Terraform. Try running "terraform plan" to
see any changes that are required for your infrastructure. All Terraform
commands should now work.

If you ever set or change modules or backend configuration for Terraform,
rerun this command to reinitialize your working directory. If you forget,
other commands will detect it and remind you to do so if necessary.
```

NOTE You need to have Terraform installed on your machine for this to work, if you do not have it already.

1.2.4 Deploying the EC2 instance

Now we're ready to deploy the EC2 instance using Terraform. Do this by executing the `terraform apply` command.

WARNING Performing this action may result in charges to your AWS account for EC2 and CloudWatch Logs.

```
$ terraform apply

An execution plan has been generated and is shown below.
Resource actions are indicated with the following symbols:
  + create

Terraform will perform the following actions:

  # aws_instance.helloworld will be created
  + resource "aws_instance" "helloworld" {
      + ami                          = "ami-09dd2e08d601bff67"
      + arn                          = (known after apply)
      + associate_public_ip_address  = (known after apply)
      + availability_zone            = (known after apply)
      + cpu_core_count               = (known after apply)
      + cpu_threads_per_core         = (known after apply)
      + get_password_data            = false
      + host_id                      = (known after apply)
      + id                           = (known after apply)
      + instance_state               = (known after apply)
      + instance_type                = "t2.micro"
      + ipv6_address_count           = (known after apply)
      + ipv6_addresses               = (known after apply)
      + key_name                     = (known after apply)
      + network_interface_id         = (known after apply)
      + outpost_arn                  = (known after apply)
      + password_data                = (known after apply)
      + placement_group              = (known after apply)
      + primary_network_interface_id = (known after apply)
```

ami attribute

instance_type attribute

```
  + private_dns                   = (known after apply)
  + private_ip                    = (known after apply)
  + public_dns                    = (known after apply)
  + public_ip                     = (known after apply)
  + security_groups               = (known after apply)
  + source_dest_check             = true
  + subnet_id                     = (known after apply)
  + tags                          = {
      + "Name" = "HelloWorld"
    }
  + tenancy                       = (known after apply)
  + volume_tags                   = (known after apply)
  + vpc_security_group_ids        = (known after apply)

  + ebs_block_device {
      + delete_on_termination = (known after apply)
      + device_name           = (known after apply)
      + encrypted             = (known after apply)
      + iops                  = (known after apply)
      + kms_key_id            = (known after apply)
      + snapshot_id           = (known after apply)
      + volume_id             = (known after apply)
      + volume_size           = (known after apply)
      + volume_type           = (known after apply)
    }

  + ephemeral_block_device {
      + device_name  = (known after apply)
      + no_device    = (known after apply)
      + virtual_name = (known after apply)
    }

  + metadata_options {
      + http_endpoint               = (known after apply)
      + http_put_response_hop_limit = (known after apply)
      + http_tokens                 = (known after apply)
    }

  + network_interface {
      + delete_on_termination = (known after apply)
      + device_index          = (known after apply)
      + network_interface_id  = (known after apply)
    }

  + root_block_device {
      + delete_on_termination = (known after apply)
      + device_name           = (known after apply)
      + encrypted             = (known after apply)
      + iops                  = (known after apply)
      + kms_key_id            = (known after apply)
      + volume_id             = (known after apply)
      + volume_size           = (known after apply)
      + volume_type           = (known after apply)
    }
}
```

```
Plan: 1 to add, 0 to change, 0 to destroy.

Do you want to perform these actions?
  Terraform will perform the actions described above.
  Only 'yes' will be accepted to approve.

  Enter a value:
```

Summary of actions

Manual approval step

TIP If you receive an error saying "No Valid Credentials Sources Found," Terraform was not able to authenticate to AWS. Refer to appendix A for a guide to obtaining credentials and configuring the AWS provider.

The CLI output is called an *execution plan* and outlines the set of actions that Terraform intends to perform to achieve your desired state. It's a good idea to review the plan as a sanity check before proceeding. There shouldn't be anything odd here unless you made a typo. When you are done reviewing the execution plan, approve it by entering `yes` at the command line.

After a minute or two (the approximate time it takes to provision an EC2 instance), the `apply` will complete successfully. Following is some example output:

```
aws_instance.helloworld: Creating...
aws_instance.helloworld: Still creating... [10s elapsed]
aws_instance.helloworld: Still creating... [20s elapsed]
aws_instance.helloworld: Creation complete after 25s [id=i-070098fcf77d93c54]

Apply complete! Resources: 1 added, 0 changed, 0 destroyed.
```

You can verify that your resource was created by locating it in the AWS console for EC2, as shown in figure 1.9. Note that this instance is in the us-west-2 region because that's what we set in the provider.

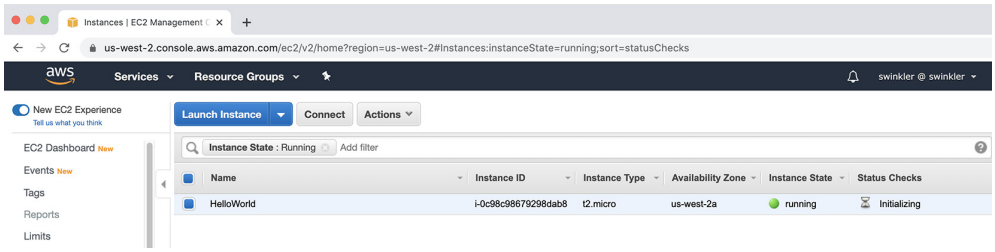


Figure 1.9 The EC2 instance in the AWS console

All of the stateful information about the resource is stored in a file called terraform .tfstate. Don't let the .tfstate extension fool you—it's really just a JSON file. The `terraform show` command can be used to print human-readable output from the state file and makes it easy to list information about the resources that Terraform manages. An example result of `terraform show` is as follows:

```
$ terraform show
# aws_instance.helloworld:
resource "aws_instance" "helloworld" {
    ami                          = "ami-09dd2e08d601bff67"
    arn                          =
    ➥ "arn:aws:ec2:us-west-2:215974853022:instance/i-070098fcf77d93c54"
    associate_public_ip_address  = true
    availability_zone            = "us-west-2a"
    cpu_core_count               = 1
    cpu_threads_per_core         = 1
    disable_api_termination      = false
    ebs_optimized                = false
    get_password_data            = false
    hibernation                  = false
    id                           = "i-070098fcf77d93c54"
    instance_state               = "running"
    instance_type                = "t2.micro"
    ipv6_address_count           = 0
    ipv6_addresses               = []
    monitoring                   = false
    primary_network_interface_id = "eni-031d47704eb23eaf0"
    private_dns                  =
    ➥ "ip-172-31-25-172.us-west-2.compute.internal"
    private_ip                   = "172.31.25.172"
    public_dns                   =
    ➥ "ec2-52-24-28-182.us-west-2.compute.amazonaws.com"
    public_ip                    = "52.24.28.182"
    secondary_private_ips        = []
    security_groups              = [
        "default",
    ]
    source_dest_check            = true
    subnet_id                    = "subnet-0d78ac285558cff78"
    tags                         = {
        "Name" = "HelloWorld"
    }
    tenancy                      = "default"
    vpc_security_group_ids       = [
        "sg-0d8222ef7623a02a5",
    ]

    credit_specification {
        cpu_credits = "standard"
    }

    enclave_options {
        enabled = false
    }

    metadata_options {
        http_endpoint               = "enabled"
        http_put_response_hop_limit = 1
        http_tokens                 = "optional"
    }
```

id is an important computed attribute.

```
    root_block_device {
        delete_on_termination = true
        device_name           = "/dev/sda1"
        encrypted             = false
        iops                  = 100
        tags                  = {}
        throughput            = 0
        volume_id             = "vol-06b149cdd5722d6bc"
        volume_size           = 8
        volume_type           = "gp2"
    }
}
```

There are a lot more attributes here than we originally set in the resource block because most of the attributes of `aws_instance` are either optional or computed. You can customize `aws_instance` by setting some of the optional arguments. Consult the AWS provider documentation if you want to know what these are.

1.2.5 Destroying the EC2 instance

Now it's time to say goodbye to the EC2 instance. You always want to destroy any infrastructure you are no longer using, as it costs money to run stuff in the cloud. Terraform has a special command to destroy all resources: `terraform destroy`. When you run this command, you are prompted to manually confirm the destroy operation:

```
$ terraform destroy
aws_instance.helloworld: Refreshing state... [id=i-070098fcf77d93c54]

Terraform used the selected providers to generate the following execution plan.
Resource actions are indicated with the following symbols:
  - destroy

Terraform will perform the following actions:

  # aws_instance.helloworld will be destroyed
  - resource "aws_instance" "helloworld" {
      - ami                          = "ami-09dd2e08d601bff67" -> null
      - arn                          = "arn:aws:ec2:us-west-2:215974853022:
        ➥ instance/i-070098fcf77d93c54" -> null
      - associate_public_ip_address  = true -> null
      - availability_zone            = "us-west-2a" -> null
      - cpu_core_count               = 1 -> null
      - cpu_threads_per_core         = 1 -> null
      - disable_api_termination      = false -> null
      - ebs_optimized                = false -> null
      - get_password_data            = false -> null
      - hibernation                  = false -> null
      - id                           = "i-070098fcf77d93c54" -> null
      - instance_state               = "running" -> null
      - instance_type                = "t2.micro" -> null
      - ipv6_address_count           = 0 -> null
      - ipv6_addresses               = [] -> null
      - monitoring                   = false -> null
```

```
      - primary_network_interface_id = "eni-031d47704eb23eaf0" -> null
      - private_dns                  =
        ➥ "ip-172-31-25-172.us-west-2.compute.internal" -> null
      - private_ip                   = "172.31.25.172" -> null
      - public_dns                   =
        ➥ "ec2-52-24-28-182.us-west-2.compute.amazonaws.com" -> null
      - public_ip                    = "52.24.28.182" -> null
      - secondary_private_ips        = [] -> null
      - security_groups              = [
          - "default",
        ] -> null
      - source_dest_check            = true -> null
      - subnet_id                    = "subnet-0d78ac285558cff78" -> null
      - tags                         = {
          - "Name" = "HelloWorld"
        } -> null
      - tenancy                      = "default" -> null
      - vpc_security_group_ids       = [
          - "sg-0d8222ef7623a02a5",
        ] -> null

      - credit_specification {
          - cpu_credits = "standard" -> null
        }

      - enclave_options {
          - enabled = false -> null
        }

      - metadata_options {
          - http_endpoint               = "enabled" -> null
          - http_put_response_hop_limit = 1 -> null
          - http_tokens                 = "optional" -> null
        }

      - root_block_device {
          - delete_on_termination = true -> null
          - device_name           = "/dev/sda1" -> null
          - encrypted             = false -> null
          - iops                  = 100 -> null
          - tags                  = {} -> null
          - throughput            = 0 -> null
          - volume_id             = "vol-06b149cdd5722d6bc" -> null
          - volume_size           = 8 -> null
          - volume_type           = "gp2" -> null
        }
    }

Plan: 0 to add, 0 to change, 1 to destroy.
```

Summary of actions Terraform intends to take

```
Do you really want to destroy all resources?
  Terraform will destroy all your managed infrastructure, as shown above.
  There is no undo. Only 'yes' will be accepted to confirm.

  Enter a value:
```

> **WARNING** It is important not to manually edit or delete the `terraform.tfstate` file, or Terraform will lose track of managed resources.

The destroy plan is just like the previous execution plan, except it is for the delete operation.

> **NOTE** `terraform destroy` does exactly the same thing as you deleting all configuration code and running `terraform apply`.

Confirm that you wish to apply the destroy plan by typing `yes` at the prompt. Wait a few minutes for Terraform to resolve, and then you will be notified that Terraform has finished destroying all resources. Your output will look like the following:

```
aws_instance.helloworld: Destroying… [id=i-070098fcf77d93c54]
aws_instance.helloworld: Still destroying...
➥ [id=i-070098fcf77d93c54, 10s elapsed]
aws_instance.helloworld: Still destroying...
➥ [id=i-070098fcf77d93c54, 20s elapsed]
aws_instance.helloworld: Still destroying...
➥ [id=i-070098fcf77d93c54, 30s elapsed]
aws_instance.helloworld: Destruction complete after 31s

Destroy complete! Resources: 1 destroyed.
```

You can verify that the resources have indeed been destroyed by either refreshing the AWS console or running `terraform show` and confirming that it returns nothing:

```
$ terraform show
```

1.3 Brave new "Hello Terraform!"

I like the classic "Hello World!" example and feel it is a good starter project, but I don't think it does justice to the technology as a whole. Terraform can do much more than simply provision resources from static configuration code. It's also able to provision resources dynamically based on the results of external queries and data lookups. Let us now consider *data sources*, which are elements that allow you to fetch data at runtime and perform computations.

This section improves the classic "Hello World!" example by adding a data source to dynamically look up the latest value of the Ubuntu AMI. We'll pass the output value into `aws_instance` so we don't have to statically set the AMI in the EC2 instance resource configuration (see figure 1.10).

Because we've already configured the AWS provider and initialized Terraform with `terraform init`, we can skip some of the steps we did previously. Here, we'll do the following:

1. Modify Terraform configuration to add the data source.
2. Redeploy with `terraform apply`.
3. Clean up with `terraform destroy`.

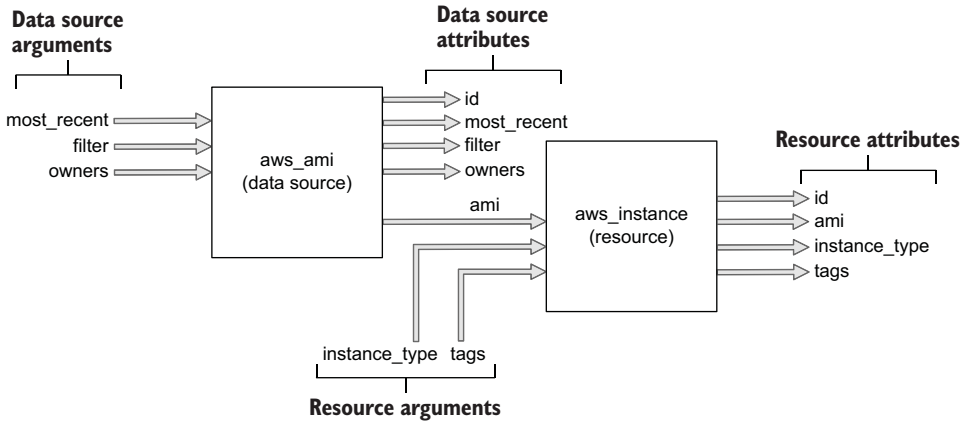


Figure 1.10 How the output of the `aws_ami` data source will be chained to the input of the `aws_instance` resource

This flow is illustrated in figure 1.11.

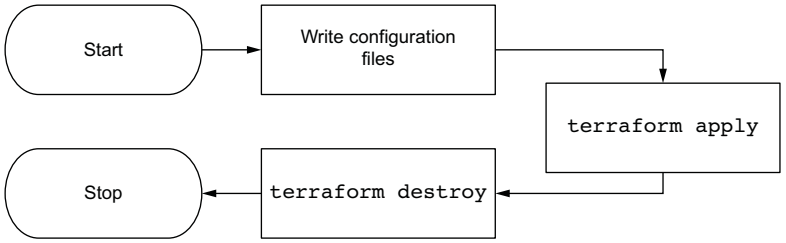


Figure 1.11 Deployment sequence diagram

1.3.1 Modifying the Terraform configuration

We need to add the code to read from the external data source, allowing us to query the most recent Ubuntu AMI published to AWS. Edit main.tf to look like the following listing.

Listing 1.3 main.tf

```
provider "aws" {
  region = "us-west-2"
}

data "aws_ami" "ubuntu" {
  most_recent = true

  filter {
```

Declares an aws_ami data source with name "ubuntu"

Sets a filter to select all AMIs with name matching this regex expression

```
    name   = "name"
    values = ["ubuntu/images/hvm-ssd/ubuntu-focal-20.04-amd64-server-*"]
  }

  owners = ["099720109477"]                    <- Canonical Ubuntu AWS account id
}

resource "aws_instance" "helloworld" {
  ami           = data.aws_ami.ubuntu.id       <- Chains resources together
  instance_type = "t2.micro"
  tags = {
    Name = "HelloWorld"
  }
}
```

Like resources, data sources are declared by creating an HCL object with type "data" having exactly two labels. The first label specifies the type of data source, and the second is the name of the data source. Together, the type and name are referred to as the data source's *identifier* and must be unique within a module. Figure 1.12 illustrates the syntax of a data source.

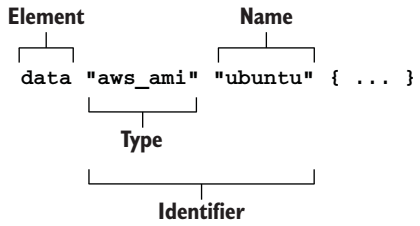


Figure 1.12 Syntax of a data source

The contents of a data source code block are called *query constraint arguments*. They behave exactly the same as arguments do for resources. The query constraint arguments are used to specify resource(s) from which to fetch data. Data sources are unmanaged resources that Terraform can read data from but that Terraform doesn't directly control.

1.3.2 Applying changes

Let's go ahead and apply our changes by having Terraform deploy an EC2 instance with the Ubuntu data source output value for AMI. Do this by running `terraform apply`. Your CLI output will be as follows:

```
$ terraform apply

Terraform used the selected providers to generate the following execution
    plan.
Resource actions are indicated with the following symbols:
  + create

Terraform will perform the following actions:

  # aws_instance.helloworld will be created
  + resource "aws_instance" "helloworld" {
      + ami                          = "ami-0928f4202481dfdf6"   <- Set from the output of the data source
      + arn                          = (known after apply)
      + associate_public_ip_address  = (known after apply)
      + availability_zone            = (known after apply)
```

```
      + cpu_core_count              = (known after apply)
      + cpu_threads_per_core        = (known after apply)
      + get_password_data           = false
      + host_id                     = (known after apply)
      + id                          = (known after apply)
      + instance_state              = (known after apply)
      + instance_type               = "t2.micro"
     // skip some logs
    }

Plan: 1 to add, 0 to change, 0 to destroy.

Do you want to perform these actions?
  Terraform will perform the actions described above.
  Only 'yes' will be accepted to approve.

  Enter a value:
```

Apply the changes by entering `yes` at the command line. After waiting a few minutes, your output will be as follows:

```
aws_instance.helloworld: Creating...
aws_instance.helloworld: Still creating... [10s elapsed]
aws_instance.helloworld: Creation complete after 19s [id=i-0c0a6a024bb4ba669]

Apply complete! Resources: 1 added, 0 changed, 0 destroyed.
```

As before, you can verify the changes by either navigating through the AWS console or invoking `terraform show`.

1.3.3 Destroying the infrastructure

Destroy the infrastructure created in the previous step by running `terraform destroy`. You'll receive another manual confirmation:

```
$ terraform destroy
aws_instance.helloworld: Refreshing state... [id=i-0c0a6a024bb4ba669]

Terraform used the selected providers to generate the following execution
    plan.
Resource actions are indicated with the following symbols:
  - destroy

Terraform will perform the following actions:

  # aws_instance.helloworld will be destroyed
  - resource "aws_instance" "helloworld" {
      - ami                         = "ami-0928f4202481dfdf6" -> null
      - arn                         = "arn:aws:ec2:us-west-2:215974853022
      ➥ :instance/i-0c0a6a024bb4ba669" -> null
      - associate_public_ip_address  = true -> null
// skip some logs
    }

Plan: 0 to add, 0 to change, 1 to destroy.
```

```
Do you really want to destroy all resources?
  Terraform will destroy all your managed infrastructure, as shown above.
  There is no undo. Only 'yes' will be accepted to confirm.

  Enter a value:
```

After manually confirming and waiting a few more minutes, the EC2 instance is now gone:

```
aws_instance.helloworld: Destroying... [id=i-0c0a6a024bb4ba669]
aws_instance.helloworld: Still destroying...
➥ [id=i-0c0a6a024bb4ba669, 10s elapsed]
aws_instance.helloworld: Still destroying...
➥ [id=i-0c0a6a024bb4ba669, 20s elapsed]
aws_instance.helloworld: Still destroying...
➥ [id=i-0c0a6a024bb4ba669, 30s elapsed]
aws_instance.helloworld: Destruction complete after 30s

Destroy complete! Resources: 1 destroyed.
```

1.4 Fireside chat

In this introductory chapter, not only did we discuss what Terraform is and how it compares to other IaC tools, but we also performed two real-world deployments. The first was the de facto "Hello World!" of Terraform, and the second was my personal favorite because it utilized a data source to demonstrate the dynamic capabilities of Terraform.

In the next few chapters, we go through the fundamentals of how Terraform works and the major constructs and syntax elements of the Terraform HCL language. This leads to chapter 4, when we deploy a multi-tiered web application onto AWS.

Summary

- Terraform is a declarative IaC provisioning tool. It can deploy resources onto any public or private cloud.
- Terraform is (1) a provisioning tool, (2) easy to use, (3) free and open source, (4) declarative, (5) cloud-agnostic, and (6) expressive and extensible.
- The major elements of Terraform are resources, data sources, and providers.
- Code blocks can be chained together to perform dynamic deployments.
- To deploy a Terraform project, you must first write configuration code, then configure providers and other input variables, initialize Terraform, and finally apply changes. Cleanup is done with a `destroy` command.

2 Life cycle of a Terraform resource

This chapter covers

- Generating and applying execution plans
- Analyzing when Terraform triggers function hooks
- Using the Local provider to create and manage files
- Simulating, detecting, and correcting for configuration drift
- Understanding the basics of Terraform state management

When you do away with all the bells and whistles, Terraform is a surprisingly simple technology. Fundamentally, Terraform is a state management tool that performs CRUD operations (create, read, update, delete) on managed resources. Often, managed resources are cloud-based resources, but they don't have to be. Anything that can be represented as CRUD can be managed as a Terraform resource.

In this chapter, we deep-dive into the internals of Terraform by walking through the life cycle of a single resource. We can use any resource for this task, so let's use a resource that doesn't call any remote network APIs. These special resources are called *local-only resources* and exist within the confines of Terraform or the machine

running Terraform. Local-only resources typically serve marginal purposes, such as to glue "real" infrastructure together, but they also make a great teaching aid. Examples of local-only resources include resources for creating private keys, self-signed TLS certificates, and random ids.

2.1 Process overview

We will use the `local_file` resource from the Local provider for Terraform to create, read, update, and delete a text file containing the first few passages of Sun Tzu's *The Art of War*. Our high-level architecture diagram is shown in figure 2.1.

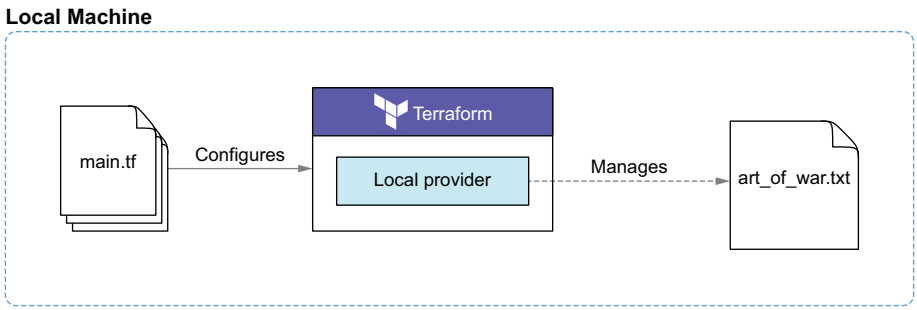


Figure 2.1 Inputs and outputs of the Sun Tzu scenario

> **NOTE** Although a text file isn't normally considered infrastructure, you can still deploy it the same way you would an EC2 instance. Does that mean that it's real infrastructure? Does the distinction even matter? I'll leave it for you to decide.

First, we'll create the resource. Next, we'll simulate configuration drift and perform an update. Finally, we'll clean up with `terraform destroy`. The procedure is shown in figure 2.2.

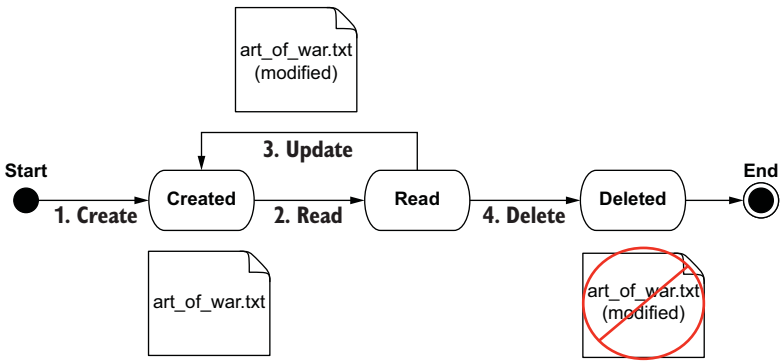


Figure 2.2 (1) We create the resource, then (2) read and (3) update it, and finally (4) delete it.

2.1.1 Life cycle function hooks

All Terraform resources implement the resource schema interface. The resource schema mandates, among other things, that resources define CRUD functions hooks, one each for `Create()`, `Read()`, `Update()`, and `Delete()`. Terraform invokes these hooks when certain conditions are met. Generally speaking, `Create()` is called during resource creation, `Read()` during plan generation, `Update()` during resource updates, and `Delete()` during deletes. There's a bit more to it than that, but you get the idea.

Because it's a resource, `local_file` also implements the resource schema interface. That means it defines function hooks for `Create()`, `Read()`, `Update()`, and `Delete()`. This is in contrast to the `local_file` data source, which only implements `Read()` (see figure 2.3). In this scenario, I will point out when and why each of these function hooks is called.

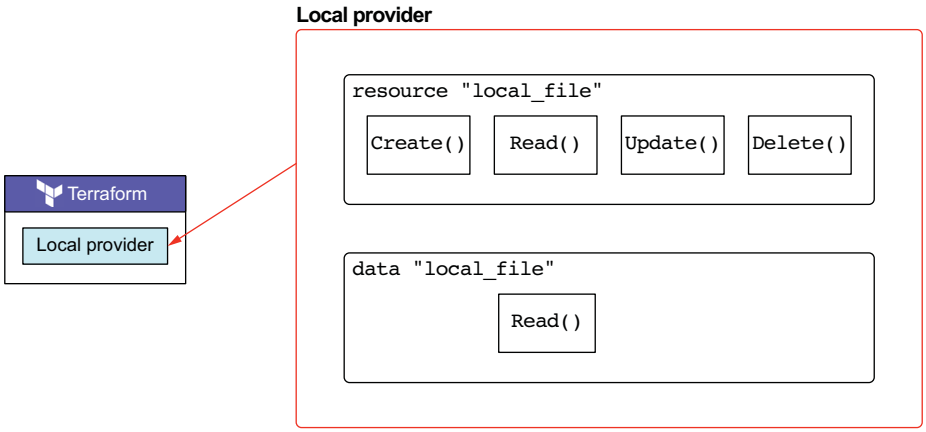


Figure 2.3 The two resources in the Local provider are a managed resource and an unmanaged data source. The managed resource implements full CRUD, while the data source only implements `Read()`.

2.2 Declaring a local file resource

Let's get started by creating a new workspace for Terraform. Do this by creating a new empty directory somewhere on your computer. Make sure the folder doesn't contain any existing configuration code, because Terraform concatenates all .tf files together. In this workspace, make a new file called main.tf and add the following code.

Listing 2.1 main.tf

```
terraform {
  required_version = ">= 0.15"
  required_providers {
    local = {
```

Terraform settings blocks

```
      source  = "hashicorp/local"
      version = "~> 2.0"
    }
  }
}

resource "local_file" "literature" {
    filename = "art_of_war.txt"
    content     = <<-EOT
      Sun Tzu said: The art of war is of vital importance to the State.

      It is a matter of life and death, a road either to safety or to
      ruin. Hence it is a subject of inquiry which can on no account be
      neglected.
    EOT
}
```

Heredoc syntax for multi-line strings

> **TIP** The `<<-` sequence indicates an indented heredoc string. Anything between the opening identifier and the closing identifier (`EOT`) is interpreted literally. Leading whitespace, however, is ignored (unlike traditional heredoc syntax).

There are two configuration blocks in listing 2.1. The first block, `terraform {...}`, is a special configuration block responsible for configuring Terraform. Its primary use is version-locking your code, but it can also configure where your state file is stored and where providers are downloaded (we discuss this more in chapter 6). As a reminder, the Local provider has not yet been installed. To do that, we first need to perform `terraform init`.

The second configuration block is a resource block that declares a `local_file` resource. It provisions a text file with a given filename and content value. In this scenario, the content will contain the first couple stanzas of Sun Tzu's masterpiece, *The Art of War*, and the filename will be art_of_war.txt. We will use heredoc syntax (`<<-`) to input a multiline string literal.

2.3 Initializing the workspace

At this point, Terraform isn't aware of your workspace, let alone that it's supposed to create or manage anything, because it hasn't been initialized. Terraform configuration must always be initialized at least once, but you may have to initialize again if you add new providers or modules. Don't fret about when to run `terraform init`, because Terraform will always remind you. Moreover, `terraform init` is an *idempotent* command, which means you can call it as many times as you want in a row with no side effects.

Run `terraform init` now:

```
$ terraform init

Initializing the backend...

Initializing provider plugins...
- Finding hashicorp/local versions matching "~> 2.0"...
```

```
- Installing hashicorp/local v2.0.0...
- Installed hashicorp/local v2.0.0 (signed by HashiCorp)

Terraform has created a lock file .terraform.lock.hcl to record the
provider selections it made above. Include this file in your version
control repository so that Terraform can guarantee to make the same
selections by default when you run "terraform init" in the future.

Terraform has been successfully initialized!

You may now begin working with Terraform. Try running "terraform plan" to
see any changes that are required for your infrastructure. All Terraform
commands should now work.

If you ever set or change modules or backend configuration for Terraform,
rerun this command to reinitialize your working directory. If you forget,
other commands will detect it and remind you to do so if necessary.
```

After initialization, Terraform creates a hidden .terraform directory for installing plugins and modules. The directory structure for the current Terraform workspace is the following:

```
.
├── .terraform
│   └── providers
│       └── registry.terraform.io
│           └── hashicorp
│               └── local
│                   └── 2.0.0
│                       └── darwin_amd64
│                           └── terraform-provider-local_v2.0.0_x5
├── .terraform.lock.hcl
└── main.tf

7 directories, 3 files
```

Because we declared a `local_file` resource in main.tf, Terraform is smart enough to realize that there is an implicit dependency on the Local provider. So Terraform looks up the resource and downloads it from the provider registry. You don't have to declare an empty provider block (i.e. `provider "local" {}`) unless you want to.

> **TIP** Version lock any providers you use, whether they are implicitly or explicitly defined, to ensure that any deployment you make is repeatable.

2.4 Generating an execution plan

Before we create the `local_file` resource with `terraform apply`, we can preview what Terraform intends to do by running `terraform plan`. You should always run `terraform plan` before deploying. I often skip this step in the book for the sake of brevity, but you should still do it, even if I do not call it out. `terraform plan` informs you about what Terraform intends to do and acts as a linter, letting you know about any syntax or dependency errors. It's a read-only action that does not alter the state of deployed infrastructure, and like `terraform init`, it's idempotent.

Generate an execution plan now by running `terraform plan`:

```
$ terraform plan
Refreshing Terraform state in-memory prior to plan…
The refreshed state will be used to calculate this plan, but will not be
persisted to local or remote state storage.

------------------------------------------------------------------------

An execution plan has been generated and is shown below.
Resource actions are indicated with the following symbols:
  + create

Terraform will perform the following actions:

  # local_file.literature will be created
  + resource "local_file" "literature" {
      + content              = <<~EOT
            Sun Tzu said: The art of war is of vital importance to the State.

            It is a matter of life and death, a road either to safety or to
            ruin. Hence it is a subject of inquiry which can on no account be
            neglected.
        EOT
      + directory_permission = "0777"
      + file_permission      = "0777"
      + filename             = "art_of_war.txt"
      + id                   = (known after apply)
}

Plan: 1 to add, 0 to change, 0 to destroy.

------------------------------------------------------------------------

Note: You didn't specify an "-out" parameter to save this plan, so
Terraform can't guarantee that exactly these actions will be performed if
"terraform apply" is subsequently run.
```

Computed meta-attribute

When might my plan fail?

Terraform plans can fail for many reasons, such as if your configuration code is invalid or if there's a versioning issue or network-related problems. Sometimes, albeit rarely, a plan fails due to a bug in the provider's source code. You need to carefully read whatever error message you receive to know for sure. For more verbose logs, you can turn on trace-level logging by setting the environment variable `TF_LOG=trace` to a non-zero value, e.g. `export TF_LOG=trace`.

As you can see from the output, Terraform is letting us know that it wants to create a `local_file` resource. Besides the attributes that we supply, it also wants to set a computed attribute called `id`, which is a meta-attribute that Terraform sets on all resources. It's used to uniquely identify real-world resources and for internal calculations.

Although this particular `terraform plan` should have exited quickly, some plans take a while to complete. It all has to do with how many resources you are deploying and how many resources you already have in your state file.

TIP If `terraform plan` is running slowly, turn off trace-level logging and consider increasing parallelism (`-parallelism=n`).

Although the output of the plan is fairly straightforward, a lot is going on that you should be aware of. The three main stages of a `terraform plan` are as follows:

1. *Read the configuration and state.* Terraform reads your configuration and state files (if they exist).
2. *Determine actions to take.* Terraform performs a calculation to determine what needs to be done to achieve the desired state. This can be one of `Create()`, `Read()`, `Update()`, `Delete()`, or `No-op`.
3. *Output the plan.* An execution plan ensures that actions occur in the right order to avoid dependency problems. This is more relevant when you have lots of resources.

Figure 2.4 is a detailed flow diagram showing what happens during `terraform plan`.

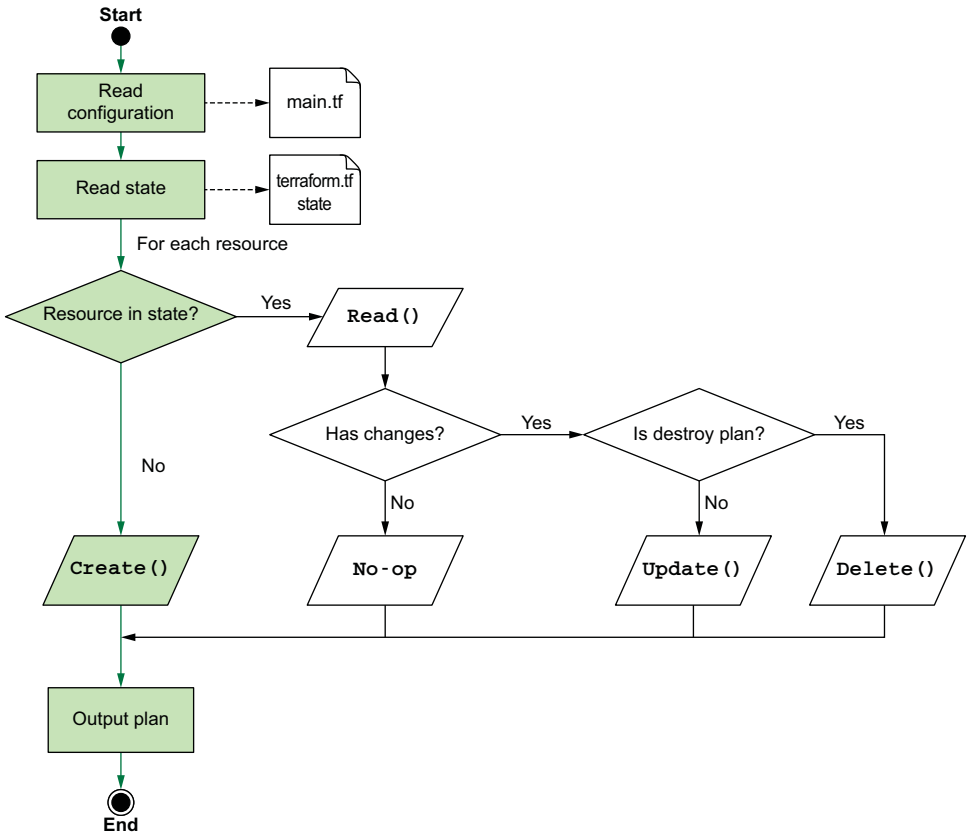


Figure 2.4 Steps that Terraform performs when generating an execution plan for a new deployment

We haven't yet talked about the dependency graph, but it's a big part of Terraform, and every `terraform plan` generates one for respecting implicit and explicit dependencies between resource and provider nodes. Terraform has a special command for visualizing the dependency graph: `terraform graph`. This command outputs a dot-file that can be converted to a digraph using a variety of tools. Figure 2.5 shows the produced DOT graph.

NOTE DOT is a graph description language. DOT graphs are files with the filename extension .dot. Various programs can process and render DOT files in graphical form.

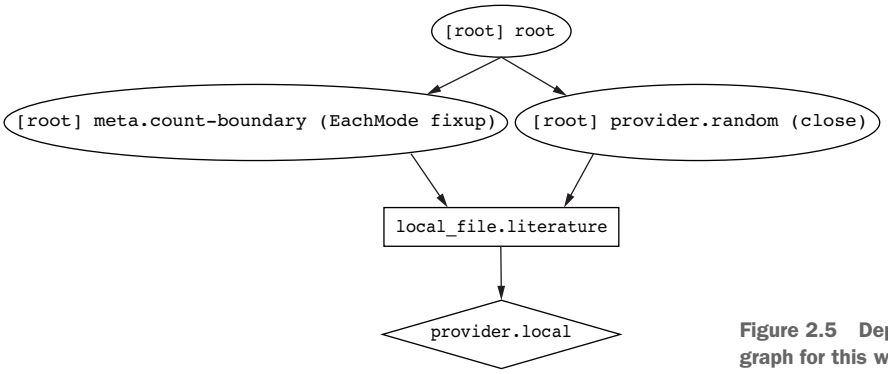


Figure 2.5 Dependency graph for this workspace

The dependency graph for this workspace has a few nodes, including one for the Local provider, one for the `local_file` resource, and a few other meta nodes that correspond to housekeeping actions. During an `apply`, Terraform walks the dependency graph to ensure that everything is done in the correct order. We examine a more complex digraph in the next chapter.

2.4.1 Inspecting the plan

It's possible to read the output of `terraform plan` in JSON format, which can be useful when integrating with custom tools or enforcing policy as code (we discuss policy as code in chapter 13).

First, save the output of the plan by setting the optional `-out` flag:

```
$ terraform plan -out plan.out
Refreshing Terraform state in-memory prior to plan…
The refreshed state will be used to calculate this plan, but will not be
persisted to local or remote state storage.

------------------------------------------------------------------------

An execution plan has been generated and is shown below.
Resource actions are indicated with the following symbols:
  + create
```

```
Terraform will perform the following actions:

  # local_file.literature will be created
  + resource "local_file" "literature" {
      + content              = <<~EOT
            Sun Tzu said: The art of war is of vital importance to the State.

            It is a matter of life and death, a road either to safety or to
            ruin. Hence it is a subject of inquiry which can on no account be
            neglected.
        EOT
      + directory_permission = "0777"
      + file_permission      = "0777"
      + filename             = "art_of_war.txt"
      + id                   = (known after apply)
}

Plan: 1 to add, 0 to change, 0 to destroy.
─────────────────────────────────────────────────────────────────────────────

This plan was saved to: plan.out

To perform exactly these actions, run the following command to apply:
terraform apply "plan.out"
```

plan.out is now saved as a binary file, so the next step is to convert it to JSON format. This can be done (rather unintuitively) by ingesting it with `terraform show` and piping it to an output file:

```
$ terraform show -json plan.out > plan.json
```

Finally, we have the plan in human-readable format:

```
$ cat plan.json
{"format_version":"0.1","terraform_version":"0.15.0","planned_values":{"roo
t_module":{"resources":[{"address":"local_file.literature","mode":"managed"
,"type":"local_file","name":"literature","provider_name":"registry.terrafor
m.io/hashicorp/local","schema_version":0,"values":{"content":"Sun Tzu said:
The art of war is of vital importance to the State.\n\nIt is a matter of
life and death, a road either to safety or to \nruin. Hence it is a subject
of inquiry which can on no account
be\nneglected.\n","content_base64":null,"directory_permission":"0777","file
_permission":"0777","filename":"art_of_war.txt","sensitive_content":null}}]
}},"resource_changes":[{"address":"local_file.literature","mode":"managed",
"type":"local_file","name":"literature","provider_name":"registry.terraform
.io/hashicorp/local","change":{"actions":["create"],"before":null,"after":{
"content":"Sun Tzu said: The art of war is of vital importance to the
State.\n\nIt is a matter of life and death, a road either to safety or to
\nruin. Hence it is a subject of inquiry which can on no account
be\nneglected.\n","content_base64":null,"directory_permission":"0777","file
_permission":"0777","filename":"art_of_war.txt","sensitive_content":null},"
after_unknown":{"id":true}}}],"configuration":{"root_module":{"resources":[
{"address":"local_file.literature","mode":"managed","type":"local_file","na
me":"literature","provider_config_key":"local","expressions":{"content":{"c
onstant_value":"Sun Tzu said: The art of war is of vital importance to the
```

```
State.\n\nIt is a matter of life and death, a road either to safety or to
\nruin. Hence it is a subject of inquiry which can on no account
be\nneglected.\n"},"filename":{"constant_value":"art_of_war.txt"}},"schema_
version":0}]}}}
```

2.5 Creating the local file resource

Now let's run `terraform apply` to compare the output against the generated execution plan. The command and output are as follows:

```
$ terraform apply

Terraform used the selected providers to generate the following execution plan.
Resource actions are indicated with the following symbols:
  + create

Terraform will perform the following actions:

  # local_file.literature will be created
  + resource "local_file" "literature" {
      + content              = <<-EOT
            Sun Tzu said: The art of war is of vital importance to the State.

            It is a matter of life and death, a road either to safety or to
            ruin. Hence it is a subject of inquiry which can on no account be
            neglected.
        EOT
      + directory_permission = "0777"
      + file_permission      = "0777"
      + filename             = "art_of_war.txt"
      + id                   = (known after apply)
}

Plan: 1 to add, 0 to change, 0 to destroy.

Do you want to perform these actions?
  Terraform will perform the actions described above.
  Only 'yes' will be accepted to approve.

  Enter a value:
```

Do they look similar? It's no coincidence. The execution plan generated by `terraform apply` is exactly the same as the plan generated by `terraform plan`. In fact, you can even apply the results of `terraform plan` explicitly:

```
$ terraform plan -out plan.out && terraform apply "plan.out"
```

> **TIP** Separating `plan` and `apply` like this could be useful when running Terraform in automation, something we will explore in chapter 12.

Regardless of how you generate an execution plan, it's always a good idea to review the contents of the plan before applying. During an `apply`, Terraform creates and destroys real infrastructure, which of course has real-world consequences. If you are not careful, then a simple mistake or typo could wipe out your entire infrastructure

before you even have a chance to react. For this workspace, there's nothing to worry about because we aren't creating "real" infrastructure.

Returning to the command line, enter `yes` at the prompt to approve the manual confirmation step. Your output will be as follows:

```
$ terraform apply
...
  Enter a value: yes

local_file.literature: Creating...
local_file.literature: Creation complete after 0s [id=df1bf9d6-c6cf-f9cb-
34b7-dc0ba10d5a1d]

Apply complete! Resources: 1 added, 0 changed, 0 destroyed.
```

Two files were created as a result of this command: art_of_war.txt and terraform .tfstate. Your current directory (excluding hidden files) is now as follows:

```
.
├── art_of_war.txt
├── main.tf
└── terraform.tfstate
```

The terraform.tfstate file you see here is the state file that Terraform uses to keep track of the resources it manages. It's used to perform diffs during the `plan` and detect configuration drift. Here's what the current state file looks like.

Listing 2.2 terraform.tfstate

```
{
  "version": 4,
  "terraform_version": "0.15.0",
  "serial": 1,
  "lineage": "df1bf9d6-c6cf-f9cb-34b7-dc0ba10d5a1d",
  "outputs": {},
  "resources": [
    {
      "mode": "managed",
      "type": "local_file",
      "name": "literature",
      "provider": "provider[\"registry.terraform.io/hashicorp/local\"]",
      "instances": [
        {
          "schema_version": 0,
          "attributes": {
            "content": "Sun Tzu said: The art of war is of vital importance
to the State.\n\nIt is a matter of life and death, a road either to safety
or to \nruin. Hence it is a subject of inquiry which can on no account
be\nneglected.\n",
            "content_base64": null,
            "directory_permission": "0777",
            "file_permission": "0777",
            "filename": "art_of_war.txt",
```

Metadata about Terraform run

Resource state data

```
            "id": "907b35148fa2bce6c92cba32410c25b06d24e9af",
            "sensitive_content": null,
            "source": null
          },
          "sensitive_attributes": [],
          "private": "bnVsbA=="
        }
      ]
    }
  ]
}
```

WARNING It's important not to edit, delete, or otherwise tamper with the terraform.tfstate file, or Terraform could potentially lose track of the resources it manages. It is possible to restore a corrupted or missing state file, but doing so is difficult and time-consuming.

We can verify that art_of_war.txt matches what we expect by `cat`-ing the file. The command and output are as follows:

```
$ cat art_of_war.txt
Sun Tzu said: The art of war is of vital importance to the State.

It is a matter of life and death, a road either to safety or to
ruin. Hence it is a subject of inquiry which can on no account be
neglected.
```

How did Terraform create this file? During the `apply`, Terraform called `Create()` on `local_file` (see figure 2.6).

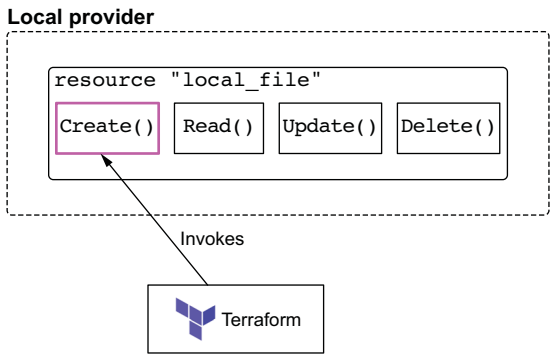


Figure 2.6 Calling `Create()` on `local_file` during `terraform apply`

To give you an idea of what `Create()` does, the following listing shows the source code from the provider.

NOTE Relax and don't worry about understanding the code just yet. We will examine the inner workings of providers in chapter 11.

Listing 2.3 Local file create

```
func resourceLocalFileCreate(d *schema.ResourceData, _ interface{}) error {
  content, err := resourceLocalFileContent(d)
  if err != nil {
    return err
  }

  destination := d.Get("filename").(string)

  destinationDir := path.Dir(destination)
  if _, err := os.Stat(destinationDir); err != nil {
    dirPerm := d.Get("directory_permission").(string)
    dirMode, _ := strconv.ParseInt(dirPerm, 8, 64)
    if err := os.MkdirAll(destinationDir, os.FileMode(dirMode)); err != nil {
      return err
    }
  }

  filePerm := d.Get("file_permission").(string)

  fileMode, _ := strconv.ParseInt(filePerm, 8, 64)

  if err := ioutil.WriteFile(destination, []byte(content),
     os.FileMode(fileMode));
     ➥ err != nil {
    return err
  }

  checksum := sha1.Sum([]byte(content))
  d.SetId(hex.EncodeToString(checksum[:]))

  return nil
}
```

2.6 Performing No-Op

Terraform can read existing resources to ensure that they are in a desired configuration state. One way to do this is by running `terraform plan`. When `terraform plan` is run, Terraform calls `Read()` on each resource in the state file. Since our state file has only one resource, Terraform calls `Read()` on just `local_file`. Figure 2.7 shows what this looks like.

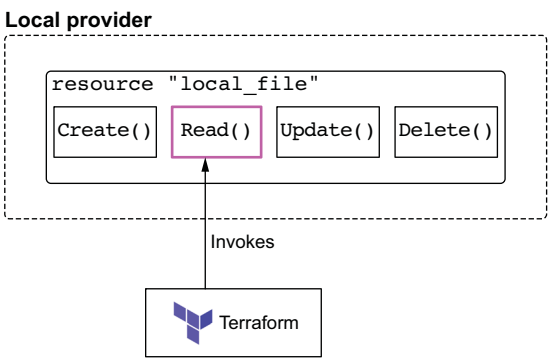


Figure 2.7 Terraform plan calls `Read()` on the `local_file` resource.

Let's run `terraform plan` now:

```
$ terraform plan
local_file.literature: Refreshing state...
[id=907b35148fa2bce6c92cba32410c25b06d24e9af]

No changes. Infrastructure is up-to-date.

That Terraform did not detect any differences between your configuration
and the remote system(s). As a result, there are no actions to take.
```

There are no changes, as we would expect. When a `Read()` returns no changes, the resulting action is a no-operation (no-op). This is shown in figure 2.8.

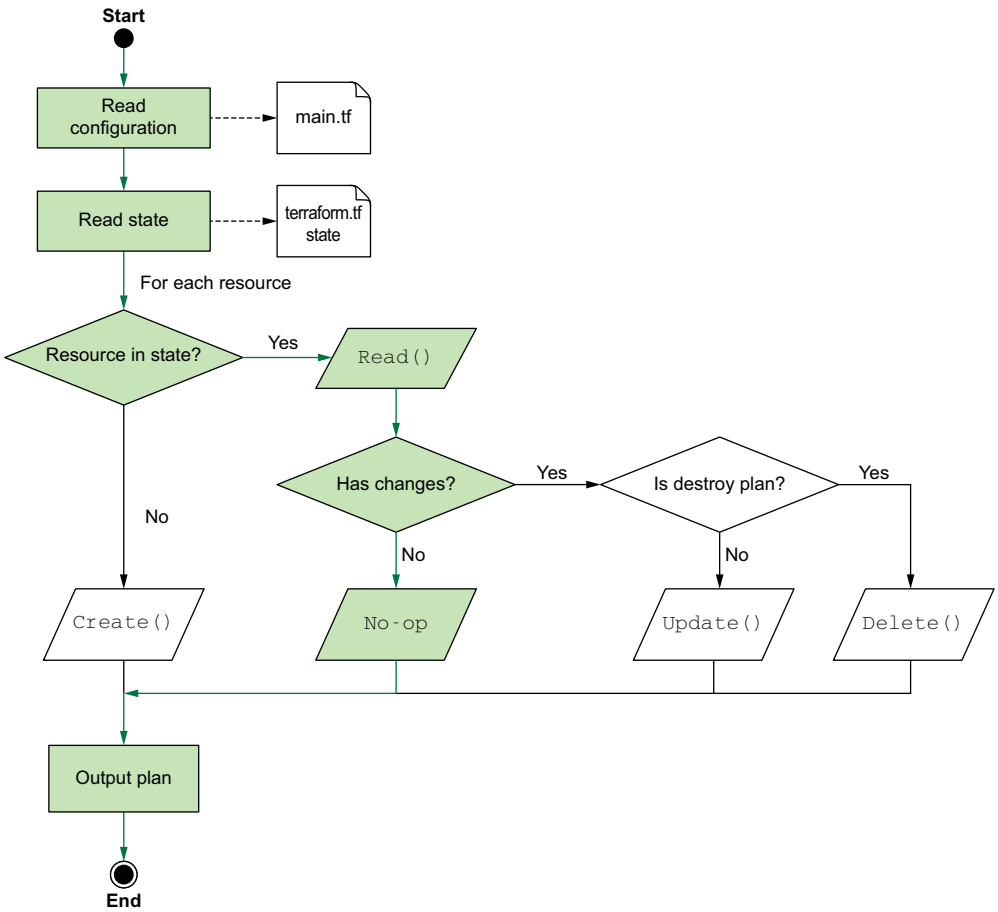


Figure 2.8 Steps that Terraform performs when generating an execution plan for an existing deployment already in the desired state

Finally, here is the code from the provider that is performing `Read()`. Again, don't worry about understanding it completely.

Listing 2.4 Local file read

```
func resourceLocalFileRead(d *schema.ResourceData, _ interface{}) error {
    // If the output file doesn't exist, mark the resource for creation.
    outputPath := d.Get("filename").(string)
    if _, err := os.Stat(outputPath); os.IsNotExist(err) {
        d.SetId("")
        return nil
    }

    // Verify that the content of the destination file matches the content we
    // expect. Otherwise, the file might have been modified externally and we
    // must reconcile.
    outputContent, err := ioutil.ReadFile(outputPath)
    if err != nil {
        return err
    }

    outputChecksum := sha1.Sum([]byte(outputContent))
    if hex.EncodeToString(outputChecksum[:]) != d.Id() {
        d.SetId("")
        return nil
    }

    return nil
}
```

2.7 Updating the local file resource

You know what's better than having a file containing the first two stanzas of *The Art of War*? Having a file containing the first *four* stanzas of *The Art of War*! Updates are integral to Terraform, and it's important to understand how they work. Update your main.tf code to look like the following listing.

Listing 2.5 main.tf

```
terraform {
  required_version = ">= 0.15"
  required_providers {
    local = {
      source  = "hashicorp/local"
      version = "~> 2.0"
    }
  }
}

resource "local_file" "literature" {
  filename = "art_of_war.txt"
  content     = <<-EOT
    Sun Tzu said: The art of war is of vital importance to the State.
```

```
    It is a matter of life and death, a road either to safety or to
    ruin. Hence it is a subject of inquiry which can on no account be
    neglected.

    The art of war, then, is governed by five constant factors, to be
    taken into account in one's deliberations, when seeking to
    determine the conditions obtaining in the field.

    These are: (1) The Moral Law; (2) Heaven; (3) Earth; (4) The
    Commander; (5) Method and discipline.
  EOT
}
```

Adding two additional stanzas

There isn't a special command for performing an update; all that needs to happen is a `terraform apply`. Before we do that, though, let's run `terraform plan` to see what the generated execution plan looks like. The command and output are as follows:

```
$ terraform plan
local_file.literature: Refreshing state...
     [id=907b35148fa2bce6c92cba32410c25b06d24e9af]

Terraform used the selected providers to generate the following execution
     plan.
Resource actions are indicated with the following symbols:
-/+ destroy and then create replacement

Terraform will perform the following actions:

  # local_file.literature must be replaced
-/+ resource "local_file" "literature" {
      ~ content              = <<-EOT # forces replacement
            Sun Tzu said: The art of war is of vital importance to the State.

            It is a matter of life and death, a road either to safety or to
            ruin. Hence it is a subject of inquiry which can on no account be
            neglected.
          +
          + The art of war, then, is governed by five constant factors, to be
          + taken into account in one's deliberations, when seeking to
          + determine the conditions obtaining in the field.
          +
          + These are: (1) The Moral Law; (2) Heaven; (3) Earth; (4) The
          + Commander; (5) Method and discipline.
        EOT
      ~ id                   = "907b35148fa2bce6c92cba32410c25b06d24e9af"
-> (known after apply)
        # (3 unchanged attributes hidden)
    }

Plan: 1 to add, 0 to change, 1 to destroy.

------------------------------------------------------------------------

Note: You didn't use the -out option to save this plan, so Terraform can't
guarantee to take exactly these actions if you run "terraform apply" now.
```

Read() happens first.

Force new re-creates the resource.

As you can see, Terraform has noticed that we altered the `content` attribute and is therefore proposing to destroy the old resource and create a new resource in its stead. This is done rather than updating the attribute in place because `content` is marked as a *force new attribute*, which means if you change it, the whole resource is tainted. To achieve the new desired state, Terraform must re-create the resource from scratch. This is a classic example of immutable infrastructure, although not all attributes of managed Terraform resources behave like this. In fact, most resources have regular in-place (i.e. mutable) updates. The difference between mutable and immutable updates is shown in figure 2.9.

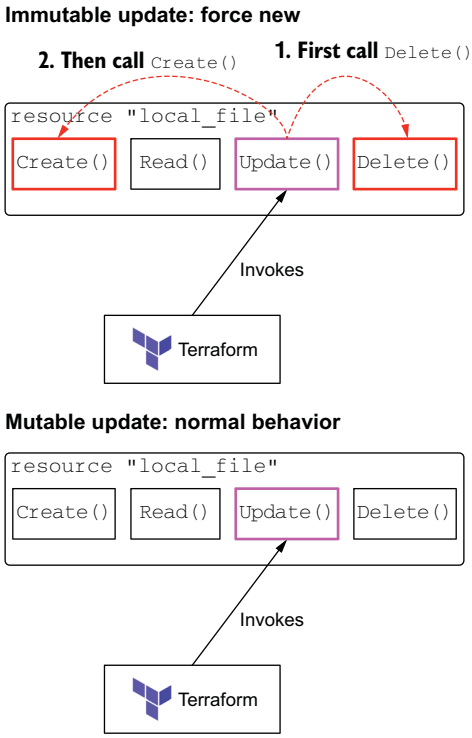


Figure 2.9 Difference between immutable and mutable updates

"Force new" updates sound terrifying!

Although destroying and re-creating tainted infrastructure may sound disturbing at first, `terraform plan` will always let you know what Terraform is going to do ahead of time, so it will never come as a surprise. Furthermore, Terraform is great at creating repeatable environments, so re-creating a single piece of infrastructure is not a problem. The only potential issue is if there is downtime for your service. If you absolutely cannot tolerate any downtime, then stick around for chapter 9 when we cover how to perform zero-downtime deployments with Terraform.

The flow chart for the execution plan is shown in figure 2.10.

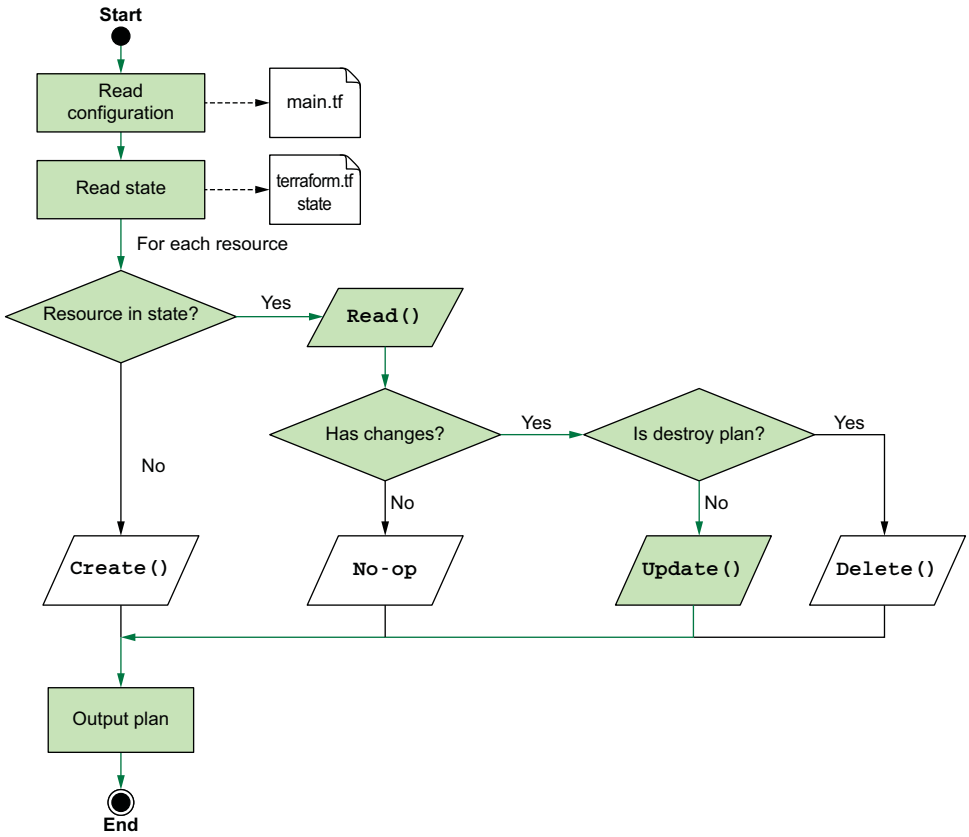


Figure 2.10 Steps that Terraform performs when generating an execution plan for an update

Go ahead and apply the proposed changes from the execution plan by running the command `terraform apply -auto-approve`. The optional `-auto-approve` flag tells Terraform to skip the manual approval step and immediately apply changes:

```
$ terraform apply -auto-approve
local_file.literature: Refreshing state...
     [id=907b35148fa2bce6c92cba32410c25b06d24e9af]
local_file.literature: Destroying...
     [id=907b35148fa2bce6c92cba32410c25b06d24e9af]
local_file.literature: Destruction complete after 0s
local_file.literature: Creating...
local_file.literature: Creation complete after 0s
     [id=657f681ea1991bc54967362324b5cc9e07c06ba5]

Apply complete! Resources: 1 added, 0 changed, 1 destroyed.
```

WARNING `-auto-approve` can be dangerous if you have not already reviewed the results of the plan.

You can verify that the file is now up to date by `cat`-ing the file once more. The command and output are as follows:

```
$ cat art_of_war.txt
Sun Tzu said: The art of war is of vital importance to the State.

It is a matter of life and death, a road either to safety or to
ruin. Hence it is a subject of inquiry which can on no account be
neglected.

The art of war, then, is governed by five constant factors, to be
taken into account in one's deliberations, when seeking to
determine the conditions obtaining in the field.

These are: (1) The Moral Law; (2) Heaven; (3) Earth; (4) The
Commander; (5) Method and discipline.
```

2.7.1 Detecting configuration drift

So far, we've been able to create and update a text file resource. But what happens if there are ad hoc changes to the file through means outside of Terraform? Configuration drift is a common occurrence in situations where multiple privileged users are on the same file system. If you have cloud-based resources, this is equivalent to someone making point-and-click changes to deployed infrastructure in the console. How does Terraform deal with configuration drift? By calculating the difference between the current state and the desired state and performing an update.

We can simulate configuration drift by directly modifying art_of_war.txt. In this file, replace all occurrences of "Sun Tzu" with "Napoleon".

The contents of our art_of_war.txt file will now be

```
Napoleon said: The art of war is of vital importance to the
State.

It is a matter of life and death, a road either to safety or to
ruin. Hence it is a subject of inquiry which can on no account be
neglected.

The art of war, then, is governed by five constant factors, to be
taken into account in one's deliberations, when seeking to
determine the conditions obtaining in the field.

These are: (1) The Moral Law; (2) Heaven; (3) Earth; (4) The
Commander; (5) Method and discipline.
```

This misquote is patently untrue, so we'd like Terraform to detect that configuration drift has occurred and fix it. Run `terraform plan` to see what Terraform has to say for itself:

```
$ terraform plan
local_file.literature: Refreshing state...
     [id=657f681ea1991bc54967362324b5cc9e07c06ba5]

Terraform used the selected providers to generate the following execution
     plan.
Resource actions are indicated with the following symbols:
  + create

Terraform will perform the following actions:

  # local_file.literature will be created
  + resource "local_file" "literature" {
      + content              = <<-EOT
            Sun Tzu said: The art of war is of vital importance to the State.

            It is a matter of life and death, a road either to safety or to
            ruin. Hence it is a subject of inquiry which can on no account be
            neglected.

            The art of war, then, is governed by five constant factors, to be
            taken into account in one's deliberations, when seeking to
            determine the conditions obtaining in the field.

            These are: (1) The Moral Law; (2) Heaven; (3) Earth; (4) The
            Commander; (5) Method and discipline.
        EOT
      + directory_permission = "0777"
      + file_permission      = "0777"
      + filename             = "art_of_war.txt"
      + id                   = (known after apply)
    }

Plan: 1 to add, 0 to change, 0 to destroy.

------------------------------------------------------------------------

Note: You didn't use the -out option to save this plan, so Terraform can't
guarantee to take exactly these actions if you run "terraform apply" now.
```

This is suprising!

Wait, what just happened? Terraform appears to have forgotten that the resource it manages even exists and is therefore proposing to create a new resource. In fact, Terraform has not forgotten that the resource it manages exists—the resource is still present in the state file, and you can verify by running `terraform show`:

```
$ terraform show
# local_file.literature:
resource "local_file" "literature" {
    content              = <<-EOT
        Sun Tzu said: The art of war is of vital importance to the State.

        It is a matter of life and death, a road either to safety or to
        ruin. Hence it is a subject of inquiry which can on no account be
        neglected.
```

```
        The art of war, then, is governed by five constant factors, to be
        taken into account in one's deliberations, when seeking to
        determine the conditions obtaining in the field.

        These are: (1) The Moral Law; (2) Heaven; (3) Earth; (4) The
        Commander; (5) Method and discipline.
    EOT
    directory_permission = "0777"
    file_permission      = "0777"
    filename             = "art_of_war.txt"
    id                   = "657f681ea1991bc54967362324b5cc9e07c06ba5"
}
```

The surprising outcome of `terraform plan` is merely the result of the provider choosing to do something a little odd with the way `Read()` was implemented. I don't know why the provider chose to do it that way, but the provider decided that if the file contents don't exactly match what's in the state file, then the resource no longer exists. The consequence is that Terraform thinks the resource no longer exists, even though there's still a file with the same name. It won't make a difference when the `apply` happens because the existing file will be overridden, but is surprising nonetheless.

2.7.2 Terraform refresh

How can we fix configuration drift? Well, Terraform automatically fixes it if you run `terraform apply`, but let's not do that right away. For now, let's have Terraform reconcile the state that it knows about with what is currently deployed. This can be done with `terraform refresh`.

You can think of `terraform refresh` like a `terraform plan` that also alters the state file. It's a read-only operation that does not modify managed existing infrastructure—just Terraform state.

Returning to the command line, run `terraform refresh` to reconcile the Terraform state:

```
$ terraform refresh
local_file.literature: Refreshing state...
     [id=657f681ea1991bc54967362324b5cc9e07c06ba5]
```

Now, if you run `terraform show`, you can see that the state file has been updated:

```
$ terraform show
```

However, nothing is returned because this is part of the weirdness of how `local_file` works (it thinks the old file no longer exists). At least it is now consistent.

> **NOTE** I rarely find `terraform refresh` useful, but some people really like it.

Returning to the command line, we can correct the art_of_war.txt file with `terraform apply`:

```
$ terraform apply -auto-approve
local_file.literature: Creating...
local_file.literature: Creation complete after 0s
     [id=657f681ea1991bc54967362324b5cc9e07c06ba5]

Apply complete! Resources: 1 added, 0 changed, 0 destroyed.
```

Now the contents of art_of_war.txt have been restored to what they should be. If this was a cloud-based resource provisioned in Amazon Web Services (AWS), Google Cloud Platform (GCP), or Azure, any point-and-click changes made in the console would be gone at this point. You can verify that the file was successfully restored by `cat`-ing the file once more:

```
$ cat art_of_war.txt
Sun Tzu said: The art of war is of vital importance to the State.

It is a matter of life and death, a road either to safety or to
ruin. Hence it is a subject of inquiry which can on no account be
neglected.

The art of war, then, is governed by five constant factors, to be
taken into account in one's deliberations, when seeking to
determine the conditions obtaining in the field.

These are: (1) The Moral Law; (2) Heaven; (3) Earth; (4) The
Commander; (5) Method and discipline.
```

2.8 Deleting the local file resource

Our *Art of War* file has served us well, but now it's time to say goodbye. Let's clean up by running `terraform destroy`:

```
$ terraform destroy -auto-approve
local_file.literature: Refreshing state...
     [id=657f681ea1991bc54967362324b5cc9e07c06ba5]
local_file.literature: Destroying...
     [id=657f681ea1991bc54967362324b5cc9e07c06ba5]
local_file.literature: Destruction complete after 0s

Destroy complete! Resources: 1 destroyed.
```

> **NOTE** The optional flag `-auto-approve` for `terraform destroy` is exactly the same as for `terraform apply`; it automatically approves the result of the execution plan.

The `terraform destroy` command first generates an execution plan as if there were no resources in the configuration files by performing a `Read()` on each resource and marking all existing resources for deletion. This can be seen in figure 2.11.

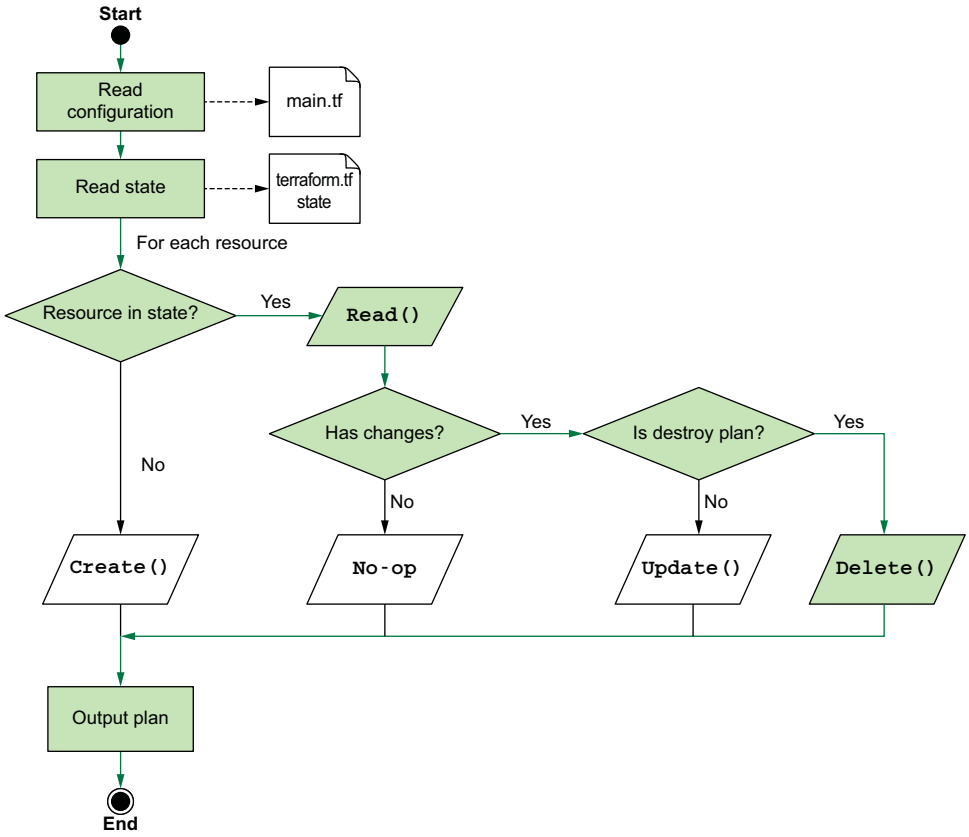


Figure 2.11 Steps that Terraform performs when generating an execution plan for a delete

During the actual execution of the `destroy` operation, Terraform invokes `Delete()` on each resource in the state file. Again, since there's only one resource in the state file, Terraform effectively just calls `Delete()` on `local_file`. This is illustrated in figure 2.12.

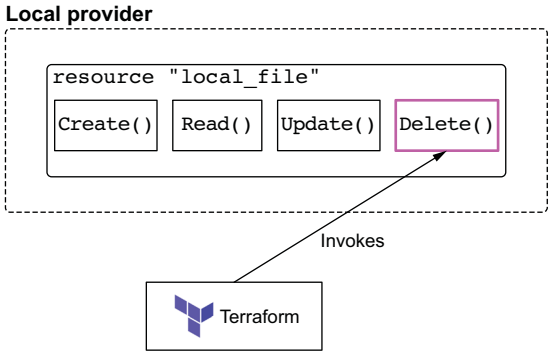


Figure 2.12 Terraform destroy calls `Delete()` on each resource in the state file.

So now the art_of_war.txt file has been deleted. The current directory is the following:

```
.
├── main.tf
├── terraform.tfstate
└── terraform.tfstate.backup
```

> **NOTE** Deleting all configuration files and running `terraform apply` is equivalent to `terraform destroy`.

Although it's gone, its memory lives on in a new file, `terraform.tfstate.backup`. This backup file is a copy of the previous state file and is there for purely archival purposes. This file typically is not needed and can be safely deleted if you wish, but I usually leave it be. Our current state file is empty (as far as Terraform is concerned) and is shown next.

Listing 2.6 terraform.tfstate

```
{
  "version": 4,
  "terraform_version": "0.15.0",
  "serial": 9,
  "lineage": "df1bf9d6-c6cf-f9cb-34b7-dc0ba10d5a1d",
  "outputs": {},
  "resources": []
}
```

Finally, for your personal edification, here is the `Delete()` code from the Local provider (it's quite simple).

Listing 2.7 Local file delete

```
func resourceLocalFileDelete(d *schema.ResourceData, _ interface{}) error {
    os.Remove(d.Get("filename").(string))
    return nil
}
```

2.9 Fireside chat

In this chapter, we dove into the internals of Terraform, how it works, how it provisions infrastructure, and how it calculates diffs. Terraform is fundamentally a state management tool for performing CRUD operations on managed resources. This can seem perplexing in the context of the cloud, which is already magic, but it's not as difficult as it appears. Terraform uses the same APIs you would use if you were writing an automation script to deploy infrastructure. The difference is that Terraform doesn't just deploy infrastructure: Terraform manages it. Terraform intrinsically understands dependencies between resources and can even detect and correct for configuration drift. Terraform is a simple state management engine. The value of Terraform derives mainly from the many providers that are published and available on the Terraform

Registry. In the next chapter, we look at two new such providers: the Random and Archive providers for Terraform.

Summary

- The Local provider for Terraform allows you to create and manage text files on your machine. This is normally used to glue together "real" infrastructure but can also be useful by itself as a teaching aid.
- Resources are created in a certain sequence as dictated by the execution plan. The sequence is calculated automatically based on implicit dependencies.
- Each managed resource has life cycle function hooks associated with it: `Create()`, `Read()`, `Update()`, and `Delete()`. Terraform invokes these function hooks as part of its normal operations.
- Changing Terraform configuration code and running `terraform apply` will update an existing managed resource. You can also use `terraform refresh` to update the state file based on what is currently deployed.
- Terraform reads the state file during a plan to decide what actions to take during an `apply`. It's important not to lose the state file, or Terraform will lose track of all the resources it's managing.

3 Functional programming

This chapter covers

- Using the full gamut of input variables, local values, and output values
- Making Terraform more expressive with functions and for expressions
- Incorporating two new providers: Random and Archive
- Templating with `templatefile()`
- Scaling resources with `count`

Functional programming is a declarative programming paradigm that allows you to do many things in a single line of code. By composing small modular functions, you can tell a computer *what* you want it to do instead of *how* to do it. Functional programming is called that because, as the name implies, programs consist almost entirely of functions. The core principles of functional programming are as follows:

- *Pure functions*—Functions return the same value for the same arguments, never having any side effects.

- *First-class and higher-order functions*—Functions are treated like any other variables and can be saved, passed around, and used to create higher-order functions.
- *Immutability*—Data is never directly modified. Instead, new data structures are created each time data would change.

To give you an idea of the difference between procedural and functional programming, here is some procedural JavaScript code that multiples all even numbers in an array by 10 and adds the results together:

```
const numList = [1, 2, 3, 4, 5, 6, 7, 8, 9, 10]
let result = 0;
for (let i = 0; i < numList.length; i++) {
  if (numList[i] % 2 === 0) {
    result += (numList[i] * 10)
  }
}
```

And here is the same problem solved with functional programming (JavaScript)

```
const numList = [1, 2, 3, 4, 5, 6, 7, 8, 9, 10]
const result = numList
               .filter(n => n % 2 === 0)
               .map(a => a * 10)
               .reduce((a, b) => a + b)
```

and in Terraform:

```
locals {
  numList = [0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10]
  result  = sum([for x in local.numList : 10 * x if x % 2 == 0])
}
```

Although you may not consider yourself a programmer, it's still important to grasp the basics of functional programming. Terraform does not directly support procedural programming, so any logic you want to express needs to be declarative and functional. In this chapter, we take a deep dive into functions, expressions, templates, and other dynamics features that make up the Terraform language.

3.1 Fun with Mad Libs

The specific scenario we will look at builds a program that generates Mad Libs paragraphs from template files. Mad Libs, in case you aren't aware, is a phrasal templating word game in which one player prompts another for words to fill in the blanks of a story. An example input is shown here:

> *To make a pizza, you need to take a lump of <noun> and make a thin, round, <adjective> <noun>.*

For the given template string, a random noun, an adjective, and another noun will be selected to fill in the placeholders. An example output would therefore be as follows:

To make a pizza, you need to take a lump of roses and make a thin, round, colorful jewelry.

Let's start by generating a single Mad Libs story. To do that, we need a randomized pool of words to select from, and a template file. The rendered content will then be printed to the CLI. An architecture diagram for what we're about to do is shown in figure 3.1.

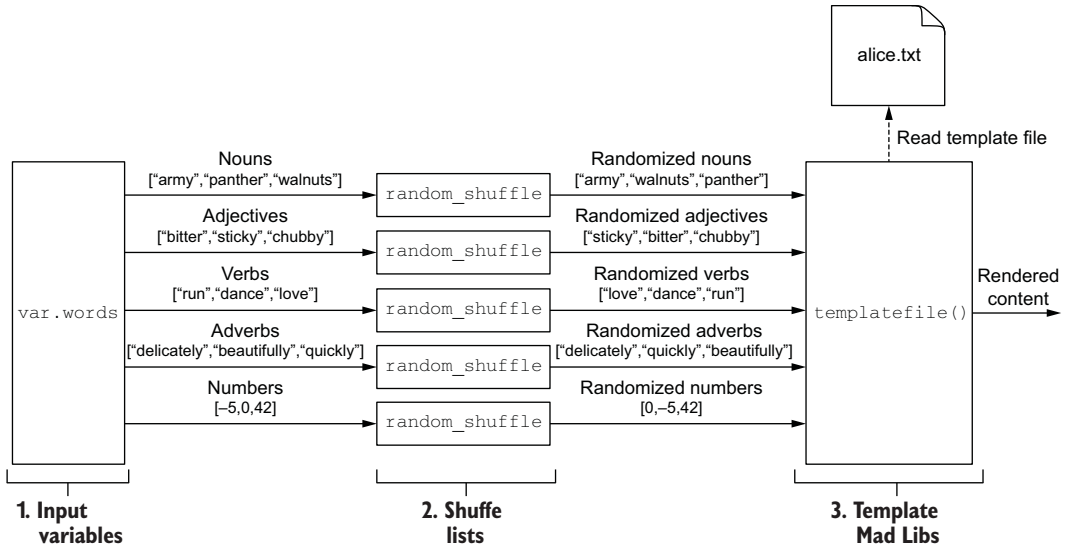


Figure 3.1 Architecture diagram of the Mad Libs template engine

3.1.1 Input variables

First, we need to create the word pool. That means we need to talk about input variables—what they are, how they are declared, and how they can be set and validated.

Input variables (or *Terraform variables*, or just *variables*) are user-supplied values that parametrize Terraform modules without altering the source code. Variables are declared with a variable block, which is an HCL object with two labels. The first label indicates the object type, which is `variable`, and the second is the variable's name. A variable's name can be almost anything, as long as it is unique within a given module and not a reserved identifier. Figure 3.2 shows the syntax of a variable block.

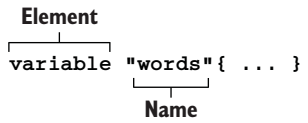


Figure 3.2 Syntax of a variable

Variable blocks accept four input arguments:

- `default`—A preselected option to use when no alternative is available. Leaving this argument blank means a variable is mandatory and must be explicitly set.

- `description`—A string value providing helpful documentation to the user.
- `type`—A type constraint to set for the variable. Types can be either primitive (e.g. string, integer, bool) or complex (e.g. list, set, map, object, tuple).
- `validation`—A nested block that can enforce custom validation rules.

NOTE Variable values can be accessed within a given module by using the expression `var.<VARIABLE_NAME>`.

For this scenario, we could define a separate variable for each particle of speech, such as nouns, adjectives, verbs, etc. If we did that, our code would look like this:

```
variable "nouns" {
  description = "A list of nouns"
  type        = list(string)
}

variable "adjectives" {
  description = "A list of adjectives"
  type        = list(string)
}

variable "verbs" {
  description = "A list of verbs"
  type        = list(string)
}

variable "adverbs" {
  description = "A list of adverbs"
  type        = list(string)
}

variable "numbers" {
  description = "A list of numbers"
  type        = list(number)
}
```

Although this code is clear, we'll instead group the variables into a single complex variable because then later we can iterate over the words using a `for` expression.

Create a new project workspace for your Terraform configuration, and make a new file called madlibs.tf. Add in the following code.

Listing 3.1 madlibs.tf

```
terraform {
  required_version = ">= 0.15"
}

variable "words" {
  description = "A word pool to use for Mad Libs"
  type = object({
    nouns      = list(string),
    adjectives = list(string),
```

Terraform settings block

Any set value must be coercible into this complex type.

```
    verbs      = list(string),
    adverbs    = list(string),
    numbers    = list(number),
  })
}
```

Type coercion: How everything you know and love is a string

The type of object key `numbers` in `var.words` could be `list(string)` instead of `list(number)` because of type coercion. *Type coercion* is the ability to convert any primitive type in Terraform to its string representation. For example, boolean `true` and `false` are converted to `"true"` and `"false"`, while numbers are similarly converted (e.g. `17` to `"17"`).

Many people are not aware that type coercion exists, because it happens so seamlessly. In fact, type coercion occurs whenever you perform string interpolation without explicitly casting the value to a string with `tostring()`. It's important to be aware of type coercion because accidently coercing a value into a string changes the result of certain calculations (for example, the expression `17=="17"` returns `false` instead of `true`).

3.1.2 Assigning values with a variable definition file

Assigning variable values with the `default` argument is not a good idea because doing so does not facilitate code reuse. A better way to set variable values is with a variables definition file, which is any file ending in either .tfvars or .tfvars.json. A variables definition file uses the same syntax as Terraform configuration code but consists exclusively of variable assignments.

Create a new file in the workspace called terraform.tfvars, and add the following code.

Listing 3.2 terraform.tfvars

```
words = {
  nouns      = ["army", "panther", "walnuts", "sandwich", "Zeus", "banana",
  ➥ "cat", "jellyfish", "jigsaw", "violin", "milk", "sun"]
  adjectives = ["bitter", "sticky", "thundering", "abundant", "chubby",
  ➥  "grumpy"]
  verbs      = ["run", "dance", "love", "respect", "kicked", "baked"]
  adverbs    = ["delicately", "beautifully", "quickly", "truthfully",
  ➥ "wearily"]
  numbers    = [42, 27, 101, 73, -5, 0]
}
```

3.1.3 Validating variables

Input variables can be validated with custom rules by declaring a nested `validation` block. To validate that at least 20 nouns are passed into `var.words`, you can write a `validation` block:

```
variable "words" {
  description = "A word pool to use for Mad Libs"
  type = object({
    nouns      = list(string),
    adjectives = list(string),
    verbs      = list(string),
    adverbs    = list(string),
    numbers    = list(number),
  })

  validation {
    condition     = length(var.words["nouns"]) >= 20
    error_message = "At least 20 nouns must be supplied."
  }
}
```

The condition argument in `validation` is an expression that determines whether a variable is valid. `true` means it's valid, while `false` means invalid. Invalid expressions will exit with an error, and the error message `error_message` will be displayed to the user. Here is an example from the user's perspective:

```
Error: Invalid value for variable

  on madlibs.tf line 5:
   5: variable "words" {

At least 20 nouns must be supplied.

This was checked by the validation rule at madlibs.tf:14,1-11.
```

TIP There is no limit to the number of `validation` blocks you can have on a variable, allowing you to be as fine-grained with validation as you like.

3.1.4 Shuffling lists

Now that we have words in our word pool, the next step is to shuffle them. If we don't shuffle the lists, the order will be fixed, which means exactly the same Mad Libs paragraph would be generated on each execution. Nobody wants to read the same Mad Libs story over and over again, because where is the fun in that? You might expect there to be a function called `shuffle()` that would shuffle a generic list, but there isn't. It's lacking because Terraform strives to be a functional programming language, which means all functions (with the exception of two) are pure functions. *Pure functions* return the same result for a given set of input arguments and do not cause any additional side effects. `shuffle()` cannot be allowed because generated execution plans would be unstable, never converging on a fixed configuration.

NOTE `uuid()` and `timestamp()` are the only two impure Terraform functions. These are legacy functions that should be avoided whenever possible because of their potential for introducing subtle bugs and because they are likely to be deprecated at some point.

The Random provider for Terraform introduces a `random_shuffle` resource for safely shuffling lists, so that's what we'll use. Since we have five lists, we need five `random_shuffle`s. This is illustrated in figure 3.3.

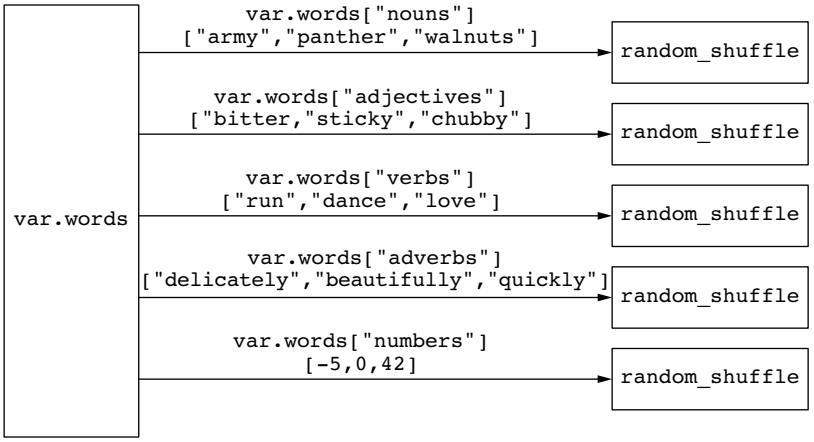


Figure 3.3 Shuffling lists of strings from `var.words`

Randomness within limits

The Random provider allows for constrained randomness within Terraform configurations and is great for generating random strings, uuids, and even pet names. It's also helpful for preventing namespace collisions of Terraform resources and generating dynamic secrets like usernames and database passwords. A word of caution: if you do use the Random provider to generate dynamic secrets, be sure not to hardcode a seed, and be sure to secure your state and plan files. We talk more about how to do this in chapter 13.

Paste the code from the next listing into madlibs.tf to shuffle the words.

Listing 3.3 madlibs.tf

```
terraform {
  required_version = ">= 0.15"
  required_providers {
    random = {
      source  = "hashicorp/random"
      version = "~> 3.0"
    }
  }
}
```

```
variable "words" {
  description = "A word pool to use for Mad Libs"
  type = object({
    nouns      = list(string),
    adjectives = list(string),
    verbs      = list(string),
    adverbs    = list(string),
    numbers    = list(number),
  })
}

resource "random_shuffle" "random_nouns" {
  input = var.words["nouns"]
}

resource "random_shuffle" "random_adjectives" {
  input = var.words["adjectives"]
}

resource "random_shuffle" "random_verbs" {
  input = var.words["verbs"]
}

resource "random_shuffle" "random_adverbs" {
  input = var.words["adverbs"]
}

resource "random_shuffle" "random_numbers" {
  input = var.words["numbers"]
}
```

A new shuffled list is generated from the input list.

3.1.5 Functions

We'll use the randomized list of words to replace placeholder values in a template file, rendering content for a new Mad Libs story. The built-in `templatefile()` functions allows us to do this easily. Terraform *functions* are expressions that transform inputs into outputs. Unlike other programming languages, Terraform does not have support for user-defined functions, nor is there a way to import functions from external libraries. Instead, you are restricted to the roughly 100 functions built in to the Terraform language. That's a lot for a declarative programming language but almost nothing compared to traditional programming languages.

> **NOTE** You extend Terraform by writing your own provider, not by writing new functions.

Returning to the problem at hand, figure 3.4 shows the `templatefile()` syntax more closely.

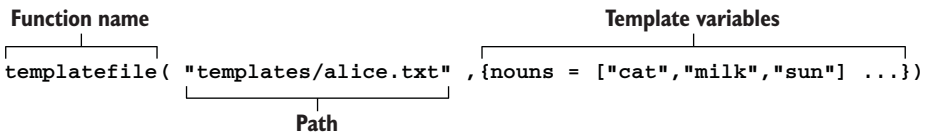


Figure 3.4 Syntax of `templatefile()`

As you can see, `templatefile()` accepts two arguments: a path to the template file and a map of template variables to be rendered. We'll construct the map of template variables by aggregating together the lists of shuffled words (see figure 3.5).

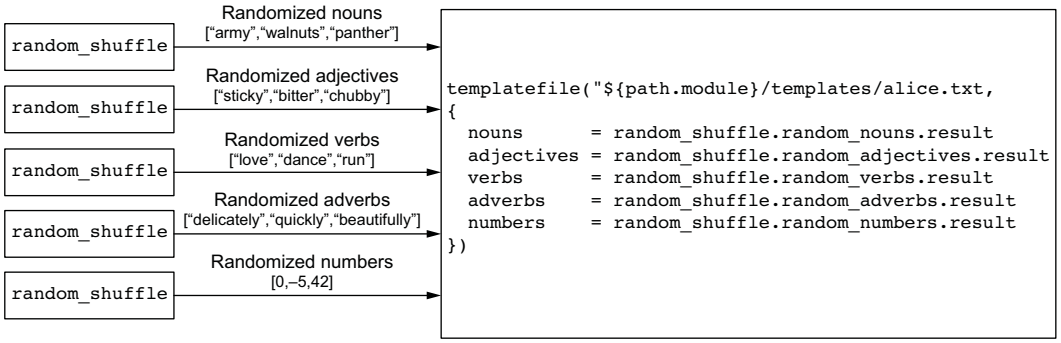


Figure 3.5 Aggregating the lists of shuffled words into a map of template variables

Here's the `templatefile()` code:

```
templatefile("${path.module}/templates/alice.txt",
    {
        nouns=random_shuffle.random_nouns.result
        adjectives=random_shuffle.random_adjectives.result
        verbs=random_shuffle.random_verbs.result
        adverbs=random_shuffle.random_adverbs.result
        numbers=random_shuffle.random_numbers.result
    })
```

3.1.6 Output values

We can return the result of `templatefile()` to the user with an output value. Output values are used to do two things:

- Pass values between modules
- Print values to the CLI

We talk more about passing values between modules in chapter 4; for now, we are interested in printing values to the CLI. The syntax for an output block is shown in figure 3.6.

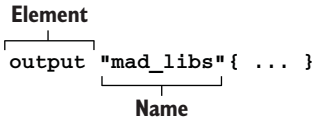


Figure 3.6 Syntax of an output value

Add the output block to madlibs.tf. Your configuration is now as shown in the following listing.

Listing 3.4 madlibs.tf

```
terraform {
  required_version = ">= 0.15"
  required_providers {
    random = {
      source  = "hashicorp/random"
      version = "~> 3.0"
    }
  }
}

variable "words" {
  description = "A word pool to use for Mad Libs"
  type = object({
    nouns      = list(string),
    adjectives = list(string),
    verbs      = list(string),
    adverbs    = list(string),
    numbers    = list(number),
  })
}

resource "random_shuffle" "random_nouns" {
  input = var.words["nouns"]
}

resource "random_shuffle" "random_adjectives" {
  input = var.words["adjectives"]
}

resource "random_shuffle" "random_verbs" {
  input = var.words["verbs"]
}

resource "random_shuffle" "random_adverbs" {
  input = var.words["adverbs"]
}

resource "random_shuffle" "random_numbers" {
  input = var.words["numbers"]
}

output "mad_libs" {
  value = templatefile("${path.module}/templates/alice.txt",
    {
      nouns      = random_shuffle.random_nouns.result
      adjectives = random_shuffle.random_adjectives.result
      verbs      = random_shuffle.random_verbs.result
      adverbs    = random_shuffle.random_adverbs.result
      numbers    = random_shuffle.random_numbers.result
  })
}
```

NOTE `path.module` is a reference to the filesystem path of the containing module.

3.1.7 Templates

The last thing to do is create an alice.txt template file. Template syntax is the same as for interpolation values in the main Terraform language, which is anything enclosed in `${ ... }` markers. String templates allow you to evaluate expressions and coerce the result to a string.

Any expression can be evaluated with template syntax; however, you are restricted by variable scope. Only passed-in template variables are in scope; all other variables and resources—even within the same module—are not.

Let's create the template file now. First, create a new directory called templates to contain template files; in this directory, create an alice.txt file.

> **TIP** Some people like to give template files a .tpl extension to indicate their purpose, but I find this unhelpful and confusing. I recommend giving template files the proper extension for what they actually are.

The next listing shows the contents of alice.txt.

Listing 3.5 alice.txt

```
ALICE'S UPSIDE-DOWN WORLD

Lewis Carroll's classic, "Alice's Adventures in Wonderland", as well
as its ${adjectives[0]} sequel, "Through the Looking ${nouns[0]}",
have enchanted both the young and old ${nouns[1]}s for the last
${numbers[0]} years, Alice's ${adjectives[1]} adventures begin
when she ${verbs[0]}s down a/an ${adjectives[2]} hole and lands
in a strange and topsy-turvy ${nouns[2]}. There she discovers she
can become a tall ${nouns[3]} or a small ${nouns[4]} simply by
nibbling on alternate sides of a magic ${nouns[5]}. In her travels
through Wonderland, Alice ${verbs[1]}s such remarkable
characters as the White ${nouns[6]}, the ${adjectives[3]} Hatter,
the Cheshire ${nouns[7]}, and even the Queen of ${nouns[8]}s.
Unfortunately, Alice's adventures come to a/an ${adjectives[4]}
end when Alice awakens from her ${nouns[8]}.
```

3.1.8 Printing output

We're finally ready to generate our first Mad Libs paragraph. Initialize Terraform by performing a `terraform init`, and then apply these changes:

```
$ terraform init && terraform apply -auto-approve
...
random_shuffle.random_adjectives: Creation complete after 0s [id=-]
random_shuffle.random_numbers: Creation complete after 0s [id=-]
random_shuffle.random_nouns: Creation complete after 0s [id=-]

Apply complete! Resources: 5 added, 0 changed, 0 destroyed.

Outputs:

mad_libs = <<EOT
ALICE'S UPSIDE-DOWN WORLD
```

```
Lewis Carroll's classic, "Alice's Adventures in Wonderland", as well
as its chubby sequel, "Through the Looking sun",
have enchanted both the young and old panthers for the last
0 years, Alice's bitter adventures begin
when she kickeds down a/an thundering hole and lands
in a strange and topsy-turvy army. There she discovers she
can become a tall banana or a small jigsaw simply by
nibbling on alternate sides of a magic Zeus. In her travels
through Wonderland, Alice respects such remarkable
characters as the White walnuts, the sticky Hatter,
the Cheshire milk, and even the Queen of violins.
Unfortunately, Alice's adventures come to a/an abundant
end when Alice awakens from her violin.

EOT
```

NOTE This would be a good place to use `terraform plan` before applying changes.

3.2 Generating many Mad Libs stories

We can generate a single Mad Libs story from a randomized pool of words and output the result to the CLI. But what if we wanted to generate more than one Mad Libs at a time? It's easy to do using expressions and the `count` meta argument.

To accomplish this, we need to make some changes to the original architecture. Here is the list of design changes:

1. Create 100 Mad Libs paragraphs.
2. Use three template files (alice.txt, observatory.txt, and photographer.txt).

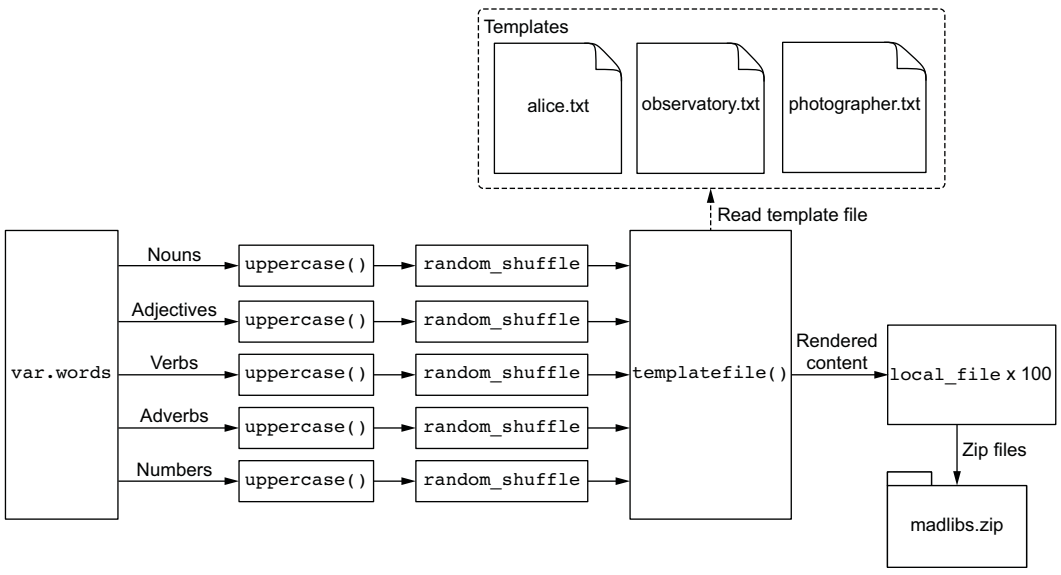


Figure 3.7 Revised architecture for the Mad Libs templating engine

3 Capitalize each word before shuffling.
4 Save the Mad Libs paragraphs as text files.
5 Zip all of them together.

Our revised architecture is shown in figure 3.7.

3.2.1 for expressions

We added a step to uppercase all strings in `var.words` prior to shuffling. This isn't strictly necessary, but it does make it easier to see templated words. The result of the uppercase function is saved into a local value, which is then fed into `random_shuffle`.

To uppercase all the strings in `var.words`, we need to employ a `for` expression. `for` expressions are anonymous functions that can transform one complex type into another. They use lambda-like syntax and are comparable to lambda expressions and streams in conventional programming languages. Figure 3.8 shows the syntax of a `for` expression that uppercases each element in an array of strings and outputs the result as a new list. Figure 3.9 illustrates the processed stream.

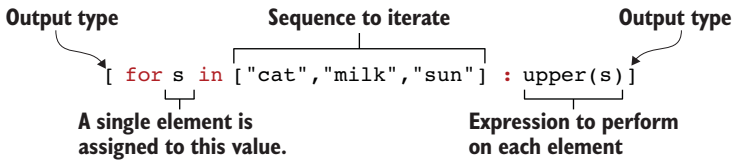


Figure 3.8 Syntax of a `for` expression that uppercases each word in a list

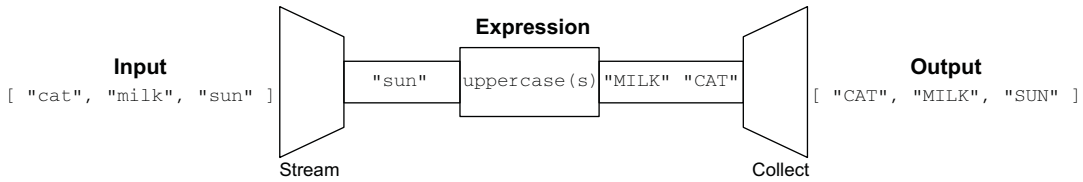


Figure 3.9 Visualization of the `for` expression from figure 3.8

The brackets around a `for` expression determine the output type. The previous code uses `[]`, which means the output will be a list. If instead we used `{}`, then the result would be an object. For example, if we wanted to loop through `var.words` and output a new map with the same key as the original map and a value that is the length of the original value, we could do that with the expression illustrated in figures 3.10 and 3.11.

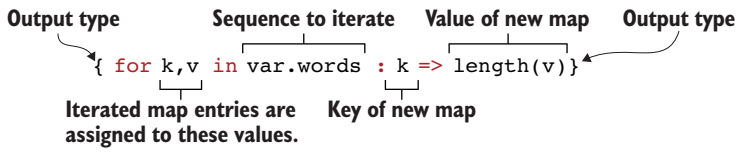


Figure 3.10 Syntax of a `for` expression that iterates over `var.words` and outputs a map

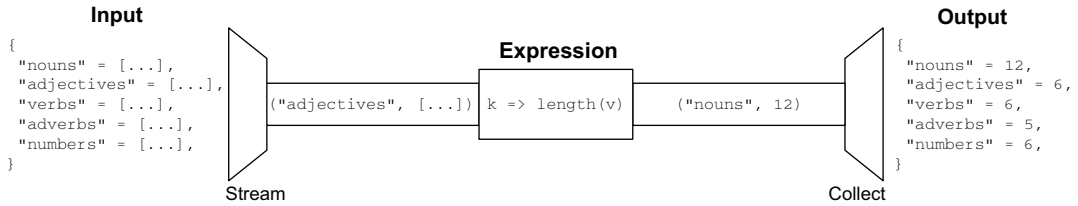


Figure 3.11 Visualization of the `for` expression from figure 3.10

`for` expressions are useful because they can convert one type to another and because simple expressions can be combined to construct higher-order functions. To make a `for` expression that uppercases each word in `var.words`, we will combine two smaller `for` expressions into one *mega* `for` expression.

> **TIP** Composed `for` expressions hurt readability and increases cyclomatic complexity, so try not to overuse them.

The general logic is as follows:

1. Loop through each key-value pair in `var.words`.
2. Uppercase each word in the value list.
3. Save the result to a local value.

Looping through each key-value pair in `var.words` and outputting a new map can be done with the following expression:

```
{for k,v in var.words : k => v }
```

The next expression uppercases each word in a list and outputs to a new list:

```
[for s in v : upper(s)]
```

By combining these two expressions, we get

```
{for k,v in var.words : k => [for s in v : upper(s)]}
```

Optionally, if you want to filter out a particular key, you can do so with the `if` clause. For example, to skip any key that matches `"numbers"`, you could do so with the following expression:

```
{for k,v in var.words : k => [for s in v : upper(s)] if k != "numbers"}
```

NOTE We do not need to skip the `"numbers"` key (even if it makes sense to do so) because `uppercase("1")` is equal to `"1"`, so it's effectively an identity function.

3.2.2 Local values

We can save the result of an expression by assigning to a local value. Local values assign a name to an expression, allowing it to be used multiple times without repetition. In making the comparison with traditional programing languages, if input variables are analogous to a function's arguments and output values are analogous to a function's return values, then local values are analogous to a function's local temporary symbols.

Local values are declared by creating a code block with the label `locals`. The syntax for a `locals` block is shown in figure 3.12.

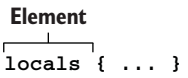


Figure 3.12 Syntax of a local value

Add the new local value to madlibs.tf, and update the reference of all `random_shuffle` resources to point to `local.uppercase_words` instead of `var.words`. The next listing shows how your code should now look.

Listing 3.6 madlibs.tf

```
terraform {
  required_version = ">= 0.15"
  required_providers {
    random = {
      source  = "hashicorp/random"
      version = "~> 3.0"
    }
  }
}

variable "words" {
  description = "A word pool to use for Mad Libs"
  type = object({
    nouns      = list(string),
    adjectives = list(string),
    verbs      = list(string),
    adverbs    = list(string),
    numbers    = list(number),
  })
}

locals {
  uppercase_words = {for k, v in var.words : k => [for s in v : upper(s)]}
}

resource "random_shuffle" "random_nouns" {
  input = local.uppercase_words["nouns"]
}
```

for expression to uppercase strings and save to a local value

```
resource "random_shuffle" "random_adjectives" {
  input = local.uppercase_words["adjectives"]
}

resource "random_shuffle" "random_verbs" {
  input = local.uppercase_words["verbs"]
}

resource "random_shuffle" "random_adverbs" {
  input = local.uppercase_words["adverbs"]
}

resource "random_shuffle" "random_numbers" {
  input = local.uppercase_words["numbers"]
}
```

3.2.3 Implicit dependencies

At this point, it's important to point out that because we're using an interpolated value to set the input attribute of `random_shuffle`, an implicit dependency is created between the two resources. An expression or resource with an implicit dependency won't be evaluated until after the dependency is resolved. In the current workspace, the dependency diagram looks like figure 3.13.

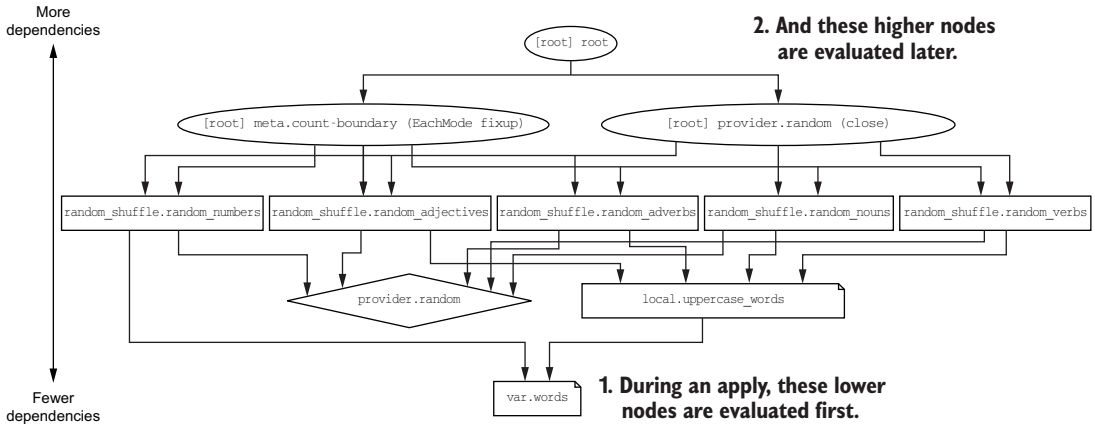


Figure 3.13 Visualizing the dependency graph and execution order

Nodes toward the bottom of the dependency graph have fewer dependencies, while nodes toward the top have more dependencies. At the very top is the root node, which is dependent on all other nodes.

You need to know the following about dependency graphs:

- Cyclical dependencies are not allowed.
- Nodes with zero dependencies are created first and destroyed last.

- You cannot guarantee any ordering between nodes at the same dependency level.

NOTE dependency graphs quickly become confusing when developing non-trivial projects. I do not find them useful except in the academic sense.

3.2.4 count parameter

To make 100 Mad Libs stories, the brute-force way would be to copy our existing code 100 times and call it a day. I wouldn't recommend doing this because it's messy and doesn't scale well. Fortunately, we have better options. For this particular scenario, we'll use the `count` meta argument to dynamically provision resources.

NOTE In chapter 7, we cover `for_each`, which is an alternative to `count`.

Count is a *meta argument*, which means all resources intrinsically support it by virtue of being a Terraform resource. The address of a managed resource uses the format `<RESOURCE TYPE>.<NAME>`. If `count` is set, the value of this expression becomes a *list* of objects representing all possible resource instances. Therefore, we could access the *N*th instance in the list with bracket notation: `<RESOURCE TYPE>.<NAME>[N]` (see figure 3.14).

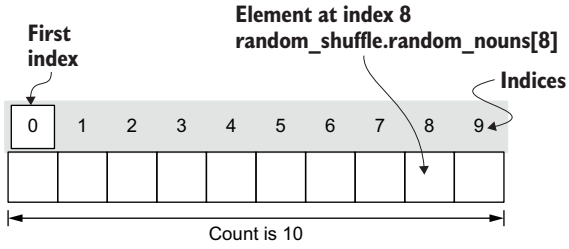


Figure 3.14 Count creates a list of resources that can be referenced using bracket notation.

Let's update our code to support producing an arbitrary number of Mad Libs stories. First, add a new variable named `var.num_files` having type `number` and a default value of `100`. Next, reference this variable to dynamically set the `count` meta argument on each of the `shuffle_resources`. Your code will look like the next listing.

Listing 3.7 madlibs.tf

```
variable "words" {
  description = "A word pool to use for Mad Libs"
  type = object({
    nouns      = list(string),
    adjectives = list(string),
    verbs      = list(string),
    adverbs    = list(string),
    numbers    = list(number),
```

```
  })
}

variable "num_files" {
    default = 100
    type    = number
}

locals {
  uppercase_words = {for k,v in var.words : k => [for s in v : upper(s)]}
}

resource "random_shuffle" "random_nouns" {
  count = var.num_files
  input = local.uppercase_words["nouns"]
}

resource "random_shuffle" "random_adjectives" {
  count = var.num_files
  input = local.uppercase_words["adjectives"]
}

resource "random_shuffle" "random_verbs" {
    count = var.num_files
    input = local.uppercase_words["verbs"]
}

resource "random_shuffle" "random_adverbs" {
  count = var.num_files
  input = local.uppercase_words["adverbs"]
}

resource "random_shuffle" "random_numbers" {
  count = var.num_files
  input = local.uppercase_words["numbers"]
}
```

Declares an input variable for setting count on the random_shuffle resources

References the num_files variable to dynamically set the count meta argument

3.2.5 Conditional expressions

Conditional expressions are ternary operators that alter control flow based on the results of a boolean condition. They can be used to selectively evaluate one of two expressions: the first for when the condition is true and the second for when it's false. Before variables had validation blocks, conditional expressions were used to validate input variables. Nowadays, they serve a niche role. The syntax of a conditional expression is shown in figure 3.15.

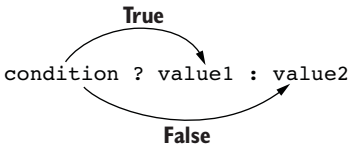


Figure 3.15 Syntax of a conditional expression

The following conditional expression validates that at least one noun is supplied to the `nouns` word list. If the condition fails, then an error will be thrown (because it is preferable to throw an error than proceed with invalid input):

```
locals {
    v = length(var.words["nouns"])>=1 ? var.words["nouns"] : [][0]
}
```

var.words["nouns"] must contain at least one word.

If `var.words["nouns"]` contains at least one word, then application flow continues as normal. Otherwise, an error is thrown:

```
Error: Invalid index

  on main.tf line 8, in locals:
   8:     v = length(var.words["nouns"])>=1 ? var.words["nouns"] : [][0]
```

Lazy evaluation is why this validation trick works. Only the expression that needs to be evaluated is evaluated—the other control path is ignored. The expression `[][0]` always throws an error if it's evaluated (since it attempts to access the first element of an empty list), but it's not evaluated *unless* the boolean condition is false.

Conditional expressions are most commonly used to toggle whether a resource will be created. For example, if you had a boolean input variable called `shuffle_enabled`, you could conditionally create a resource with the following expression:

```
count = var.shuffle_enabled ? 1 : 0
```

WARNING Conditional expressions hurt readability a lot, so avoid using them if you can.

3.2.6 More templates

Let's add two more template files to spice things up a bit. We'll cycle between them so we have equal number of Mad Libs stories using each template. Make a new template file called observatory.txt in the templates directory, and set the contents as follows.

Listing 3.8 observatory.txt

```
THE OBSERVATORY

Out class when on a field trip to a ${adjectives[0]} observatory. It
was located on top of a ${nouns[0]}, and it looked like a giant
${nouns[1]} with a slit down its ${nouns[2]}. We went inside and
looked through a ${nouns[3]} and were able to see ${nouns[4]}s in
the sky that were millions of ${nouns[5]}s away. The men and
women who ${verbs[0]} in the observatory are called
${nouns[6]}s, and they are always watching for comets, eclipses,
and shooting ${nouns[7]}s. An eclipse occurs when a ${nouns[8]}
comes between the earth and the ${nouns[9]} and everything
gets ${adjectives[1]}. Next week, we place to ${verbs[1]} the
Museum of Modern ${nouns[10]}.
```

Next, make another template file called photographer.txt and set the contents as follows.

Listing 3.9 photographer.txt

```
HOW TO BE A PHOTOGRAPHER

Many ${adjectives[0]} photographers make big money
photographing ${nouns[0]}s and beautiful ${nouns[1]}s. They sell
the prints to ${adjectives[1]} magazines or to agencies who use
them in ${nouns[2]} advertisements. To be a photographer, you
have to have a ${nouns[3]} camera. You also need an
${adjectives[2]} meter and filters and a special close-up
${nouns[4]}. Then you either hire professional ${nouns[1]}s or go
out and snap candid pictures of ordinary ${nouns[5]}s. But if you
want to have a career, you must study very ${adverbs[0]} for at
least ${numbers[0]} years.
```

3.2.7 Local file

Instead of outputting to the CLI, we'll save the results to disk with a `local_file` resource. First, though, we need to read all the text files from the templates folder into a list. This is possible with the built-in `fileset()` function:

```
locals {
  templates = tolist(fileset(path.module, "templates/*.txt"))
}
```

NOTE Sets and lists look the same but are treated as different types, so an explicit cast must be made to convert from one type to another.

Once we have the list of template files in place, we can feed the result into `local_file`. This resource generates `var.num_files` (i.e. 100) text files:

```
resource "local_file" "mad_libs" {
  count    = var.num_files
  filename = "madlibs/madlibs-${count.index}.txt"
  content  = templatefile(element(local.templates, count.index),
    {
      nouns      = random_shuffle.random_nouns[count.index].result
      adjectives = random_shuffle.random_adjectives[count.index].result
      verbs      = random_shuffle.random_verbs[count.index].result
      adverbs    = random_shuffle.random_adverbs[count.index].result
      numbers    = random_shuffle.random_numbers[count.index].result
  })
}
```

Two things worth pointing out are `element()` and `count.index`. The `element()` function operates on a list as if it were circular, retrieving elements at a given index without throwing an out-of-bounds exception. This means `element()` will evenly divide the 100 Mad Libs stories between the two template files.

The `count.index` expression references the current index of a resource (see figure 3.16). We use it to parameterize filenames and ensure that `templatefile()` receives template variables from corresponding `random_shuffle` resources.

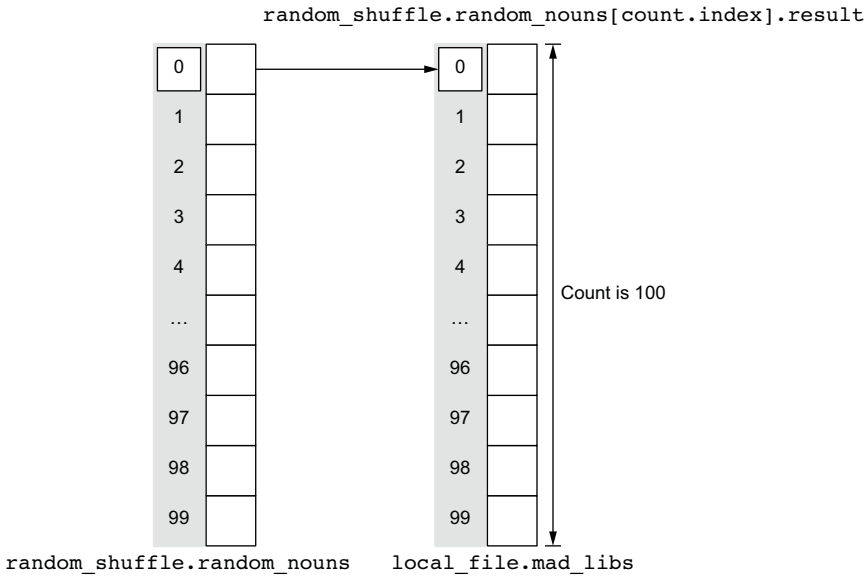


Figure 3.16 `random_nouns` and `mad_libs` are lists of resources and must be kept in sync.

3.2.8 Zipping files

We can create arbitrary numbers of Mad Libs stories and output them in a madlibs directory, but wouldn't it be great to zip the files together as well? The `archive_file` data source can do just this. It outputs all the files in a source directory to a new zip file. Add the following code to madlibs.tf:

```
data "archive_file" "mad_libs" {
  depends_on  = [local_file.mad_libs]
  type        = "zip"
  source_dir  = "${path.module}/madlibs"
  output_path = "${path.cwd}/madlibs.zip"
}
```

The `depends_on` meta argument specifies explicit dependencies between resources. Explicit dependencies describe relationships between resources that are not visible to Terraform. `depends_on` is included here because `archive_file` must be evaluated after all the Mad Libs paragraphs have been created; otherwise, it would zip up files in an empty directory. Normally we would express this relationship through an implicit dependency by using an interpolated input argument, but `archive_file` does not

accept any input arguments that it would make sense to set from the output of `local_file`, so we are forced to use an explicit dependency, instead.

> **TIP** Prefer implicit dependencies over explicit dependencies because they are clearer to someone reading your code. If you must use an explicit dependency, at least document the reason you are using it and what the hidden dependency is.

For reference, the complete code for madlibs.tf is shown in the following listing.

Listing 3.10 madlibs.tf

```
terraform {
  required_version = ">= 0.15"
  required_providers {
    random = {
      source  = "hashicorp/random"
      version = "~> 3.0"
    }
    local = {
      source  = "hashicorp/local"
      version = "~> 2.0"
    }
    archive = {
      source  = "hashicorp/archive"
      version = "~> 2.0"
    }
  }
}
variable "words" {
  description = "A word pool to use for Mad Libs"
  type = object({
    nouns      = list(string),
    adjectives = list(string),
    verbs      = list(string),
    adverbs    = list(string),
    numbers    = list(number),
  })
}

variable "num_files" {
  default = 100
  type    = number
}


locals {
  uppercase_words = { for k, v in var.words : k => [for s in v : upper(s)] }
}

resource "random_shuffle" "random_nouns" {
  count = var.num_files
  input = local.uppercase_words["nouns"]
}
```

```
resource "random_shuffle" "random_adjectives" {
  count = var.num_files
  input = local.uppercase_words["adjectives"]
}

resource "random_shuffle" "random_verbs" {
  count = var.num_files
  input = local.uppercase_words["verbs"]
}

resource "random_shuffle" "random_adverbs" {
  count = var.num_files
  input = local.uppercase_words["adverbs"]
}

resource "random_shuffle" "random_numbers" {
  count = var.num_files
  input = local.uppercase_words["numbers"]
}

locals {
  templates = tolist(fileset(path.module, "templates/*.txt"))
}

resource "local_file" "mad_libs" {
  count    = var.num_files
  filename = "madlibs/madlibs-${count.index}.txt"
  content  = templatefile(element(local.templates, count.index),
    {
      nouns      = random_shuffle.random_nouns[count.index].result
      adjectives = random_shuffle.random_adjectives[count.index].result
      verbs      = random_shuffle.random_verbs[count.index].result
      adverbs    = random_shuffle.random_adverbs[count.index].result
      numbers    = random_shuffle.random_numbers[count.index].result
  })
}

data "archive_file" "mad_libs" {
  depends_on  = [local_file.mad_libs]
  type        = "zip"
  source_dir  = "${path.module}/madlibs"
  output_path = "${path.cwd}/madlibs.zip"
}
```

3.2.9 Applying changes

We're ready to apply changes. Run `terraform init` to download the new providers, and follow it with `terraform apply`:

```
$ terraform init && terraform apply -auto-approve
...
local_file.mad_libs[71]: Creation complete after 0s
     [id=382048cc1c505b6f7c2ecd8d430fa2bcd787cec0]
local_file.mad_libs[54]: Creation complete after 0s
[id=8b6d5cc53faf1d20f913ee715bf73dda8b635b5d]
data.archive_file.mad_libs: Reading...
```

```
data.archive_file.mad_libs: Read complete after 0s
[id=4a151807e60200bff2c01fdcabeab072901d2b81]

Apply complete! Resources: 600 added, 0 changed, 0 destroyed.
```

> **NOTE** If you previously ran an `apply` before adding `archive_file`, it will say that zero resources were added, changed, and destroyed. This is somewhat surprising, but it happens because data sources are not considered resources for the purposes of an `apply`.

The files in the current directory are now as follows:

```
.
├── madlibs
│   ├── madlibs-0.txt
│   ├── madlibs-1.txt
 ...
│   ├── madlibs-98.txt
│   └── madlibs-99.txt
├── madlibs.zip
├── madlibs.tf
├── templates
│   ├── alice.txt
│   ├── observatory.txt
│   └── photographer.txt
├── terraform.tfstate
├── terraform.tfstate.backup
└── terraform.tfvars
```

Here is an example of a generated Mad Libs story for your amusement:

```
$ cat madlibs/madlibs-2.txt
HOW TO BE A PHOTOGRAPHER

Many CHUBBY photographers make big money
photographing BANANAs and beautiful JELLYFISHs. They sell
the prints to BITTER magazines or to agencies who use
them in SANDWICH advertisements. To be a photographer, you
have to have a CAT camera. You also need an
ABUNDANT meter and filters and a special close-up
WALNUTS. Then you either hire professional JELLYFISHs or go
out and snap candid pictures of ordinary PANTHERs. But if you
want to have a career, you must study very DELICATELY for at
least 27 years.
```

This is an improvement because the capitalized words stand out from the surrounding text and, of course, because we have a lot more Mad Libs. To clean up, perform `terraform destroy`.

> **NOTE** `terraform destroy` will *not* delete madlibs.zip because this file isn't a managed resource. Recall that *madlibs.zip* was created with a data source, and data sources do not implement `Delete()`.

3.3 Fireside chat

Terraform is a highly expressive programming language. Anything you want to do is possible, and the language itself is rarely an impediment. Complex logic that takes dozens of lines of procedural code can be easily expressed in one or two functional lines of Terraform code.

The focus of this chapter was on functions, expressions, and templates. We started by comparing input variables, local values, and output values to the arguments, temporary symbols, and return values of a function. We then saw how we can template files using `templatefile()`.

Next, we saw how to scale up to an arbitrary number of Mad Libs stories by using `for` expressions and `count`. `for` expressions allow you to create higher-order functions with lambda-like syntax. This is especially useful for transforming complex data before configuring resource attributes.

The final thing we did was zip up all the Mad Libs paragraphs with an `archive_file` data source. We ensured that the zipping was done at the right time by putting in an explicit `depends_on`.

Terraform includes many kinds of expressions, some of which we have not had the opportunity to cover. Table 3.1 is a reference of all expressions that currently exist in Terraform.

Table 3.1 Expression reference

Name	Description	Example
Conditional expression	Uses the value of a boolean expression to select one of two values	`condition ? true_value : false_value`
Function call	Transforms and combines values	`<FUNCTION NAME>(<ARG 1>, <ARG2>)`
`for` expression	Transforms one complex type to another	`[for s in var.list : upper(s)]`

Splat expression	Shorthand for some common use cases that could otherwise be handled by `for` expressions	`var.list[*].id`
		Following is the equivalent `for` expression:
		`[for s in var.list : s.id]`

Dynamic block	Constructs repeatable nested blocks within resources	`dynamic "ingress" {`
		`  for_each = var.service_ports`
		`  content {`
		`  from_port = ingress.value`
		`  to_port = ingress.value`
		`  protocol = "tcp"`
		`  }`
		`}`

Table 3.1 Expression reference *(continued)*

Name	Description	Example
String template interpolation	Embeds expressions in a string literal	`"Hello, ${var.name}!"`

String template directives	Uses conditional results and iterates over a collection within a string literal	`%{ for ip in var.list.*.ip }`
		`server ${ip}`
		`%{ endfor }`

Summary

- Input variables parameterize Terraform configurations. Local values save the results of an expression. Output values pass data around, either back to the user or to other modules.
- `for` expressions allow you to transform one complex type into another. They can be combined with other `for` expressions to create higher-order functions.
- Randomness must be constrained. Avoid using legacy functions such as `uuid()` and `timestamp()`, as these will introduce subtle bugs in Terraform due to a non-convergent state.
- Zip files with the Archive provider. You may need to specify an explicit dependency to ensure that the data source runs at the right time.
- `templatefile()` can template files with the same syntax used by interpolation variables. Only variables passed to this function are in scope for templating.
- The `count` meta argument can dynamically provision multiple instances of a resource. To access an instance of a resource created with `count`, use bracket notation `[]`.

4 Deploying a multi-tiered web application in AWS

This chapter covers

- Deploying a multi-tiered web application in AWS with Terraform
- Setting project variables in variables definition files
- Organizing code with nested modules
- Using modules from the Terraform Registry
- Passing data between modules using input variables and output values

Highly available, scalable web hosting has been a complex and expensive proposition until relatively recently. It wasn't until AWS released its Elastic Compute Cloud (EC2) service in 2006 that things started changing for the better. EC2 was the first pay-as-you-go service that enabled customers to provision to nearly infinite capacity on demand. As great as EC2 was, a significant tooling gap existed that could not be met with CloudFormation or existing configuration management tools. Terraform was designed to fill the tooling gap, and we are now going to look at how Terraform solves this problem. In this chapter, we deploy a highly available and scalable multi-tiered web application in AWS.

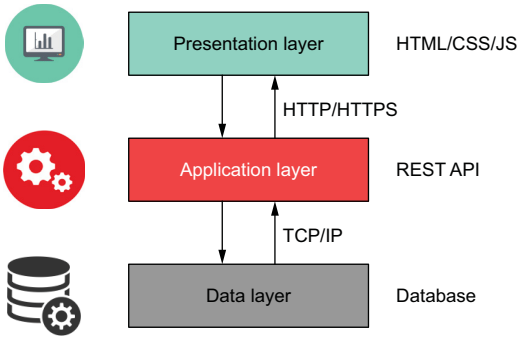


Figure 4.1 Typical multi-tiered web application

Before we begin, what is meant by a *multi-tiered* application? *Multi-tier* simply refers to a software system that is divided into logical layers, like a cake (see figure 4.1). A three-tiered design is popular because it imposes a clear boundary between the frontend and backend. The frontend is what people see and is called the UI or *presentation layer*. The backend is what people don't see and is made up of two parts: the *application layer* (typically a REST API) and the persistent storage or *data access layer* (such as a database).

In this chapter, we'll deploy a three-tiered web application for a social media site geared toward pet owners. A preview of the deployed application is shown in figure 4.2.

NOTE If you are interested in comparable serverless or containerized deployments, stay tuned, because we cover them in chapters 5, 7, and 8.

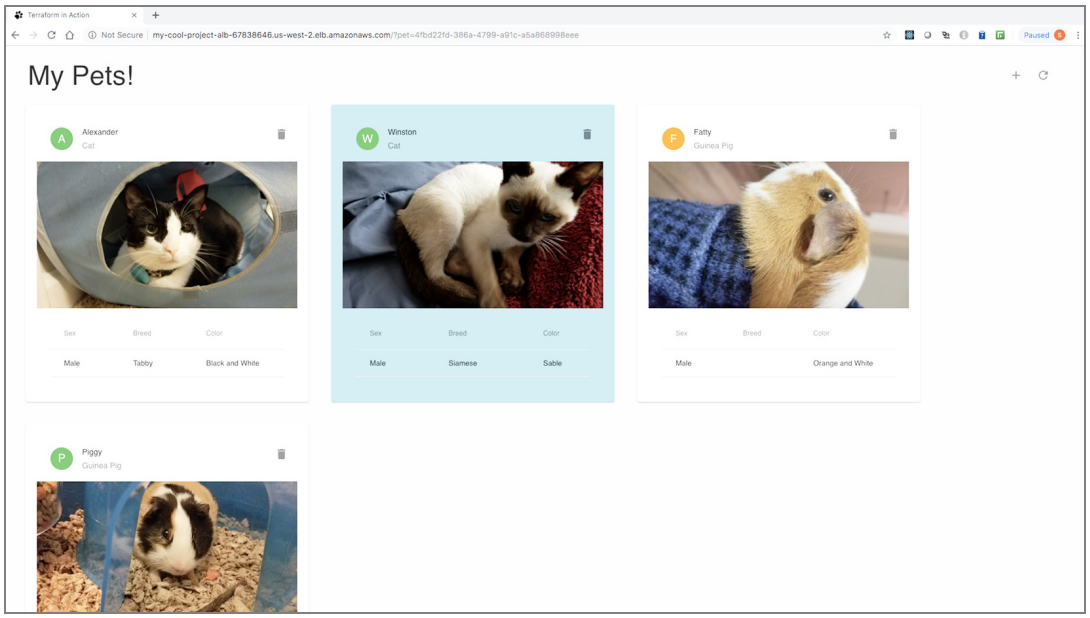


Figure 4.2 Preview of the deployed web application

4.1 Architecture

From an architectural point of view, we're going to put some EC2 instances in an autoscaling group and then put that behind a load balancer (see figure 4.3). The load balancer will be public-facing, meaning it can be accessed by anyone. In contrast, both the instances and database will be on private subnets with firewall rules dictated by security groups.

NOTE If you have used AWS, this should be a familiar architecture pattern. If not, don't worry; it won't stop you from completing the chapter.

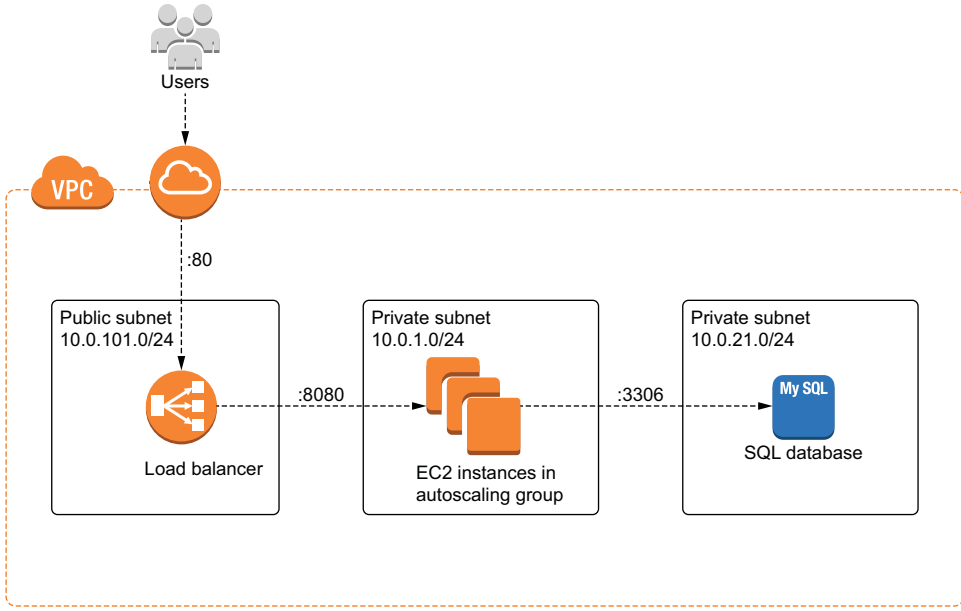


Figure 4.3 Architecture diagram for the multi-tiered web application

NOTE We aren't going to configure Secure Sockets Layer (SSL) / Transport Layer Security (TLS) on the load balancer since doing so requires validating a domain name, but know that it is possible to do by using Terraform resources for Amazon Certificate Manager (ACM) and Route53.

What is an autoscaling group?

An autoscaling group is a collection of EC2 instances that are treated as a logical unit for scaling and management. Autoscaling groups allow you to automatically scale based on the result of health checks and autoscaling policies. Instances in an AWS autoscaling group are created from a common blueprint called a *launch template*,

(continued)

which includes user data and metadata such as a version number and AMI ID. If one instance in an autoscaling group dies, a new one is started up automatically. Autoscaling groups are treated as a single target by the load balancer, so you don't have to register individual instances by IP address.

Since this is a non-trivial deployment, there are many ways to go about implementation, but I suggest splitting things into smaller components that are easier to reason about. For this scenario, we will split the project into three major components:

- *Networking*—All networking-related infrastructure, including the VPC, subnets, and security groups
- *Database*—The SQL database infrastructure
- *Autoscaling*—Load balancer, EC2 autoscaling group, and launch template resources

These three major components are illustrated in figure 4.4.

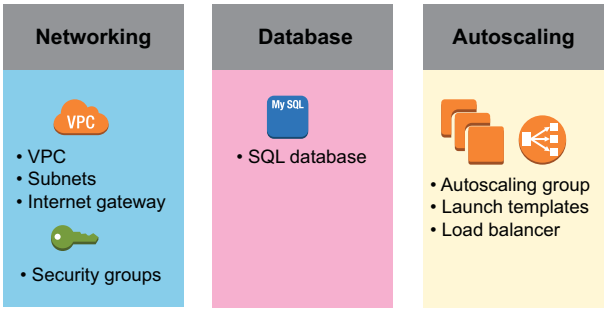


Figure 4.4 Infrastructure split into three major components

In Terraform, the components into which resources are organized using this approach are called *modules*. Before we go any further, let's formally introduce modules.

4.2 Terraform modules

Modules are self-contained packages of code that allow you to create reusable components by grouping related resources together. You don't have to know how a module works to be able to use it; you just have to know how to set inputs and outputs. Modules are useful tools for promoting software abstraction and code reuse.

4.2.1 Module syntax

When I think about modules, the analogy of building with toy blocks always comes to mind. Blocks are simple elements, yet complexity can emerge from the way they are joined. If resources and data sources are the individual building blocks of Terraform,

then modules are prefabricated groupings of many such blocks. Modules can be dropped into place with little effort; see figure 4.5.

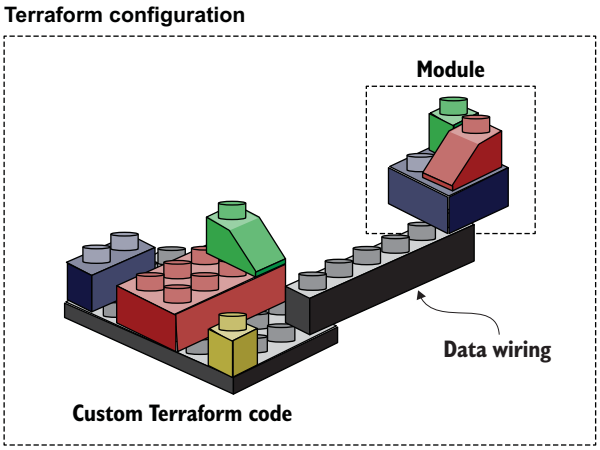


Figure 4.5 Using a module in Terraform is like using a prefabricated building block component.

The syntax for module declarations is shown in figure 4.6. They resemble resource declarations because they have meta arguments, inputs, variables, and a name.

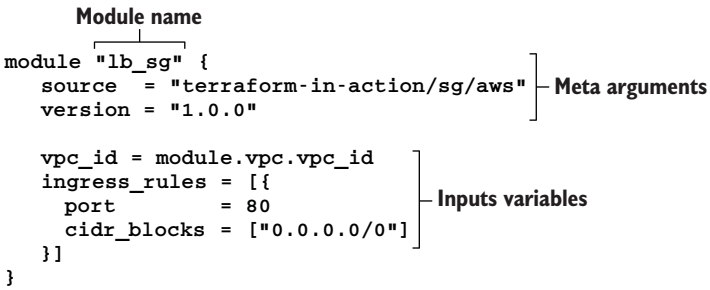


Figure 4.6 Module syntax

4.2.2 What is the root module?

Every workspace has a *root module*; it's the directory where you run `terraform apply`. Under the root module, you may have one or more child modules to help you organize and reuse configuration. Modules can be sourced either locally (meaning they are embedded within the root module) or remotely (meaning they are downloaded from a remote location as part of `terraform init`). In this scenario, we will use a combination of locally and remotely sourced modules.

As a reminder, we will have three components: networking, database, and autoscaling. Each component will be represented by a module in Terraform. Figure 4.7 shows the overall module structure for the scenario.

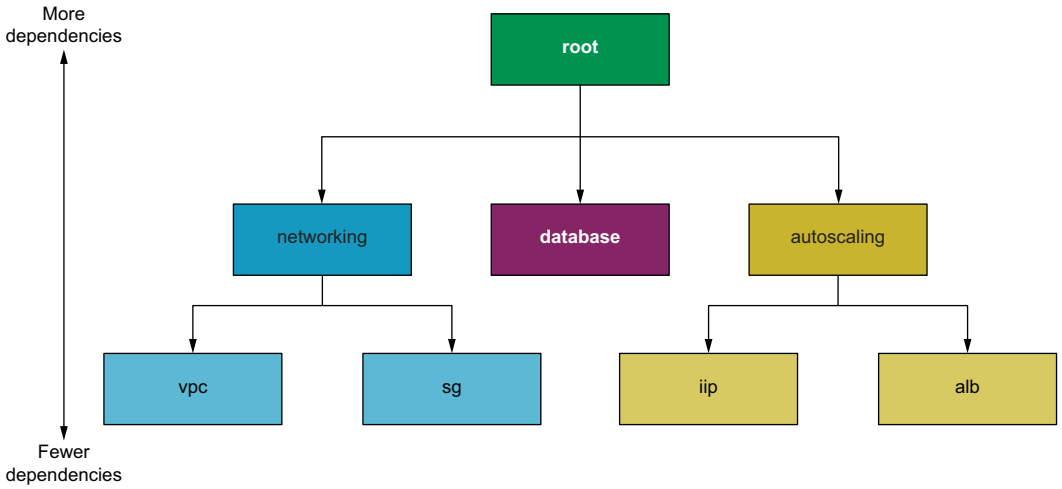


Figure 4.7 Overall module structure with nested child modules

Some child modules have their own child modules (for example, the networking and autoscaling modules). This children-within-children module pattern is called *nested modules*.

4.2.3 Standard module structure

HashiCorp strongly recommends that every module follow certain code conventions known as the *standard module structure* (www.terraform.io/docs/modules/index.html#standard-module-structure). At a minimum, this means having three Terraform configuration files per module:

- main.tf—the primary entry point
- outputs.tf—declarations for all output values
- variables.tf—declarations for all input variables

NOTE versions.tf, providers.tf, and README.md are considered required files in the root module. We will discuss this more in chapter 6.

Figure 4.8 details the overall module structure, taking into consideration additional files required as part of the standard module structure. In the next few sections, we write the configuration code for the root and child modules before deploying to AWS.

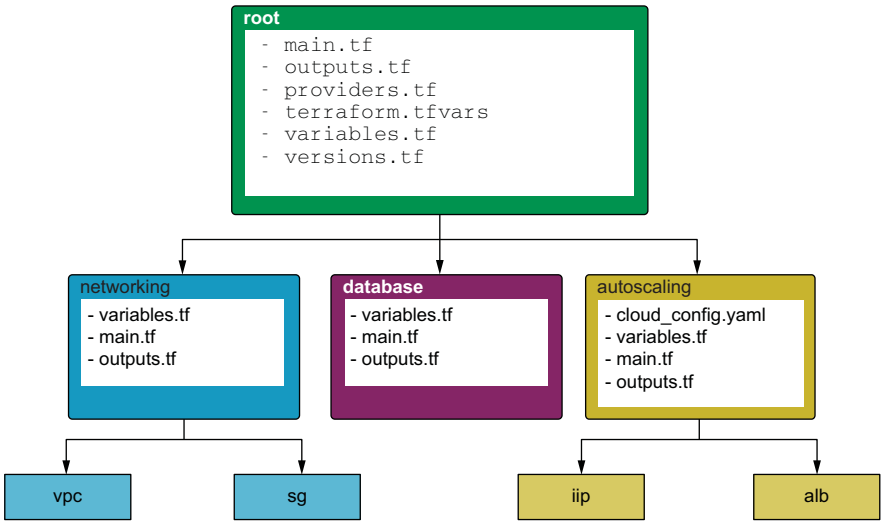


Figure 4.8 Detailed module structure

4.3 Root module

The root module is the top-level module. It's where user-supplied input variables are configured and where Terraform commands such as `terraform init` and `terraform apply` are run. In our root module, there will be three input variables and two output values. The three input variables are `namespace`, `ssh_keypair`, and `region`, and the two output values are `db_password` and `lb_dns_name`; see figure 4.9.

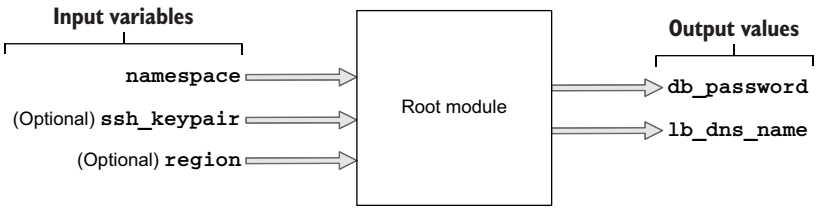


Figure 4.9 Input variables and output values for the root module

A user of the root module only needs to set the `namespace` variable to deploy the project since the other two variables are marked as optional. The output values they'll receive contain the provisioned load balancer's DNS name (`lb_dns_name`) and the database password (`db_password`). The load balancer DNS name is important because it's how the user will navigate to the website from a web browser.

Our root module consists of six files. Here's what they are and what they are for:

- *variables.tf*—Input variables
- *terraform.tfvars*—Variables definition file
- *providers.tf*—Provider declarations
- *main.tf*—Entry point for Terraform
- *outputs.tf*—Output values
- *versions.tf*—Provider version locking

In the next section, we go through the code that's in these files.

4.3.1 Code

Let's start with variables.tf. If you haven't already done so, create a new empty directory for your code to live in; in this directory, create a variables.tf file.

Listing 4.1 variables.tf

```
variable "namespace" {
  description = "The project namespace to use for unique resource naming"
  type        = string
}

variable "ssh_keypair" {
  description = "SSH keypair to use for EC2 instance"
  default     = null
  type        = string
}

variable "region" {
  description = "AWS region"
  default     = "us-west-2"
  type        = string
}
```

Null is useful for optional variables that don't have a meaningful default value.

We set variables by using a *variables definition file*. The variables definition file allows you to parameterize configuration code without having to hardcode default values. It uses the same basic syntax as Terraform configuration but consists only of variable names and assignments. Create a new file called terraform.tfvars, and insert the code from listing 4.2. This sets the `namespace` and `region` variables in variables.tf.

NOTE We won't set `ssh_keypair` because it requires having a generated SSH keypair. Refer to chapter 9 for an example of how to do this.

Listing 4.2 terraform.tfvars

```
namespace = "my-cool-project"
region    = "us-west-2"
```

The `region` variable configures the AWS provider. We can reference this variable in the provider declaration. Do this by creating a new providers.tf file and copying into it the following code.

Listing 4.3 providers.tf

```
provider "aws" {
  region  = var.region
}
```

TIP You can also set the `profile` attribute in the AWS provider declaration, if you are not using the default profile or environment variables to configure credentials.

The `namespace` variable is a project identifier. Some module authors eschew `namespace` in favor of two variables: for example, `project_name` and `environment`. Regardless of whether you choose one or two variables for your project identifier, all that matters is that your project identifier is unique and descriptive, such as `tia-chapter4-dev`.

We'll pass `namespace` into each of the three child modules. Although we have not yet fleshed out what the child modules do, we can stub them with the information we do know. Create a main.tf file with the code from the next listing.

Listing 4.4 main.tf

```
module "autoscaling" {
  source      = "./modules/autoscaling"
  namespace   = var.namespace
}

module "database" {
  source    = "./modules/database"
  namespace = var.namespace
}

module "networking" {
  source    = "./modules/networking"
  namespace = var.namespace
}
```

Each module uses var.namespace for resource naming.

Nested child modules are sourced from a local modules directory.

Now that we have stubbed out the module declarations in main.tf, we will stub out the output values in a similar fashion. Create an outputs.tf file with the following code.

Listing 4.5 outputs.tf

```
output "db_password" {
  value = "tbd"
}
```

```
output "lb_dns_name" {
  value = "tbd"
}
```

The last thing we need to do is lock in the provider and Terraform versions. Normally, I would recommend waiting until after running `terraform init` to do this step so you simply note the provider versions that are downloaded and use those; but we will version-lock now since I've done this step ahead of time. Create versions.tf with the code from the next listing.

Listing 4.6 versions.tf

```
terraform {
  required_version = ">= 0.15"
  required_providers {
    aws = {
      source  = "hashicorp/aws"
      version = "~> 3.28"
    }
    random = {
      source  = "hashicorp/random"
      version = "~> 3.0"
    }
    cloudinit = {
      source  = "hashicorp/cloudinit"
      version = "~> 2.1"
    }
  }
}
```

4.4 Networking module

The networking module is the first of three child modules we'll look at. This module is responsible for provisioning all networking-related components of the web app, including Virtual Private Cloud (VPC), subnets, the internet gateway, and security groups. Overall inputs and outputs are shown in figure 4.10.

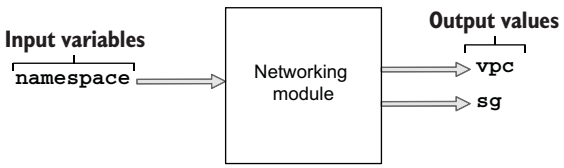


Figure 4.10 Overall inputs and outputs of the networking module

From a black box perspective, you can simply treat modules as functions with side effects (i.e. *nonpure functions*). We already know what the module's inputs and outputs are, but what are the side effects? Side effects are just the resources provisioned as a result of `terraform apply` (see figure 4.11).

NOTE Some of the resources provisioned by the networking module are not covered under the AWS free tier.

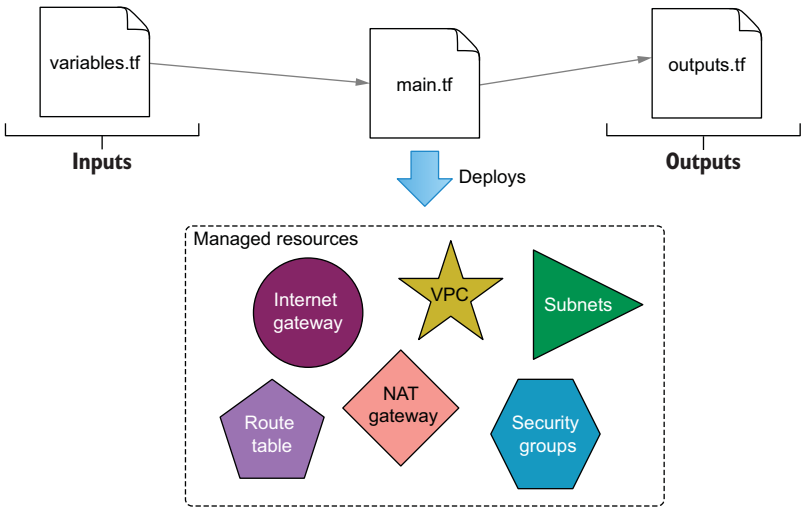


Figure 4.11 Managed resources provisioned by the networking module

Create a new directory with the path ./modules/networking. In this directory, create three files: variables.tf, main.tf, and outputs.tf. We'll start with variables.tf: copy the following code into it.

Listing 4.7 variables.tf

```
variable "namespace" {
    type = string
}
```

Before I throw the main code at you, I want to explain how it is structured. Generally, resources declared at the top of the module have the fewest dependencies, while resources declared at the bottom have the most dependencies. Resources are

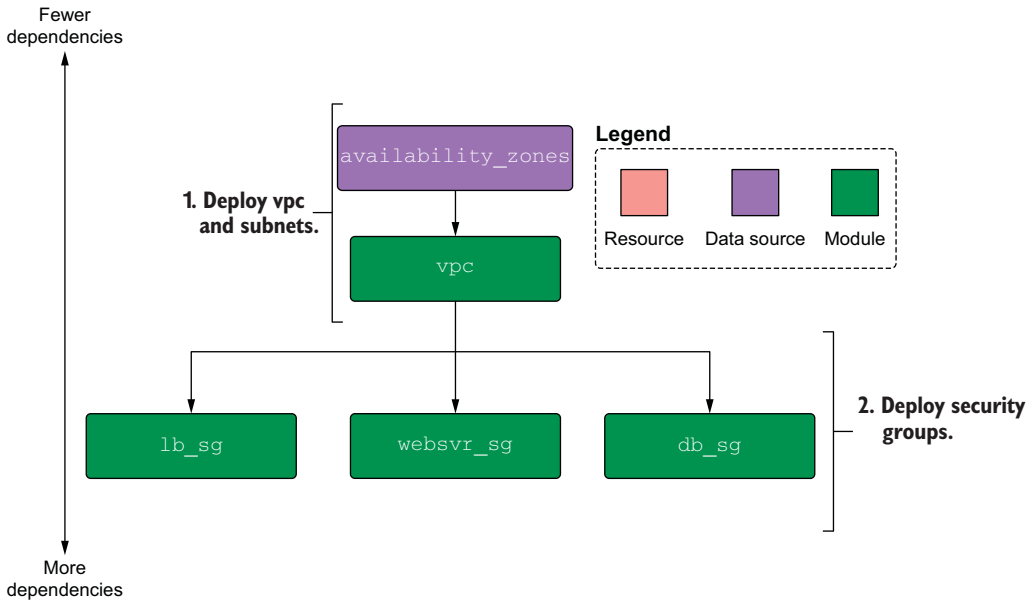


Figure 4.12 Dependency diagram for the networking module

declared so that they feed into each other, one after another (this is also sometimes called *resource chaining*). Refer to figure 4.12 for a visual representation.

> **NOTE** Some people like to declare security groups in the module where they will be used instead of in a separate networking module. It's entirely a matter of preference; do what makes sense to you.

The next listing has the code for main.tf; copy it into your file. Don't worry too much about understanding all of the code; just pay attention to how everything connects.

Listing 4.8 main.tf

```
data "aws_availability_zones" "available" {}

module "vpc" {                                    <-- AWS VPC module published in the Terraform Registry
  source                  = "terraform-aws-modules/vpc/aws"
  version                 = "2.64.0"
  name                    = "${var.namespace}-vpc"
  cidr                    = "10.0.0.0/16"
  azs                     = data.aws_availability_zones.available
                            ➥ .names
  private_subnets         = ["10.0.1.0/24", "10.0.2.0/24",
                            ➥ "10.0.3.0/24"]
  public_subnets          = ["10.0.101.0/24", "10.0.102.0/24",
                            ➥ "10.0.103.0/24"]
```

```
  database_subnets                 = ["10.0.21.0/24", "10.0.22.0/24",
                                     ➥ "10.0.23.0/24"]

  create_database_subnet_group     = true
  enable_nat_gateway               = true
  single_nat_gateway               = true
}

module "lb_sg" {
  source = "terraform-in-action/sg/aws"
  vpc_id = module.vpc.vpc_id
  ingress_rules = [{
    port        = 80
    cidr_blocks = ["0.0.0.0/0"]
  }]
}

module "websvr_sg" {
  source = "terraform-in-action/sg/aws"
  vpc_id = module.vpc.vpc_id
  ingress_rules = [
    {
      port            = 8080
      security_groups = [module.lb_sg.security_group.id]
    },
    {
      port        = 22
      cidr_blocks = ["10.0.0.0/16"]
    }
  ]
}

module "db_sg" {
  source = "terraform-in-action/sg/aws"
  vpc_id = module.vpc.vpc_id
  ingress_rules     = [{
    port            = 3306
    security_groups = [module.websvr_sg.security_group.id]
  }]
}
```

Security group module published by me

Allows SSH for a potential bastion host

It should be evident that the module is mostly made up of other modules. This pattern is known as *software componentization*: the practice of breaking large, complex code into smaller subsystems. For example, instead of writing the code for deploying a VPC ourselves, we are using a VPC module maintained by the AWS team. Meanwhile, the security group module is maintained by me. Both modules can be found on the public Terraform Registry, which we talk more about in chapter 6.

> **NOTE** Since I don't own the VPC module, I have version-locked it to ensure compatibility when you run the code. In this book, I do not version-lock my own modules because I always want you to download the latest version, in case I have to patch something.

Building vs. buying

Modules are powerful tools for software abstraction. You have the benefit of using battle-tested, production-hardened code without having to write it yourself. However, this doesn't mean freely using other people's code is always the best idea.

Whenever you use a module, you should always decide whether you will build it yourself or use someone else's (buy it). If you use someone else's module, you save time in the short term but have a dependency that may cause trouble later if something breaks in an unexpected way. Relying on modules from the public Terraform Registry is inherently risky, as there could be backdoors or unmaintained code, or the source repository could simply be deleted without notice. Forking the repo and/or version-locking solves this problem to some extent, but it's all about whom you trust. Personally, I only trust modules with a lot of stars on GitHub because at least that way I know people are maintaining the code. Even then, it's best to at least skim the source code to verify that it isn't doing anything malicious.

Finally, the code for outputs.tf is shown in listing 4.9. Notice that the `vpc` output passes a reference to the entire output of the VPC module. This allows us to be succinct in the output code, especially when passing data through multiple layers of nested modules. Also notice that the `sg` output is made up of a new object containing the IDs of the security groups. This pattern is useful for grouping related attributes from different resources in a single output value.

TIP Grouping related attributes into a single output value helps with code organization.

Listing 4.9 outputs.tf

```
output "vpc" {
  value = module.vpc
}

output "sg" {
  value = {
    lb     = module.lb_sg.security_group.id
    db     = module.db_sg.security_group.id
    websvr = module.websvr_sg.security_group.id
  }
}
```

Passes a reference to the entire vpc module as an output

Constructs a new object containing the ID for each of the three security groups

4.5 Database module

The database module does exactly what you would expect: it provisions a database. The inputs and outputs are shown in figure 4.13.

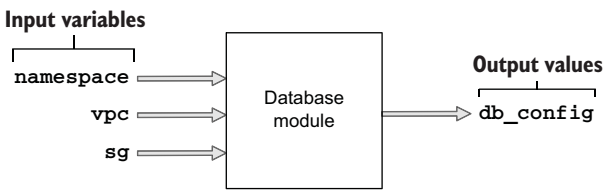


Figure 4.13 Inputs and outputs of the database module

This module creates only one managed resource, so the side effect diagram is simple compared to that of the networking module (see figure 4.14). We didn't write this one first because the database module has an implicit dependency on the networking module, and it requires references to the VPC and database security groups.

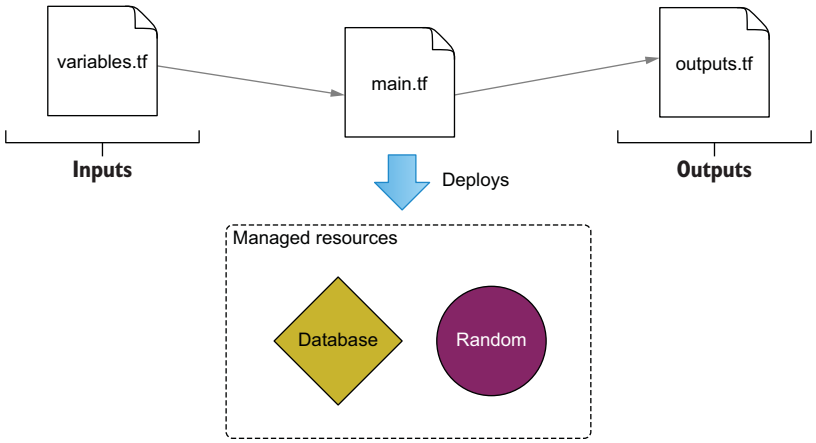


Figure 4.14 Managed resources provisioned by the database module

Figure 4.15 shows the dependency diagram. It's concise, as only two resources are being created, and one of them is local-only.

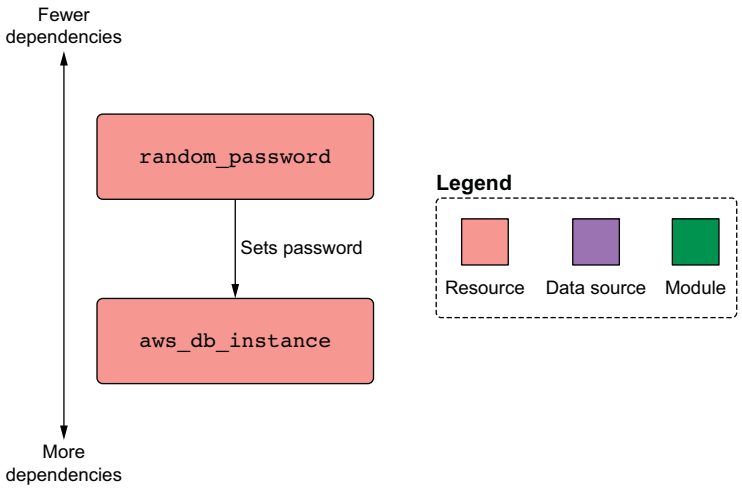


Figure 4.15 Dependency diagram for the database module

4.5.1 Passing data from the networking module

The database module requires references to VPC and database security group ID. Both of these are declared as outputs of the networking module. But how do we get this data into the database module? By "bubbling up" from the networking module into the root module and then "trickling down" into the database module; see figure 4.16.

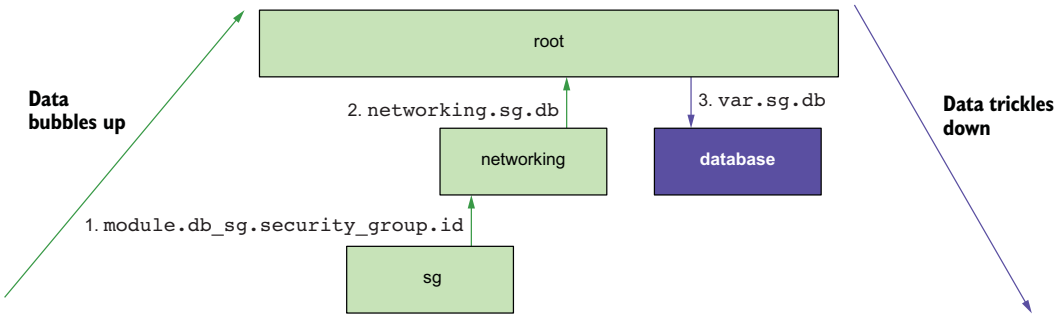


Figure 4.16 Data flow as the database's security group ID makes its way from the networking module into the database module

> **TIP** Because passing data between modules is tedious and hurts readability, you should avoid doing so as much as possible. Organize your code such that resources that share a lot of data are closer together or, better yet, part of the same module.

The root module isn't doing a lot except declaring component modules and allowing them to pass data between themselves. You should know that data passing is a two-way street, meaning two modules can depend on each other, as long as a cyclical dependency isn't formed; see figure 4.17. I don't use interdependent modules anywhere in this book because I think it's a bad design pattern.

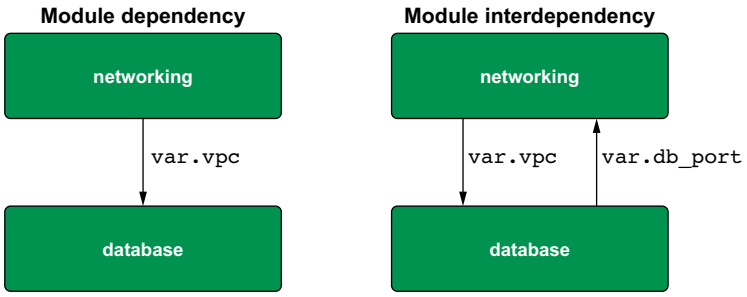


Figure 4.17 Dependent vs. interdependent modules

> **TIP** Avoid having interdependent modules—they make things confusing!

Let's get down to business. Update the database module declaration in the root module to include a reference to the networking module outputs (see listing 4.10). This takes care of bubbling the networking module's outputs up to the root level and then trickling them down as input variables in the database module.

Listing 4.10 main.tf in the root module

```
module "autoscaling" {
  source      = "./modules/autoscaling"
  namespace   = var.namespace
}

module "database" {
  source    = "./modules/database"
  namespace = var.namespace

  vpc = module.networking.vpc
  sg  = module.networking.sg
}

module "networking" {
  source    = "./modules/networking"
  namespace = var.namespace
}
```

Data bubbles up from the networking module and trickles down into the database module.

Next, we have to create the database module. Create a ./modules/database directory, and create three files in it: variables.tf, main.tf, and outputs.tf. The variables.tf file contains the input variables for `namespace`, `vpc`, and `sg`.

Listing 4.11 variables.tf

```
variable "namespace" {
  type = string
}

variable "vpc" {
  type = any
}

variable "sg" {
  type = any
}
```

A type constraint of "any" type means Terraform will skip type checking.

In this code, we specify the type of `vpc` and `sg` as `any`. This means we allow any kind of data structure to be passed in, which is convenient for times when you don't care about strict typing.

> **WARNING** While it may be tempting to overuse the `any` type, doing so is a lazy coding habit that will get you into trouble more often than not. Only use `any` when passing data between modules, never for configuring the input variables on the root module.

4.5.2 Generating a random password

Now that we have declared our input variables, we can reference them in the configuration code. The following listing shows the code for main.tf. In addition to the database, we also generate a random password for the database with the help of our old friend, the Random provider.

Listing 4.12 main.tf

```
resource "random_password" "password" {
  length           = 16
  special          = true
  override_special = "_%@/'\""
}

resource "aws_db_instance" "database" {
  allocated_storage      = 10
  engine                 = "mysql"
  engine_version         = "8.0"
  instance_class         = "db.t2.micro"
  identifier             = "${var.namespace}-db-instance"
  name                   = "pets"
  username               = "admin"
  password               = random_password.password.result
  db_subnet_group_name   = var.vpc.database_subnet_group
  vpc_security_group_ids = [var.sg.db]
  skip_final_snapshot    = true
}
```

Uses the random provider to create a 16-character password

These values came from the networking module.

Next, construct an output value consisting of the database configuration required by the application to connect to the database (listing 4.13). This is done similarly to what we did with the `sg` output of the networking module. In this situation, instead of aggregating data from multiple resources into one, we use this object to bubble up just the minimum amount of data that the autoscaling module needs to function. This is in accordance with the *principle of least privilege*.

Listing 4.13 outputs.tf

```
output "db_config" {
  value = {
    user     = aws_db_instance.database.username
    password = aws_db_instance.database.password
    database = aws_db_instance.database.name
    hostname = aws_db_instance.database.address
    port     = aws_db_instance.database.port
  }
}
```

All the data in db_config comes from select output of the aws_db_instance resource.

TIP To reduce security risk, never grant more access to data than is needed for legitimate purposes.

Changing back to the root module, let's add some plumbing: we can make the database password available to the CLI user by adding an output value in outputs.tf. Doing

so makes the database password appear in the terminal when `terraform apply` is run.

Listing 4.14 outputs.tf in the root module

```
output "db_password" {
  value = module.database.db_config.password
}

output "lb_dns_name" {
  value = "tbd"
}
```

4.6 Autoscaling module

Luckily, I have saved the most complex module for last. This module provisions the autoscaling group, load balancer, Identity and Access Management (IAM) instance role, and everything else the web server needs to run. The inputs and outputs for the module are shown in figure 4.18. Figure 4.19 illustrates the resources being deployed by this module.

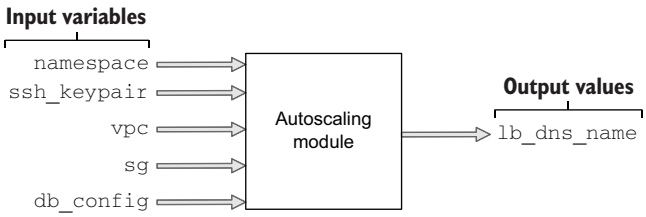


Figure 4.18 Inputs and outputs of the autoscaling module

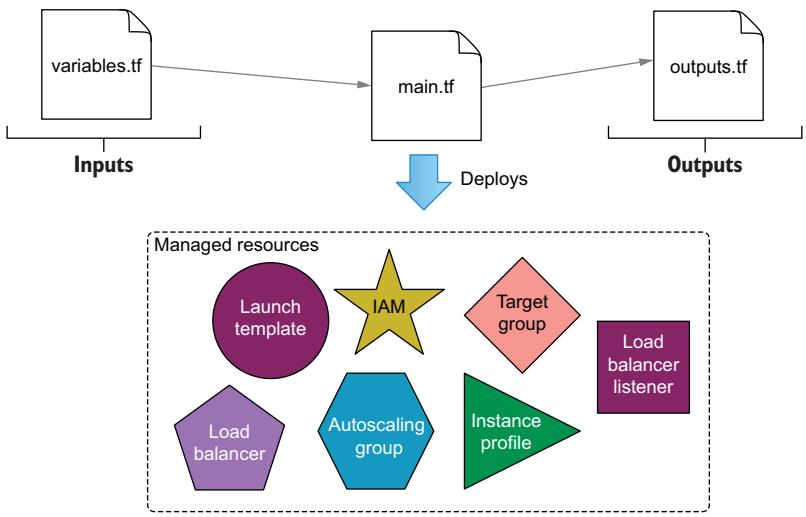


Figure 4.19 Managed resources provisioned by the autoscaling module

As we did in the networking module, we'll use helper child modules to provision resources that would otherwise take many more lines of code. Specifically, we'll do this for the IAM instance profile and load balancer.

4.6.1 Trickling down data

The three input variables of the autoscaling module are `vpc`, `sg`, and `db_config`. `vpc` and `sg` come from the networking module, while `db_config` comes from the database module. Figure 4.20 shows how data bubbles up from the networking module and trickles down into the application load balancer (ALB) module.

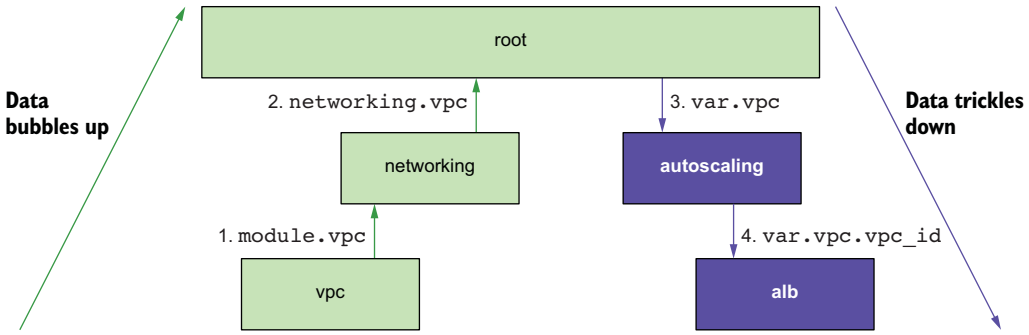


Figure 4.20 Data flow as the `vpc` ID makes its way from the VPC module to the ALB module

Similarly, `db_config` bubbles up from the database module and trickles down into the autoscaling module, as shown in figure 4.21. The web application uses this configuration to connect to the database at runtime.

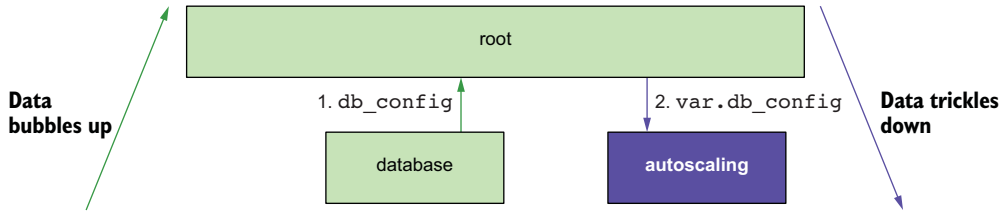


Figure 4.21 Data flow as `db_config` makes its way from the database module to the autoscaling module

The first thing we need to do is update main.tf in the root module to trickle data down into the autoscaling module.

Listing 4.15 main.tf in the root module

```
module "autoscaling" {
  source      = "./modules/autoscaling"
  namespace   = var.namespace
  ssh_keypair = var.ssh_keypair

  vpc       = module.networking.vpc
  sg        = module.networking.sg
  db_config = module.database.db_config
}

module "database" {
  source    = "./modules/database"
  namespace = var.namespace

  vpc = module.networking.vpc
  sg  = module.networking.sg
}

module "networking" {
  source    = "./modules/networking"
  namespace = var.namespace
}
```

input arguments for the autoscaling module, set by other module's outputs

As before, the module's input variables are declared in variables.tf. Create a ./modules/autoscaling directory, and in it create variables.tf. The code for variables.tf is shown next.

Listing 4.16 variables.tf

```
variable "namespace" {
  type = string
}

variable "ssh_keypair" {
  type = string
}

variable "vpc" {
  type = any
}

variable "sg" {
  type = any
}

variable "db_config" {
  type = object(
    {
      user     = string
      password = string
      database = string
```

Enforces a strict type schema for the db_config object. The value set for this variable must implement the same type schema.

```
      hostname = string
      port     = string
    }
  )
}
```

Enforces a strict type schema for the db_config object. The value set for this variable must implement the same type schema.

4.6.2 Templating a cloudinit_config

We are going to use a `cloudinit_config` data source to create the user data for our launch template. Again, the launch template is just a blueprint for the autoscaling group, as it bundles together user data, the AMI ID, and various other metadata. Meanwhile, the autoscaling group has a dependency on the load balancer because it needs to register itself as a target listener. The dependency diagram for the autoscaling module is shown in figure 4.22.

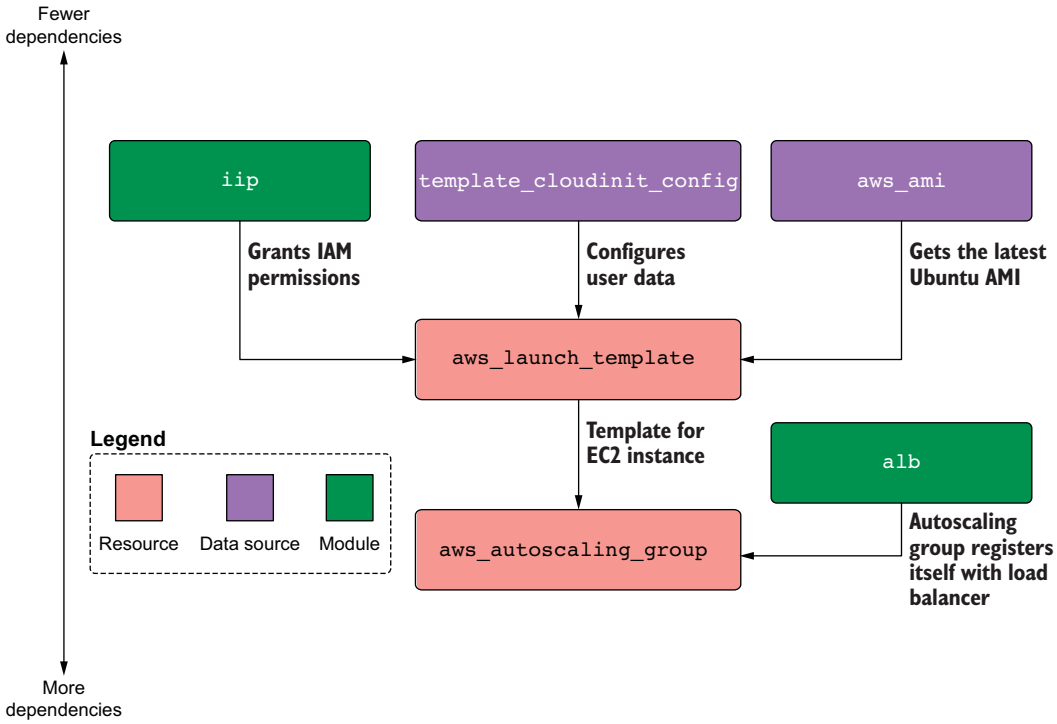


Figure 4.22 Dependency diagram for the autoscaling module

Following is the code for main.tf. Create this file, and copy in the code.

Listing 4.17 main.tf

```
module "iam_instance_profile" {
  source  = "terraform-in-action/iip/aws"
```

```
  actions = ["logs:*", "rds:*"]
}

data "cloudinit_config" "config" {
  gzip          = true
  base64_encode = true
  part {
    content_type = "text/cloud-config"
    content      = templatefile("${path.module}/cloud_config.yaml",
var.db_config)
  }
}

data "aws_ami" "ubuntu" {
  most_recent = true
  filter {
    name   = "name"
    values = ["ubuntu/images/hvm-ssd/ubuntu-bionic-18.04-amd64-server-*"]
  }
  owners = ["099720109477"]
}

resource "aws_launch_template" "webserver" {
  name_prefix   = var.namespace
  image_id      = data.aws_ami.ubuntu.id
  instance_type = "t2.micro"
  user_data     = data.cloudinit_config.config.rendered
  key_name      = var.ssh_keypair
  iam_instance_profile {
    name = module.iam_instance_profile.name
  }
  vpc_security_group_ids = [var.sg.websvr]
}

resource "aws_autoscaling_group" "webserver" {
  name                = "${var.namespace}-asg"
  min_size            = 1
  max_size            = 3
  vpc_zone_identifier = var.vpc.private_subnets
  target_group_arns   = module.alb.target_group_arns
  launch_template {
    id      = aws_launch_template.webserver.id
    version = aws_launch_template.webserver.latest_version
  }
}

module "alb" {
  source             = "terraform-aws-modules/alb/aws"
  version            = "~> 5.0"
  name               = var.namespace
  load_balancer_type = "application"
  vpc_id             = var.vpc.vpc_id
  subnets            = var.vpc.public_subnets
  security_groups    = [var.sg.lb]
```

The permissions are too open for a production deployment but good enough for dev.

Content for the cloud init configuration comes from a template file.

```
  http_tcp_listeners = [
    {
      port               = 80,
      protocol           = "HTTP"
      target_group_index = 0
    }
  ]

  target_groups = [
    { name_prefix      = "websvr",
      backend_protocol = "HTTP",
      backend_port     = 8080
      target_type      = "instance"
    }
  ]
}
```

The load balancer listens on port 80, which is mapped to 8080 on the instance.

WARNING Exposing port 80 over HTTP for a publicly facing load balancer is unacceptable security for production-level applications. Always use port 443 over HTTPS with an SSL/TLS certificate!

The cloud init configuration is templated using the `templatefile` function, which we previously saw in chapter 3. This function accepts two arguments: a path and a variable object. Our template's file path is `${path.module}/cloud_config.yaml`, which is a relative module path. This result of this function is passed into the `cloudinit_config` data source and then used to configure the `aws_launch_template` resource. The code for cloud_config.yaml is shown in listing 4.18.

TIP Template files can use any extension, not just .txt or .tpl (which many people use). I recommend choosing the extension that most clearly indicates the contents of the template file.

Listing 4.18 cloud_config.yaml

```
#cloud-config
write_files:
  -   path: /etc/server.conf
      owner: root:root
      permissions: "0644"
      content: |
        {
          "user":  "${user}",
          "password": "${password}",
          "database": "${database}",
          "netloc": "${hostname}:${port}"
        }
runcmd:
  - curl -sL https://api.github.com/repos/terraform-in-action/vanilla-webserver-
    ➥ src/releases/latest | jq -r ".assets[].browser_download_url" |
    ➥ wget -qi -
  - unzip deployment.zip
  - ./deployment/server
```

```
packages:
  - jq
  - wget
  - unzip
```

WARNING It is important that you copy this file exactly as is, or the web server will fail to start.

This is a fairly simple cloud init file. All it does is install some packages, create a configuration file (/etc/server.conf), fetch application code (deployment.zip) and start the server.

Finally, the output of the module is `lb_dns_name`. This output is bubbled up to the root module and simply makes it easier to find the DNS name after deploying.

Listing 4.19 outputs.tf

```
output "lb_dns_name" {
  value = module.alb.this_lb_dns_name
}
```

We also have to update the root module to include a refence to this output.

Listing 4.20 outputs.tf in the root module

```
output "db_password" {
  value = module.database.db_config.password
}

output "lb_dns_name" {
  value = module.autoscaling.lb_dns_name
}
```

4.7 Deploying the web application

We've created a lot of files, which is not unusual with Terraform, especially when separating code into modules. For reference, the current directory structure is as follows:

```
$ tree
.
├── main.tf
├── modules
│   ├── autoscaling
│   │   ├── cloud_config.yaml
│   │   ├── main.tf
│   │   ├── outputs.tf
│   │   └── variables.tf
│   ├── database
│   │   ├── main.tf
│   │   ├── outputs.tf
│   │   └── variables.tf
│   └── networking
│       ├── main.tf
│       ├── outputs.tf
```

```
│       └── variables.tf
├── outputs.tf
├── providers.tf
├── terraform.tfvars
├── variables.tf
└── versions.tf

4 directories, 16 files
```

At this point, we're ready to deploy the web application into AWS. Change into the root module directory, and run `terraform init` followed by `terraform apply -auto-approve`. After waiting ~10–15 minutes (it takes a while for VPC and EC2 resources to be created), the tail of your output will be something like this:

```
module.autoscaling.aws_autoscaling_group.webserver: Still creating...
[10s elapsed]
module.autoscaling.aws_autoscaling_group.webserver: Still creating...
[20s elapsed]
module.autoscaling.aws_autoscaling_group.webserver: Still creating...
[30s elapsed]
module.autoscaling.aws_autoscaling_group.webserver: Still creating...
[40s elapsed]
module.autoscaling.aws_autoscaling_group.webserver: Creation complete after
41s [id=my-cool-project-asg]

Apply complete! Resources: 40 added, 0 changed, 0 destroyed.

Outputs:

db_password = "oeZDaIkrM7om6xDy"
lb_dns_name = "my-cool-project-793358543.us-west-2.elb.amazonaws.com"
```

Your db_password and lb_dns_name will be different from mine.

Now copy the value of `lb_dns_name` into your web browser of choice to navigate to the website.

> **NOTE** If you get a 502 "bad gateway" error, wait a few more seconds before trying again, as the web server hasn't finished initializing yet. If the error persists, your cloud init file is most likely malformed.

Figure 4.23 shows the final website. You can click the + button to add pictures of your cats or other animals to the database, and the animals you add will be viewable by anyone who visits the website.

Figure 4.23 Deployed web app with no pets added yet

When you're done, don't forget to take down the stack to avoiding paying for infrastructure you don't need (again, this will take ~10–15 minutes). Do this with `terraform destroy -auto-approve`. The tail of your `destroy` run will be as follows:

```
module.networking.module.vpc.aws_internet_gateway.this[0]:
➥ Destruction complete after 11s
module.networking.module.vpc.aws_vpc.this[0]:
➥ Destroying... [id=vpc-0cb1e3df87f1f65c8]
module.networking.module.vpc.aws_vpc.this[0]: Destruction complete after 0s

Destroy complete! Resources: 40 destroyed.
```

4.8 Fireside chat

In this chapter, we designed and deployed a Terraform configuration for a multi-tiered web application in AWS. We broke out individual components into separate modules, which resulted in several layers of nested modules. Nested modules are a good design for complex Terraform projects, as they promote software abstraction and code reuse, although passing data can become tedious. In the next chapter, we investigate an alternative to nested modules: *flat modules*. A generalized way to structure nested module hierarchies is shown in figure 4.24.

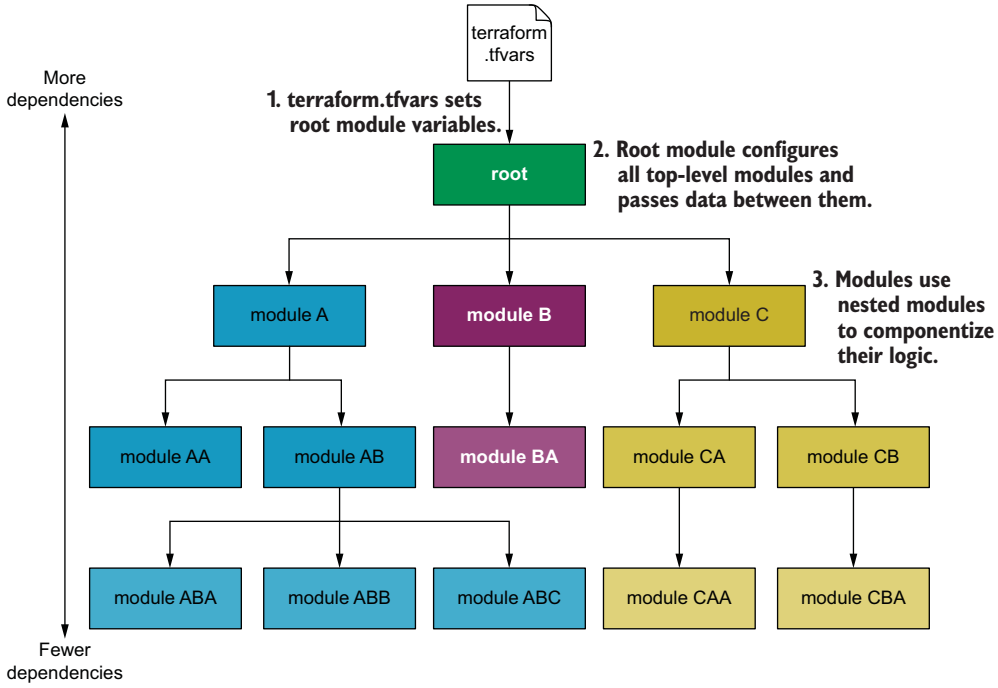


Figure 4.24 Generalized nested module hierarchy

Summary

- Complex projects, such as multi-tiered web applications in AWS, are easy to design and deploy with the help of Terraform modules.
- The root module is the main entry point for your project. You configure variables at the root level by using a variables definition file (terraform.tfvars). These variables are then trickled down as necessary into child modules.
- Nested modules organize code into child modules. Child modules can be nested within other child modules without limit. Generally, you don't want your module hierarchy to be more than three or four levels deep, because it makes it harder to understand.
- Many people have published modules in the public Terraform Registry. You can save a lot of time by using these open source modules instead of writing comparable code yourself; all it takes is learning how to use the module interface.
- Data is passed between modules using bubble-up and trickle-down techniques. Since this can result in a lot of boilerplate, it's a good idea to optimize your code so that minimal data needs to be passed between modules.

Part 2

Terraform in the wild

Now the fun begins (at least, depending on your idea of fun). We spend the next few chapters investigating real-world Terraform design patterns as they pertain to three major cloud providers (AWS, GCP, and Azure). Part 2 ends with an ambitious multi-cloud deployment that demonstrates the real power of Terraform. Although you may not like the idea of switching to unfamiliar clouds, I encourage you to persist, as the skills learned here are universally applicable. Here's what to expect.

Chapter 5 is a refreshing first look at the Azure cloud and emerging technologies. We walk through the design process of architecting and deploying a serverless web application with Terraform. By the end, you should feel comfortable writing your own Terraform configurations, even those that do not follow conventional patterns.

Chapter 6 explores Terraform's ecosystem and play-nice rules. How do you manage remote state storage? How do you publish modules on the Terraform Registry? Where do proprietary services like Terraform Cloud and Terraform Enterprise fit in? All these questions and more are answered in this chapter.

Chapter 7 introduces Kubernetes and the Google Cloud Platform (GCP). We deploy and test-run a CI/CD pipeline for running containerized applications on GCP. We also cover some of the neat tricks you can do with `local-exec` provisioners.

Chapter 8 is a fun chapter that brings together all three clouds into a single scenario. We look at multiple ways of approaching the multi-cloud, from easy (creating a multi-cloud load balancer) to hard (orchestrating and federating multiple Nomad and Consul clusters). The goal of this chapter is to impart a sense of awe and the feeling that Terraform can do just about anything you want it to do.

5 Serverless made easy

This chapter covers

- Deploying a serverless web application in Azure
- Understanding design patterns for Terraform modules
- Downloading arbitrary code with Terraform
- Combining Terraform with Azure Resource Manager (ARM)

Serverless is one of the biggest marketing gimmicks of all time. It seems like everything is marketed as "serverless" despite nobody even being able to agree on what the word means. *Serverless* definitely does *not* refer to the elimination of servers; it usually means the opposite since distributed systems often involve many more servers than traditional system design.

One thing that can be agreed on is that serverless is not a single technology; it's a suite of related technologies sharing two key characteristics:

- Pay-as-you-go billing
- Minimal operational overhead

Pay-as-you-go billing is about paying for the actual quantity of resources consumed rather than pre-purchased units of capacity (i.e. pay for what you use, not what you don't use). Minimal operational overhead means the cloud provider takes on most or all responsibility for scaling, maintaining, and managing the service.

There are many benefits of choosing serverless, chief of which is that less work is required, but the tradeoff is that you have less control. If on-premises data centers require the most work (and most control) and software as a service (SaaS) requires the least work (and offers the least control), then serverless is between these extremes but edging closer to SaaS (see figure 5.1).

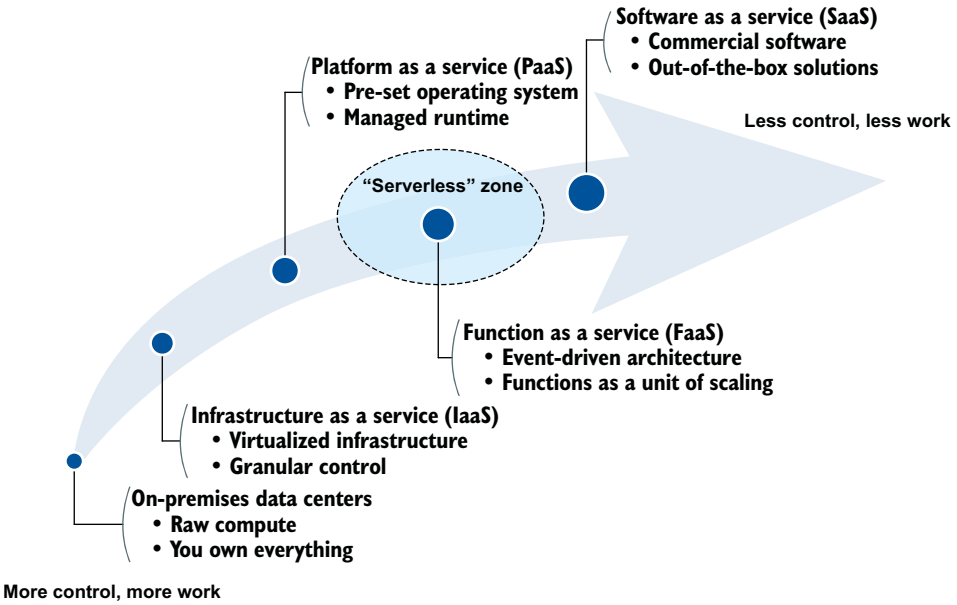


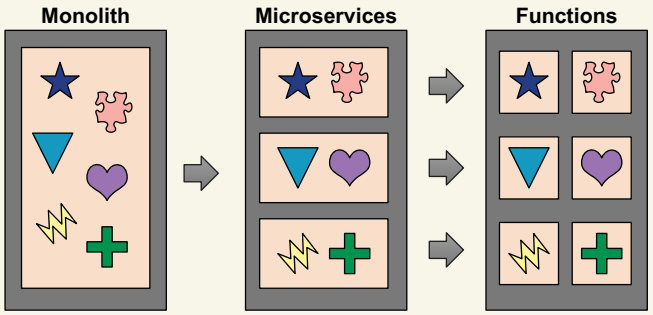
Figure 5.1 ***Serverless*** **is an umbrella term for technologies ranging between platform as a service (PaaS) and software as a service (SaaS).**

In this chapter, we deploy an Azure Functions website with Terraform. *Azure Functions* is a serverless technology similar to AWS Lambda or Google Cloud Functions, which allows you to run code without worrying about servers. Our web architecture will be similar to what we deployed in chapter 4, but serverless.

Functions are atomic

Like the indivisible nature of atoms, functions are the smallest unit of logic that can be expressed in programming. Functions are the result of breaking the monolith into its basic constituents. The primary advantages of functions are that they are easy to test and easy to scale, making them ideal for serverless applications. The downside

is that they require substantially more wiring between components since functions are stateless and inherently more compartmentalized.



Functions are the final result of breaking the monolith up into its smallest constituents

5.1 The "two-penny website"

This scenario is something I like to call "the two-penny website" because that's how much I estimate it will cost to run every month. If you can scrounge some coins from between your sofa cushions, you'll be good for at least a year of web hosting. For most low-traffic web applications, the true cost will likely be even less, perhaps even rounding down to nothing.

The website we will deploy is a ballroom dancing forum called Ballroom Dancers Anonymous. Unauthenticated users can leave public comments that are displayed on the website and stored in a database. The design is fairly simple, making it well suited for use in other applications. A sneak peek of the final product is shown in figure 5.2.

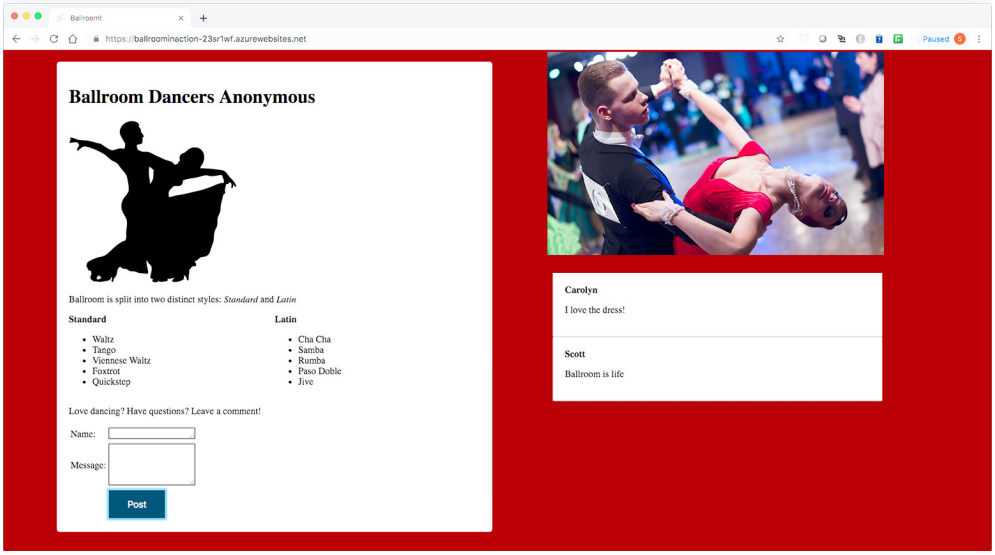


Figure 5.2 Ballroom Dancers Anonymous website

We will use Azure to deploy the serverless website, but it shouldn't feel any different than deploying to AWS. A basic deployment strategy is shown in figure 5.3.

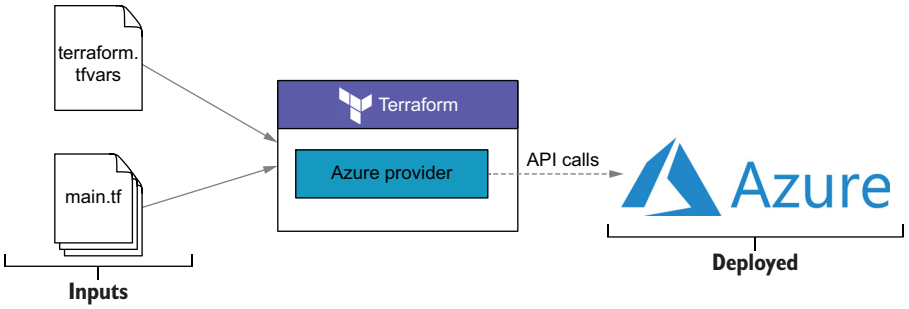


Figure 5.3 Deploying to Azure is no different from deploying to AWS.

NOTE If you would like to see an AWS Lambda example, I recommend taking a look at the source code for the pet store module deployed in chapter 11.

5.2 Architecture and planning

Although the website costs only pennies to run, it is by no means a toy. Because it's deployed on Azure Functions, it can rapidly scale out to handle tremendous spikes in

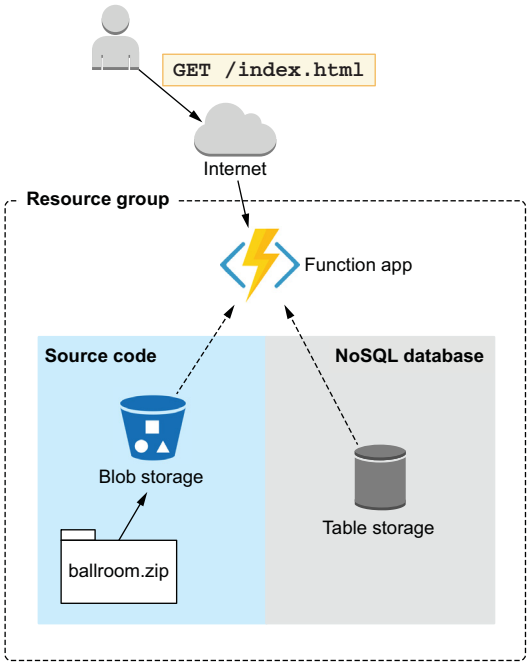


Figure 5.4 An Azure function app listens for HTTP requests coming from the internet. When a request is made, it starts a just-in-time web server from source code located in a storage container. All stateful data is stored in a NoSQL database using a service called Azure Table Storage.

traffic and do so with low latency. It also uses HTTPS (something the previous chapter's scenario did not) and a NoSQL database, and it serves both static content (HTML/CSS/JS) and a REST API. Figure 5.4 shows an architecture diagram.

5.2.1 Sorting by group and then by size

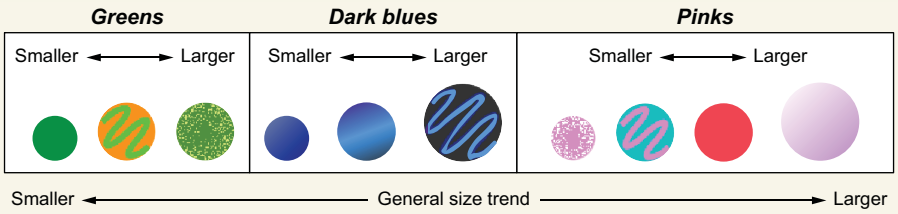
Because the code we're writing is relatively short and cohesive, it's best to put it all in a single main.tf file instead of using nested modules.

> **TIP** As a rule of thumb, I suggest having no more than a few hundred lines of code per Terraform file. Any more, and it becomes difficult to build a mental map of how the code works. Of course, the exact number is for you to decide.

If we are not going to use nested modules, how should we organize the code so that it's easy to read and understand? As discussed in chapter 4, organizing code based on the number of dependencies is a sound approach: resources with fewer dependencies are located toward the top of the file and vice versa. This leaves room for ambiguity, especially when two resources have the same number of dependencies.

Grouping resources that belong together

By "belong together," I mean the intuitive sense that things either are related or are not. Sorting resources purely by the number of dependencies is not always the best idea. For example, if you had a bag of multicolored marbles, sorting them from smallest to largest might be a good starting point, but it wouldn't help you find marbles of a particular color. It would be better to first group marbles by color, then sort by size, and finally organize the groups so that the overall trend followed increasing marble size.



Sorting marbles with respect to size and color. Generally, size increases as you go from left to right, but there are exceptions.

The idea of organizing by some characteristic other than the number of resource dependencies (henceforth called *size*) is a common strategy when writing clean Terraform code. The idea is to first group related resources, then sort each group by size, and finally organize the groups so the overall trend is increasing size (see figure 5.5). This makes your code both easy to read and easy to understand.

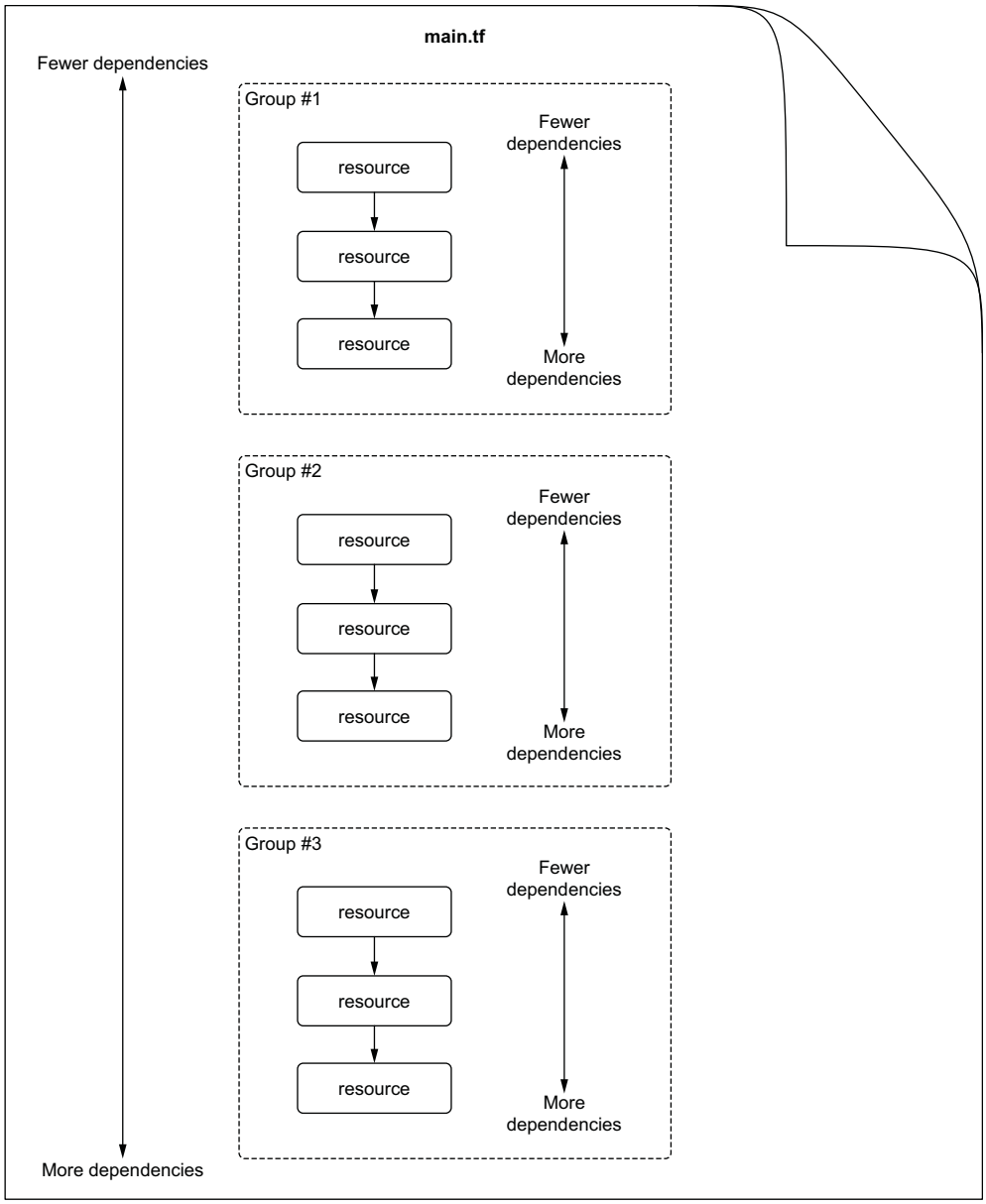


Figure 5.5 Configuration files should be sorted first by group and then by size. The overall trend is increasing size.

Just as it's quicker to search for a word in a dictionary than a word-search puzzle, it's faster to find what you're looking for when your code is organized in a sensible manner (such as the sorting pattern shown in figure 5.5). I have divided this project into

four groups, each serving a specific purpose in the overall application deployment. These groups are as follows:

- *Resource group*—This is the name of an Azure resource that creates a project container. The resource group and other base-level resources reside at the top of main.tf because they are not dependent on any other resource.
- *Storage container*—Similar to an S3 bucket, an Azure storage container stores the versioned build artifact (source code) that will be used by Azure Functions. It serves a dual purpose as the NoSQL database.
- *Storage blob*—This is like an S3 object and is uploaded to the storage container.
- *Azure Functions app*—Anything related to deploying and configuring an Azure Functions app is considered part of this group.

The overall architecture is illustrated in figure 5.6.

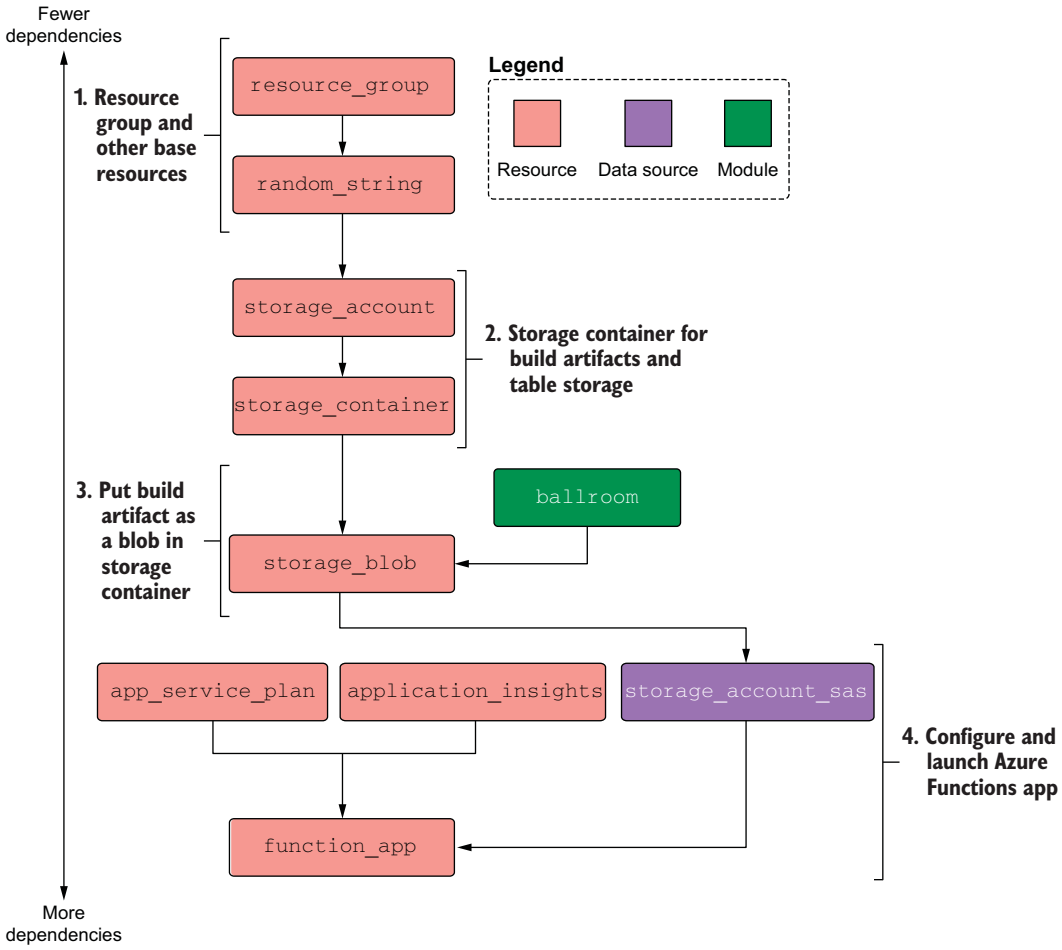


Figure 5.6 The project has four main groups, each serving a distinct purpose.

Finally, we need to consider inputs and outputs. There are two input variables: `location` and `namespace`. `location` is used to configure the Azure region, while `namespace` provides a consistent naming scheme, as we have seen before. The sole output value is `website_url`, which is a link to the final website (see figure 5.7).

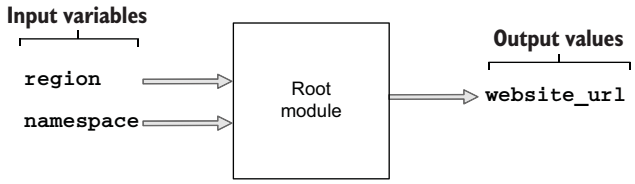


Figure 5.7 Overall input variables and output values of the root module

5.3 Writing the code

Recall the we need to create four groups:

- Resource group
- Storage container
- Storage blob
- Azure Functions app

Before jumping into the code, we need to authenticate to Microsoft Azure and set the required input variables. Refer to appendix B for a tutorial on authenticating to Azure using the CLI method.

Authenticating to Azure

The Azure provider supports four different methods for authenticating to Azure (https://registry.terraform.io/providers/hashicorp/azurerm/latest/docs):

- Using the Azure CLI
- Using a managed service identity
- Using a service principal and a client certificate
- Using a service principal and a client secret

The first method is the easiest, but the others are better when you're running Terraform in automation.

After you've obtained credentials to Azure, create a new workspace containing three files: variables.tf, terraform.tfvars, and providers.tf. Then insert the contents of the following listing into variables.tf.

Listing 5.1 variables.tf

```
variable "location" {
  type    = string
```

```
  default = "westus2"
}

variable "namespace" {
  type    = string
  default = "ballroominaction"
}
```

Now we will set the variables; the next listing shows the contents of terraform.tfvars. Technically, we don't need to set `location` or `namespace`, since the defaults are fine, but it's always a good idea to be thorough.

Listing 5.2 terraform.tfvars

```
location  = "westus2"
namespace = "ballroominaction"
```

Since I expect you to obtain credentials via the CLI login, the Azure provider declaration is empty. If you are using one of the other methods, it may not be.

> **TIP** Whatever you do, do not hardcode secrets in the Terraform configuration. You do not want to accidentally check sensitive information into version control. We discuss how to manage secrets in chapters 6 and 13.

Listing 5.3 providers.tf

```
provider "azurerm" {
  features {}
}
```

5.3.1 Resource group

Now we're ready to write the code for the first of the four groups (see figure 5.8). Before we continue, I want to clarify what resource groups are, in case you are not familiar with them.

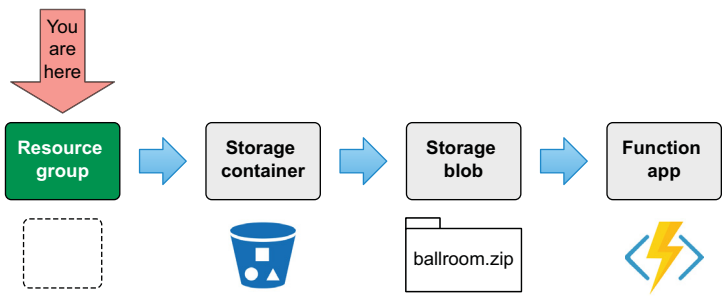


Figure 5.8 Development roadmap—step 1 of 4

In Azure, all resources must be deployed into a resource group, which is essentially a container that stores references to resources. Resource groups are convenient because if a resource group is deleted, all of the resources it contains are also deleted. Each Terraform deployment should get its own resource group to make it easier to keep track of resources (much like tagging in AWS). Resource groups are not unique to Azure—there are equivalents in AWS (https://docs.aws.amazon.com/ARG/latest/userguide/welcome.html) and Google Cloud (https://cloud.google.com/storage/docs/projects)—but Azure is the only cloud that compels their use. The code for creating a resource group is shown next.

Listing 5.4 main.tf

```
resource "azurerm_resource_group" "default" {
  name     = local.namespace
  location = var.location
}
```

In addition to the resource group, we want to use the Random provider again to ensure sufficient randomness beyond what the `namespace` variable supplies. This is because some resources in Azure must be unique not only in your account but globally (i.e. across all Azure accounts). The code in listing 5.5 shows how to accomplish this by joining `var.namespace` with the result of `random_string` to effectively create right padding. Add this code before the `azurerm_resource_group` resource to make the dependency relationship clear.

Listing 5.5 main.tf

```
resource "random_string" "rand" {
  length  = 24
  special = false
  upper   = false
}

locals {
  namespace = substr(join("-", [var.namespace, random_string.rand.result]),
  ➥ 0, 24)
}
```

Adds a right pad to the namespace variable and stores the result in a local value

5.3.2 Storage container

We will now use a Azure storage container to store application source code and documents in a NoSQL database (see figure 5.9). The NoSQL database is technically a separate service, known as Azure Table Storage, but it's really just a NoSQL wrapper around ordinary key-value pairs.

Provisioning a container in Azure is a two-step process. First you need to create a storage account, which provides some metadata about where the data will be stored and how much redundancy/data replication you'd like; I recommend sticking with

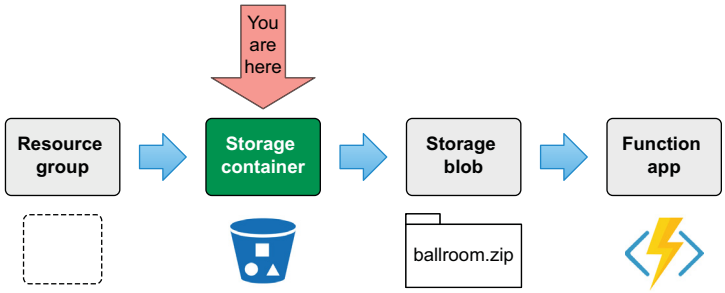


Figure 5.9 Development roadmap—step 2 of 4

standard values because it's a good balance between cost and durability. Second, you need to create the container itself. Following is the code for both steps.

Listing 5.6 main.tf

```
resource "azurerm_storage_account" "storage_account" {
  name                     = random_string.rand.result
  resource_group_name      = azurerm_resource_group.default.name
  location                 = azurerm_resource_group.default.location
  account_tier             = "Standard"
  account_replication_type = "LRS"
}

resource "azurerm_storage_container" "storage_container" {
  name                  = "serverless"
  storage_account_name  = azurerm_storage_account.storage_account.name
  container_access_type = "private"
}
```

NOTE This is the place to add a container for static website hosting in Azure Storage. For this project, it isn't necessary because Azure Functions will serve the static content along with the REST API (which is not ideal).

Why not use static website hosting in Azure Storage?

While it is possible—and even recommended—to use Azure Storage as a content delivery network (CDN) for hosting static web content, unfortunately it isn't currently possible for the Azure provider to do this. Some people have skirted the issue by using local-exec resource provisioners, but this isn't best practice. Chapter 7 covers how to use resource provisioners in depth.

5.3.3 Storage blob

One of the things I like best about Azure Functions is that it gives you many different options regarding how you want to deploy your source code. For example, you can do the following:

- Use the Azure Functions CLI tool.
- Manually edit the code using the UI.

- Use an extension for VS Code.
- Run from a zip package referenced with a publicly accessible URL.

For this scenario, we'll use the last method (running from a zip package referenced with a publicly accessible URL) because it allows us to deploy the project with a single `terraform apply` command. So now we have to upload a storage blob to the storage container (see figure 5.10).

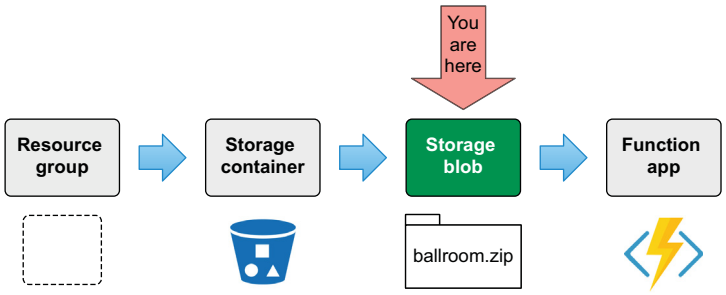


Figure 5.10 Development roadmap—step 3 of 4

At this point, you may be wondering where the source code zip file comes from. Normally, you would already have it on your machine, or it would be downloaded before Terraform executes as part of a continuous integration / continuous delivery (CI/CD) pipeline. Since I wanted this to work with no additional steps, I've packaged the source code zip into a Terraform module, instead.

Remote modules can be fetched from the Terraform Registry with either `terraform init` or `terraform get`. But not only the Terraform configuration is downloaded; *everything* in those modules is downloaded. Therefore, I have stored the entire application source code in a shim module so that it can be downloaded with `terraform init`. Figure 5.11 illustrates how this was done.

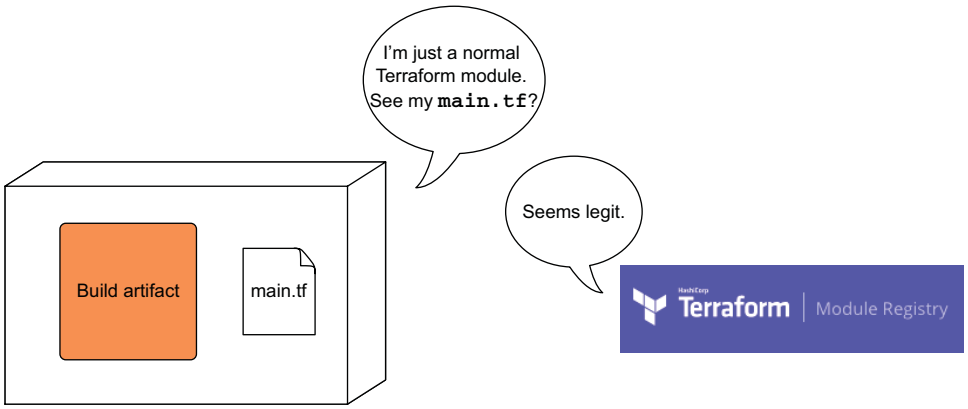


Figure 5.11 Registering a shim module with the Terraform Registry

WARNING Modules can execute malicious code on your local machine by taking advantage of local-exec provisioners. You should always skim the source code of an untrusted module before deploying it.

The shim module is a mechanism for downloading the build artifact onto your local machine. It's certainly not best practice, but it is an interesting technique, and it's convenient for our purposes. Add the following code to main.tf to do this.

Listing 5.7 main.tf

```
module "ballroom" {
  source = "terraform-in-action/ballroom/azure"
}

resource "azurerm_storage_blob" "storage_blob" {
  name                   = "server.zip"
  storage_account_name   = azurerm_storage_account.storage_account.name
  storage_container_name = azurerm_storage_container.storage_container.name
  type                   = "Block"
  source                 = module.ballroom.output_path
}
```

5.3.4 Function app

We will now write the code for the function app (figure 5.12). I wish I could say it was all smooth sailing from here on out, but sadly, that is not the case. The function app needs to be able to download the application source code from the private storage container, which requires a URL that is presigned by a shared access signature (SAS) token.

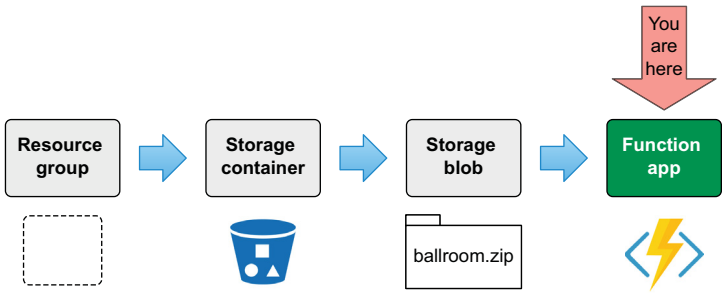


Figure 5.12 Development roadmap—step 4 of 4

Lucky for us, there is a data source for producing the SAS token with Terraform (although it is more verbose than it probably needs to be). The code in listing 5.8 creates a SAS token that allows the invoker to read from an object in the container with an expiry date set in 2048 (Azure Functions continuously uses this token to download the storage blob, so the expiry must be set far in the future).

Listing 5.8 main.tf

```
data "azurerm_storage_account_sas" "storage_sas" {
  connection_string = azurerm_storage_account.storage_account
  ➥ .primary_connection_string

  resource_types {
    service   = false
    container = false
    object    = true
  }

  services {
    blob  = true
    queue = false
    table = false
    file  = false
  }

  start  = "2016-06-19T00:00:00Z"
  expiry = "2048-06-19T00:00:00Z"

  permissions {
    read    = true
    write   = false
    delete  = false
    list    = false
    add     = false
    create  = false
    update  = false
    process = false
  }
}
```

Read-only permissions to blobs in container storage

Now that we have the SAS token, we need to generate the presigned URL. It would be wonderful if there was a data source to do this, but there is not. It's kind of a long calculation, so I took the liberty of setting it to a local value for readability purposes. Add this code to main.tf.

Listing 5.9 main.tf

```
locals {
  package_url = "https://${azurerm_storage_account.storage_account.name}
  ➥ .blob.core.windows.
net/${azurerm_storage_container.storage_container.name}/${azurerm_storage_b
lob.storage_blob.name}${data.azurerm_storage_account_sas.storage_sas.sas}"
}
```

Finally, add the code for creating an `azurerm_application_insights` resource (required for instrumentation and logging) and the `azurerm_function_app` resource.

Listing 5.10 main.tf

```
resource "azurerm_app_service_plan" "plan" {
  name                = local.namespace
  location            = azurerm_resource_group.default.location
  resource_group_name = azurerm_resource_group.default.name
  kind                = "functionapp"
  sku {
    tier = "Dynamic"
    size = "Y1"
  }
}

resource "azurerm_application_insights" "application_insights" {
  name                = local.namespace
  location            = azurerm_resource_group.default.location
  resource_group_name = azurerm_resource_group.default.name
  application_type    = "web"
}

resource "azurerm_function_app" "function" {
  name                = local.namespace
  location            = azurerm_resource_group.default.location
  resource_group_name = azurerm_resource_group.default.name
  app_service_plan_id = azurerm_app_service_plan.plan.id
  https_only          = true

  storage_account_name       = azurerm_storage_account.storage_account.name
  storage_account_access_key = azurerm_storage_account.storage_account
  ➥ .primary_access_key
  version                    = "~2"

  app_settings = {
    FUNCTIONS_WORKER_RUNTIME       = "node"
    WEBSITE_RUN_FROM_PACKAGE       = local.package_url
    WEBSITE_NODE_DEFAULT_VERSION   = "10.14.1"
    APPINSIGHTS_INSTRUMENTATIONKEY = azurerm_application_insights
    ➥ .application_insights.instrumentation_key
    TABLES_CONNECTION_STRING       = data.azurerm_storage_account_sas
    ➥ .storage_sas.connection_string
    AzureWebJobsDisableHomepage    = true
  }
}
```

Points to the build artifact

Allows the app to connect to the database

5.3.5 Final touches

We're in the home stretch! All we have to do now is version-lock the providers and set the output value so that we'll have an easy link to the deployed website. Create a new file called versions.tf, and insert the following code.

Listing 5.11 versions.tf

```
terraform {
  required_version = ">= 0.15"
  required_providers {
```

```
    azurerm = {
      source  = "hashicorp/azurerm"
      version = "~> 2.47"
    }
    archive = {
      source  = "hashicorp/archive"
      version = "~> 2.0"
    }
    random = {
      source  = "hashicorp/random"
      version = "~> 3.0"
    }
  }
}
```

The outputs.tf file is also quite simple.

Listing 5.12 outputs.tf

```
output "website_url" {
    value = "https://${local.namespace}.azurewebsites.net/"
}
```

For your reference, the complete code from main.tf is shown next.

Listing 5.13 Complete code for main.tf

```
resource "random_string" "rand" {
  length  = 24
  special = false
  upper   = false
}

locals {
  namespace = substr(join("-", [var.namespace, random_string.rand.result]),
0, 24)
}

resource "azurerm_resource_group" "default" {
  name     = local.namespace
  location = var.location
}

resource "azurerm_storage_account" "storage_account" {
  name                     = random_string.rand.result
  resource_group_name      = azurerm_resource_group.default.name
  location                 = azurerm_resource_group.default.location
  account_tier             = "Standard"
  account_replication_type = "LRS"
}

resource "azurerm_storage_container" "storage_container" {
  name                  = "serverless"
  storage_account_name  = azurerm_storage_account.storage_account.name
```

```
  container_access_type = "private"
}

module "ballroom" {
  source = "terraform-in-action/ballroom/azure"
}

resource "azurerm_storage_blob" "storage_blob" {
  name                   = "server.zip"
  storage_account_name   = azurerm_storage_account.storage_account.name
  storage_container_name = azurerm_storage_container.storage_container.name
  type                   = "Block"
  source                 = module.ballroom.output_path
}

data "azurerm_storage_account_sas" "storage_sas" {
  connection_string =
azurerm_storage_account.storage_account.primary_connection_string

  resource_types {
    service   = false
    container = false
    object    = true
  }

  services {
    blob  = true
    queue = false
    table = false
    file  = false
  }

  start  = "2016-06-19T00:00:00Z"
  expiry = "2048-06-19T00:00:00Z"

  permissions {
    read    = true
    write   = false
    delete  = false
    list    = false
    add     = false
    create  = false
    update  = false
    process = false
  }
}

locals {
  package_url = "https://${azurerm_storage_account.storage_account.name}
  ➥ .blob.core.windows.
net/${azurerm_storage_container.storage_container.name}/${azurerm_storage_b
lob.storage_blob.name}${data.azurerm_storage_account_sas.storage_sas.sas}"
}

resource "azurerm_app_service_plan" "plan" {
  name                = local.namespace
```

```
  location            = azurerm_resource_group.default.location
  resource_group_name = azurerm_resource_group.default.name
  kind                = "functionapp"

  sku {
    tier = "Dynamic"
    size = "Y1"
  }
}

resource "azurerm_application_insights" "application_insights" {
  name                = local.namespace
  location            = azurerm_resource_group.default.location
  resource_group_name = azurerm_resource_group.default.name
  application_type    = "web"
}

resource "azurerm_function_app" "function" {
  name                = local.namespace
  location            = azurerm_resource_group.default.location
  resource_group_name = azurerm_resource_group.default.name
  app_service_plan_id = azurerm_app_service_plan.plan.id
  https_only          = true

  storage_account_name       = azurerm_storage_account.storage_account.name
  storage_account_access_key =
azurerm_storage_account.storage_account.primary_access_key
  version                    = "~2"

  app_settings = {
    FUNCTIONS_WORKER_RUNTIME       = "node"
    WEBSITE_RUN_FROM_PACKAGE       = local.package_url
    WEBSITE_NODE_DEFAULT_VERSION   = "10.14.1"
    APPINSIGHTS_INSTRUMENTATIONKEY =
     azurerm_application_insights.application_insights.instrumentation_key
    TABLES_CONNECTION_STRING       =
data.azurerm_storage_account_sas.storage_sas.connection_string
    AzureWebJobsDisableHomepage    = true
  }
}
```

NOTE Some people like to declare local values all together at the top of the file, but I prefer to declare them next to the resources that use them. Either approach is valid.

5.4 Deploying to Azure

We are done with the four steps required to set up the Azure serverless project and are ready to deploy! Run `terraform init` and `terraform plan` to initialize Terraform and verify that the configuration code is correct:

```
$ terraform init && terraform plan
 ...
  # azurerm_storage_container.storage_container will be created
  + resource "azurerm_storage_container" "storage_container" {
      + container_access_type   = "private"
```

```
      + has_immutability_policy = (known after apply)
      + has_legal_hold          = (known after apply)
      + id                      = (known after apply)
      + metadata                = (known after apply)
      + name                    = "serverless"
      + properties              = (known after apply)
      + resource_group_name     = (known after apply)
      + storage_account_name    = (known after apply)
    }

  # random_string.rand will be created
  + resource "random_string" "rand" {
      + id          = (known after apply)
      + length      = 24
      + lower       = true
      + min_lower   = 0
      + min_numeric = 0
      + min_special = 0
      + min_upper   = 0
      + number      = true
      + result      = (known after apply)
      + special     = false
      + upper       = false
    }

Plan: 8 to add, 0 to change, 0 to destroy.

Changes to Outputs:
  + website_url = (known after apply)

------------------------------------------------------------------------

Note: You didn't specify an "-out" parameter to save this plan, so Terraform
can't guarantee that exactly these actions will be performed if
"terraform apply" is subsequently run.
```

Next, deploy with `terraform apply`. The command and subsequent output are shown next.

> **WARNING!** You should probably run `terraform plan` first. I use `terraform apply -auto-approve` here only to save space.

```
$ terraform apply -auto-approve
...
azurerm_function_app.function: Still creating... [10s elapsed]
azurerm_function_app.function: Still creating... [20s elapsed]
azurerm_function_app.function: Still creating... [30s elapsed]
azurerm_function_app.function: Still creating... [40s elapsed]
azurerm_function_app.function: Creation complete after 48s
[id=/subscriptions/7deeca5c-dc46-45c0-8c4c-
7c3068de3f63/resourceGroups/ballroominaction/providers/Microsoft.Web/sites/
ballroominaction-23sr1wf]

Apply complete! Resources: 8 added, 0 changed, 0 destroyed.

Outputs:

website_url = https://ballroominaction-23sr1wf.azurewebsites.net/
```

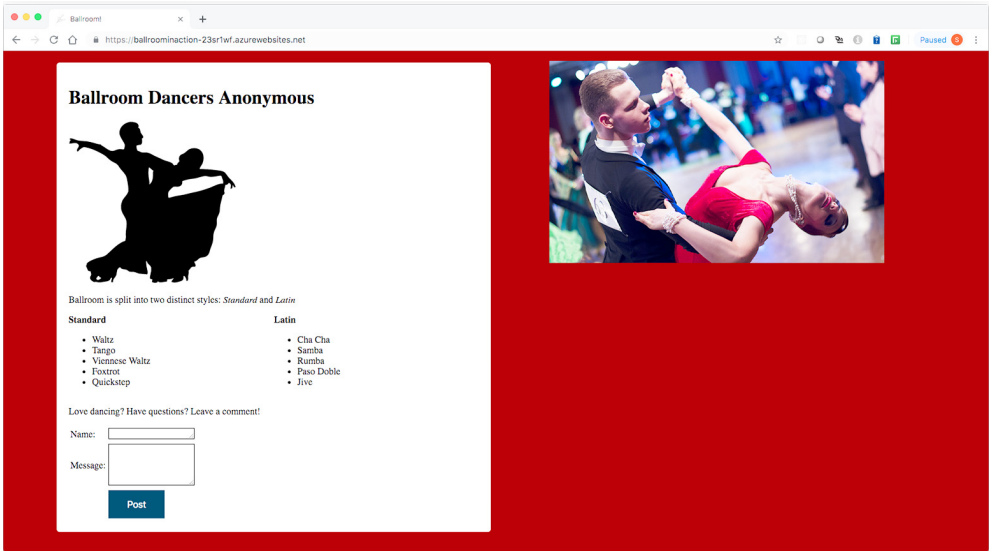


Figure 5.13 Deployed Ballroom Dancers Anonymous website

You can navigate to the deployed website in the browser. Figure 5.13 shows what this will look like.

> **NOTE** It's surprisingly hard to find simple examples for Azure serverless projects, so I've intentionally made the source code minimalistic. Feel free to peruse my work or use it as a template for your own serverless projects. You can find it on GitHub (https://github.com/terraform-in-action/terraform-azure-ballroom) or in the .terraform/modules/ballroom directory.

Don't forget to call `terraform destroy` to clean up! This tears down all the infrastructure provisioned in Azure:

```
$ terraform destroy -auto-approve
   ...
azurerm_resource_group.default: Still destroying...
[id=/subscriptions/7deeca5c-dc46-45c0-8c4c-
...de3f63/resourceGroups/ballroominaction, 1m30s elapsed]
azurerm_resource_group.default: Still destroying...
[id=/subscriptions/7deeca5c-dc46-45c0-8c4c-
...de3f63/resourceGroups/ballroominaction, 1m40s elapsed]
azurerm_resource_group.default: Destruction complete after 1m48s

Destroy complete! Resources: 8 destroyed.
```

5.5 Combining Azure Resource Manager (ARM) with Terraform

Azure Resource Manager (ARM) is Microsoft's infrastructure as code (IaC) technology that allows you to provision resources to Azure using JSON configuration files. If you've ever used AWS CloudFormation or GCP Deployment Manager, it's a lot like

that, so most of the concepts from this section carry over to those technologies. Nowadays, Microsoft is heavily promoting Terraform over ARM, but legacy use cases of ARM still exist. The three cases where I find ARM useful are as follows:

- Deploying resources that aren't yet supported by Terraform
- Migrating legacy ARM code to Terraform
- Generating configuration code

5.5.1 Deploying unsupported resources

Back in ye olden days, when Terraform was still an emerging technology, Terraform providers didn't enjoy the same level of support they have today (even for the major clouds). In Azure's case, many resources were unsupported by Terraform long after their general availability (GA) release. For example, Azure IoT Hub was announced GA in 2016 but did not receive support in the Azure provider until over two years later. In that awkward gap period, if you wished to deploy an IoT Hub from Terraform, your best bet was to deploy an ARM template from Terraform:

```
resource "azurerm_template_deployment" "template_deployment" {
  name                = "terraform-ARM-deployment"
  resource_group_name = azurerm_resource_group.resource_group.name
  template_body       = file("${path.module}/templates/iot.json")
  deployment_mode     = "Incremental"

  parameters = {
    IotHubs_my_iot_hub_name = "ghetto-hub"
  }
}
```

This was a way of bridging the gap between what was possible with Terraform and what was possible with ARM. The same held true for unsupported resources in AWS and GCP by using AWS Cloud Formation and GCP Deployment Manager.

As Terraform has matured, provider support has swelled to encompass more and more resources, and today you'd be hard-pressed to find a resource that Terraform doesn't natively support. Regardless, there are still occasional situations where using an ARM template from Terraform could be a viable strategy for deploying a resource (even if there is a native Terraform resource to do this). Some Terraform resources are just poorly implemented, buggy, or otherwise lacking features, and ARM templates may be a better fit in these circumstances.

5.5.2 Migrating from legacy code

It's likely that before you were using Terraform, you were using some other kind of deployment technology. Let's assume, for the sake of argument, that you were using ARM templates (or CloudFormation, if you are on AWS). How do you migrate your old systems into Terraform without investing considerable time up front? By using the *strangler façade pattern*.

The strangler façade pattern is a pattern for migrating a legacy system to a new system by slowly replacing the legacy parts with new parts until the new system com-

pletely supersedes the old system. At that point, the old system may be safely decommissioned. It's called the strangler façade pattern because the new system is said to "strangle" the legacy system until it dies off (see figure 5.14). You've probably encountered something like this, as it's a fairly common strategy, especially for APIs and services that must uphold a service-level agreement (SLA).

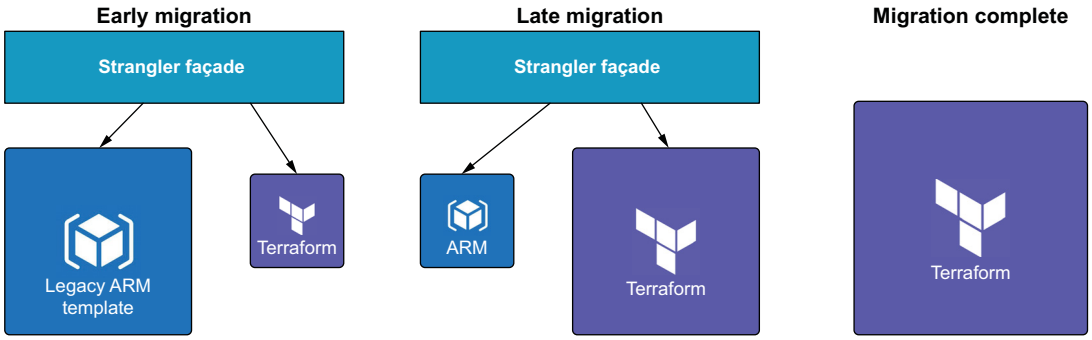


Figure 5.14 The strangler facade pattern for migrating ARM to Terraform. You start with a huge ARM template wrapped with an `azurerm_template_deployment` resource and not much else. Over time, resources are taken out of the ARM template and configured as native Terraform resources. Eventually, you no longer need the ARM template because everything is now a managed Terraform resource.

This applies to Terraform because you can migrate legacy code written in ARM or CloudFormation by wrapping it with an `azurerm_template_deployment` or `aws_cloudformation_stack` resource. Over time, you can incrementally replace specific resources from the old ARM or CloudFormation Stack with native Terraform resources until you are entirely in Terraform.

5.5.3 Generating configuration code

The most painful thing about Terraform is that it takes a lot of work to translate what you want into configuration code. It's usually much easier to point and click around the console until you have what you want and then export that as a template.

> **NOTE** A number of open source projects aim to address this problem, most notably Terraformer: https://github.com/GoogleCloudPlatform/terraformer. HashiCorp also promises that it will improve imports to natively support generating configuration code from deployed resources in a future release of Terraform.

This is exactly what Azure resource groups let you do. You can take any resource group that is currently deployed, export it as an ARM template file, and then deploy that template with Terraform (see figure 5.15).

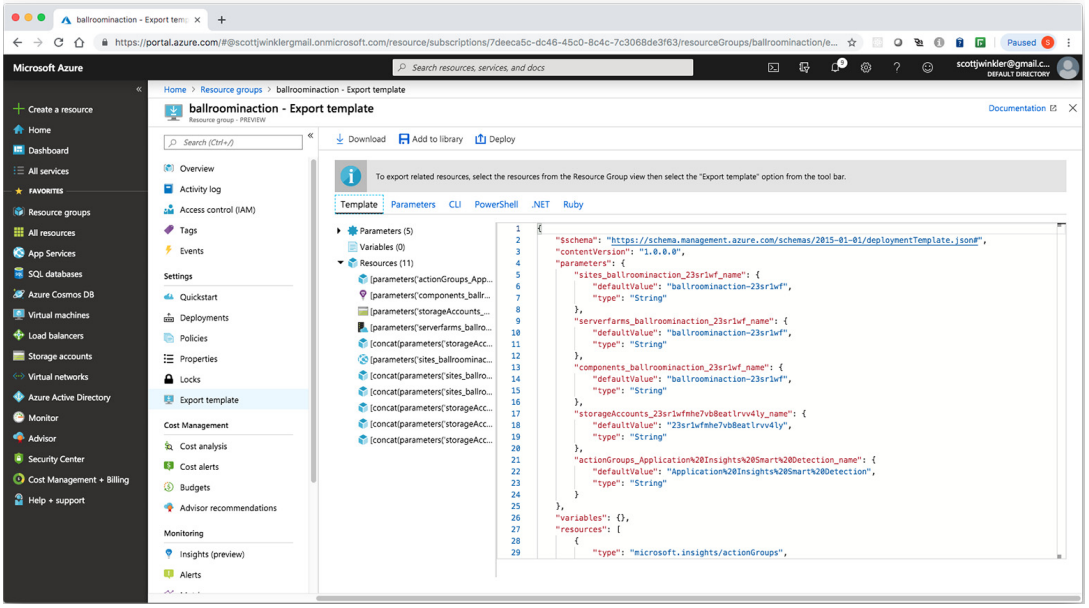


Figure 5.15 You can take any resource group that is currently deployed, export it as an ARM template file, and then deploy that template with Terraform.

> **WARNING** Generated ARM templates are not always a 1:1 mapping of what is currently deployed in a resource group. Refer to the Azure ARM documentation for a definitive reference on what is and is not currently supported: https://docs.microsoft.com/en-us/azure/templates.

The beauty (or curse) of this approach is that you can sketch your entire project in the console and deploy it via Terraform without having to write any configuration code (except a small amount of wrapper code). Sometime in the future, if you wanted to, you could then migrate this quick-and-dirty template to native Terraform using the strangler façade pattern mentioned in the previous section. I like to think of this trick as a form of rapid prototyping.

The dark road of generated code

In addition to Azure Resource Manager, various other tools promise the dream of generated configuration code. If you find yourself with a burning desire to generate configuration code, I highly recommend that you consider using Terraform modules instead. Modules are the recommended vehicle for code reuse in Terraform and can be extremely versatile when you're using features such as dynamic blocks and `for` expressions.

In my opinion, writing Terraform code is the easy part; it's figuring out what you want to do that's hard. Generated code has a high "coolness" factor associated with it;

(continued)

but I believe it's of limited use at best, especially because complex automation and code-generation tools tend to lag behind the latest version of whatever technology they are tailored to.

I'd also like to remind you that just because services like WordPress, Wix, and Squarespace allow non-technical people to create websites, that doesn't mean we've eliminated the need for quality frontend JavaScript developers. It's the same for Terraform. Tools that allow you to generate code should be thought of as potentially useful ways to augment your productivity, rather than as eliminating the need to know how to write clean Terraform code.

5.6 Fireside chat

Terraform is an infrastructure as code tool that facilitates serverless deployments with the same ease as deploying anything else. Although this chapter focused on Azure, deploying serverless onto AWS or GCP is analogous. In fact, the first version of this scenario was written for AWS. I switched to create a better setup for the multi-cloud capstone project in chapter 8. If you are a fan of Azure, then I regret to inform you that after chapter 8, we will resume using AWS for the remainder of the book.

The key takeaway from this chapter is that Terraform can solve various problems, but the way you approach designing Terraform modules is always the same. In the next chapter, we continue our discussion of modules and formally introduce the module registry.

Summary

- Terraform orchestrates serverless deployments with ease. All the resources a serverless deployment needs can be packaged and deployed as part of a single module.
- Code organization is paramount when designing Terraform modules. Generally, you should sort by group and then by size (i.e. number of resource dependencies).
- Any files in a Terraform module are downloaded as part of `terraform init` or `terraform get`. Be careful, because this can lead to downloading and running potentially malicious code.
- Azure Resource Manager (ARM) is an interesting technology that can be combined with Terraform to patch holes in Terraform or even allow you to skip writing Terraform configuration entirely. Use it sparingly, however, because it's not a panacea.

6 Terraform with friends

This chapter covers

- Developing an S3 remote backend module
- Comparing flat vs. nested module structures
- Publishing modules via GitHub and the Terraform Registry
- Switching between workspaces
- Examining Terraform Cloud and Terraform Enterprise

Software development is a team sport. At some point, you'll want to collaborate on Terraform projects with friends and coworkers. Sharing configuration code is easy—any version-controlled source (VCS) repository will do. Sharing state is where it gets difficult. Until now, our state has always been saved to a local backend, which is fine for development purposes and individual contributors but doesn't accommodate shared access. Suppose Sally from site reliability engineering (SRE) wants to make some configuration changes and redeploy. Unless she has access to the existing state file, there is no way to reconcile with what's already in production. Checking in the state file to a VCS repository is not recommended because of the

potential to expose sensitive information and also because doing so doesn't prevent race conditions.

A *race condition* is an undesirable event that occurs when two entities attempt to access or modify shared resources in a given system. In Terraform, race conditions occur when two people are trying to access the same state file at the same time, such as when one is performing a `terraform apply` and another is performing `terraform destroy`. If this happens, your state file can become out of sync with what's actually deployed, resulting in what is known as a *corrupted* state. Using a remote backend end with a state lock prevents this from happening.

In this chapter, we develop an S3 remote backend module and publish it on the Terraform Registry. Next, we deploy the backend and store some state in it. We also talk about workspaces and how they can be used to deploy multiple environments. Finally, we introduce HashiCorp's proprietary products for teams and organizations: Terraform Cloud and Terraform Enterprise.

6.1 Standard and enhanced backends

A *backend* in Terraform determines how state is loaded and how CLI operations like `terraform plan` and `terraform apply` behave. We've actually been using a *local backend* this whole time, because that's Terraform's default behavior. Backends can do the following tasks:

- Synchronize access to state files via locking
- Store sensitive information securely
- Keep a history of all state file revisions
- Override CLI operations

Some backends can completely overhaul the way Terraform works, but most are not much different from a local backend. The main responsibility of any backend is to determine how state files are stored and accessed. For remote backends, this generally means some kind of encryption at rest and state file versioning. You should refer to the documentation for the specific backend you want to use, to learn what is supported and what isn't (www.terraform.io/docs/backends/types).

Besides standard remote backends, there are also *enhanced backends*. Enhanced backends are a relatively new feature and allow you to do more sophisticated things like run CLI operations on a remote machine and stream the results back to your local terminal. They also allow you to read variables and environment variables stored remotely, so there's no need for a variables definition file (terraform.tfvars). Although enhanced backends are great, they currently only work for Terraform Cloud and Terraform Enterprise. Don't worry, though: most people who use Terraform—even at scale—will be perfectly content with any of the standard backends.

The most popular standard backend is the S3 remote backend for AWS (probably because most people use AWS). In the next few sections, I show you how to build and deploy an S3 backend module, as well as the workflow for utilizing it. Figure 6.1 shows a basic diagram of how the S3 backend works.

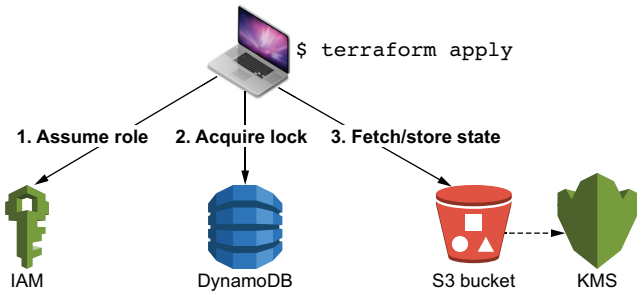


Figure 6.1 How the S3 backend works. State files are encrypted at rest using KMS. Access is controlled by a least-privileged IAM policy, and everything is synchronized with DynamoDB.

6.2 Developing an S3 backend module

Our goal is to develop a module that can eventually be used to deploy a production-ready S3 backend. If your primary cloud is Azure or Google Cloud Platform (GCP), then the code here will not be immediately relevant, but the idea is the same. Since standard backends are more similar than they are dissimilar, you can apply what you learn here to develop a custom solution for whichever backend you prefer.

This project was designed from the exacting requirements laid out in the official documentation (www.terraform.io/docs/backends/types/s3.html), which does an excellent job of explaining *what* you need to do but not *how* to do it. We are told the parts we need but not how to assemble them. Since you're probably going to want to deploy an S3 backend anyway, we'll save you the trouble by working on it together. Also, we'll publish this on the Terraform Registry so it can be shared with others.

6.2.1 Architecture

I always start by considering the overall inputs and outputs from a black-box perspective. There are three input variables for configuring various settings, which we'll talk more about soon, and one output value that has all the information required for workspaces to initialize themselves against the S3 backend. This is depicted in figure 6.2.

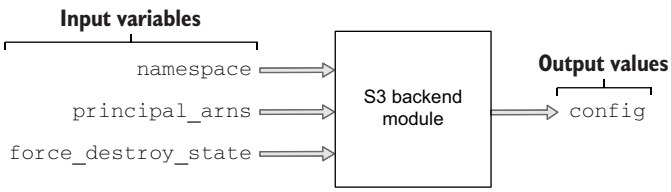


Figure 6.2 There are three inputs and one output for the S3 backend module. The output value `config` has all the information required for a workspace to initialize itself against the S3 backend.

Considering what's inside the box, four distinct components are required to deploy an S3 backend:

- *DynamoDB table*—For state locking.
- *S3 bucket and Key Management Service (KMS) key*—For state storage and encryption at rest.

- *Identity and Access Management (IAM) least-privileged role*—So other AWS accounts can assume a role to this account and perform deployments against the S3 backend.
- *Miscellaneous housekeeping resources*—We'll talk more about these later.

Figure 6.3 helps visualize the relationship from a Terraform dependency perspective. As you can see, there are four independent "islands" of resources. No dependency relationship exists among these resources because they don't depend on each other. These islands, or components, would be excellent candidates for modulization, as discussed in chapter 4, but we won't do that here as it would be overkill. Instead, I'll introduce a different design pattern for organizing code that's perfectly valid for this situation. Although popular, it doesn't have a colloquial name, so I'll simply refer to it as a *flat module*.

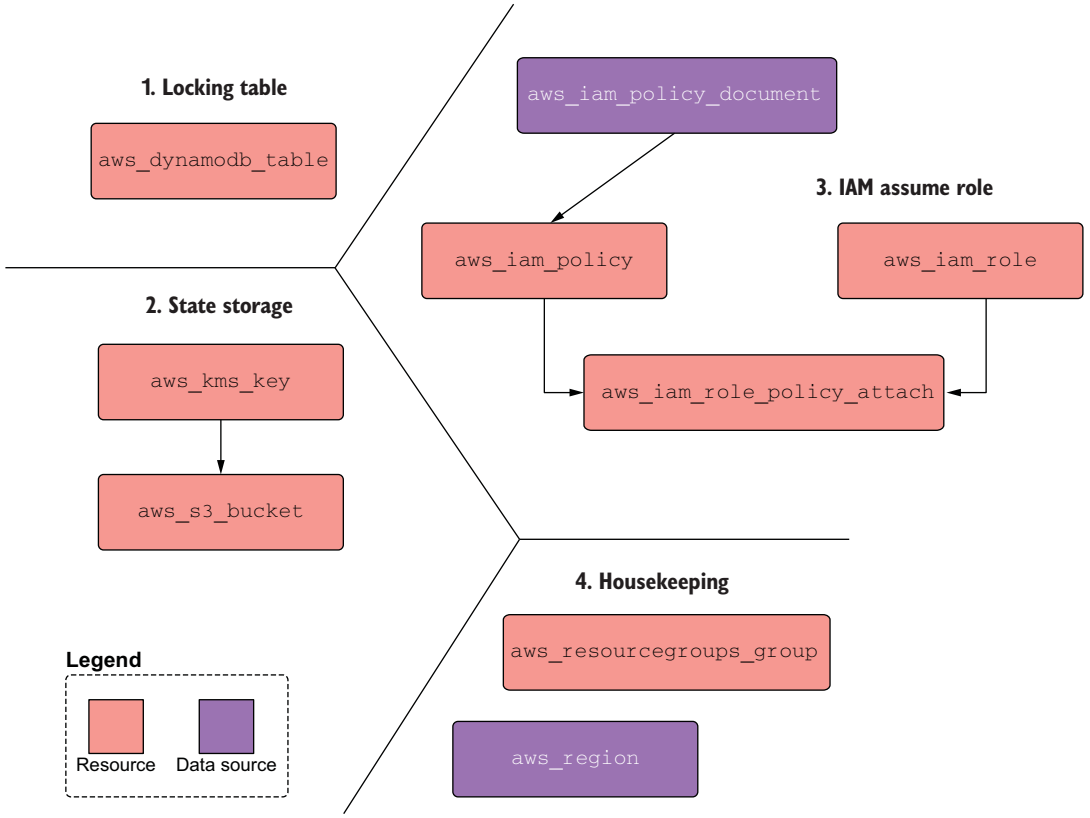


Figure 6.3 Detailed architecture diagram showing the four distinct components that make up this module

6.2.2 Flat modules

Flat modules (as opposed to *nested modules*) organize your codebase as lots of little .tf files within a single monolithic module. Each file in the module contains all the code for deploying an individual component, which would otherwise be broken out into its

own module. The primary advantage of flat modules over nested modules is a reduced need for boilerplate, as you don't have to plumb any of the modules together. For example, instead of creating a module for deploying IAM resources, the code could be put into a file named iam.tf. This is illustrated in figure 6.4.

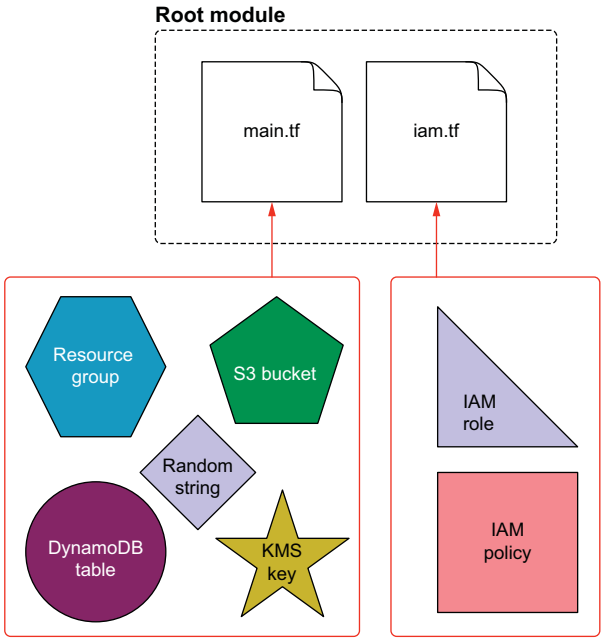


Figure 6.4 A flat module structure applied to the S3 backend module. All IAM resources go in iam.tf, and everything else goes in main.tf.

For this particular scenario, it makes a lot of sense to do it this way: the code for deploying the IAM is inconveniently long to be included in main.tf but not quite long enough to warrant being a separate module.

TIP There's no fixed rule about how long the code in a single configuration file should be, but I try not to include more than a few hundred lines. This is an entirely personal preference.

Flat vs. nested modules

Flat modules are most effective in small-to-medium sized codebases and only when your code can be cleanly subdivided into components that are functionally independent of each other (i.e. that don't have dependencies on resources declared in other files). On the other hand, nested module structures tend to be more useful for larger, more complex, and shared codebases.

To give you a reason this is the case, think of flat modules as analogous to a codebase that uses a lot of global variables. Global variables are not inherently bad and can make your code quicker to write and more compact; but if you have to chase

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where all the references to those global variables end up, it can be challenging. Of course, a lot of this has to do with your ability to write clean code; but I still think nested modules are easier to reason about, compared to flat modules, because you don't have to think as much about how changes to a resource in one file might affect resources in a different file. The module inputs and outputs serve as a convenient interface to abstract a lot of implementation details.

Regardless of the design pattern you settle on, understand that no design pattern is perfect in all situations. There are always tradeoffs and exceptions to the rule.

WARNING Think carefully before deciding to use a flat module for code organization. This pattern tends to result in a high degree of coupling between components, which can make your code more difficult to read and understand.

6.2.3 Writing the code

Let's move on to writing the code. Start by creating six files: variables.tf, main.tf, iam.tf, outputs.tf, versions.tf, and README.md. Listing 6.1 shows the code for variables.tf.

NOTE I have published this as a module in the Terraform Registry, if you want to use that and skip ahead: https://registry.terraform.io/modules/terraform-in-action/s3backend/aws/latest.

Listing 6.1 variables.tf

```
variable "namespace" {
  description = "The project namespace to use for unique resource naming"
  default     = "s3backend"
  type        = string
}

variable "principal_arns" {
  description = "A list of principal arns allowed to assume the IAM role"
  default     = null
  type        = list(string)
}

variable "force_destroy_state" {
  description = "Force destroy the s3 bucket containing state files?"
  default     = true
  type        = bool
}
```

The complete code for provisioning the S3 bucket, KMS key, and DynamoDB table is shown in the next listing. I put all this in main.tf because these are the module's most important resources and because this is the first file most people will look at when reading through your project. The key to flat module design is naming things well and putting them where people exepect to find them.

Listing 6.2 main.tf

```
data "aws_region" "current" {}

resource "random_string" "rand" {
  length  = 24
  special = false
  upper   = false
}

locals {
  namespace = substr(join("-", [var.namespace, random_string.rand.result]),
0, 24)
}

resource "aws_resourcegroups_group" "resourcegroups_group" {
  name = "${local.namespace}-group"

  resource_query {
    query = <<-JSON
{
  "ResourceTypeFilters": [
    "AWS::AllSupported"
  ],
  "TagFilters": [
    {
      "Key": "ResourceGroup",
      "Values": ["${local.namespace}"]
    }
  ]
}
  JSON
  }
}

resource "aws_kms_key" "kms_key" {
  tags = {
    ResourceGroup = local.namespace
  }
}

resource "aws_s3_bucket" "s3_bucket" {
  bucket        = "${local.namespace}-state-bucket"
  force_destroy = var.force_destroy_state

  versioning {
    enabled = true
  }

  server_side_encryption_configuration {
    rule {
      apply_server_side_encryption_by_default {
        sse_algorithm     = "aws:kms"
        kms_master_key_id = aws_kms_key.kms_key.arn
      }
    }
  }
```

Puts resources into a group based on tag

Where the state is stored

```
  tags = {
    ResourceGroup = local.namespace
  }
}

resource "aws_s3_bucket_public_access_block" "s3_bucket" {
  bucket = aws_s3_bucket.s3_bucket.id

  block_public_acls       = true
  block_public_policy     = true
  ignore_public_acls      = true
  restrict_public_buckets = true
}

resource "aws_dynamodb_table" "dynamodb_table" {
  name         = "${local.namespace}-state-lock"
  hash_key     = "LockID"
  billing_mode = "PAY_PER_REQUEST"
  attribute {
    name = "LockID"
    type = "S"
  }
  tags = {
    ResourceGroup = local.namespace
  }
}
```

Makes the database serverless instead of provisioned

The next listing is the code for iam.tf. This particular code creates a least-privileged IAM role that another AWS account can assume to deploy against the S3 backend. To clarify, all of the state files will be stored in an S3 bucket created by the S3 backend, so at a minimum, we expect deployment users to need permissions to put objects in S3. Additionally, they will need permissions to get/delete records from the DynamoDB table that manages locking.

> **NOTE** Having multiple AWS accounts assume a least-priviliged IAM role prevents users from unauthorized access. Some state files store sensitive information in plain text that shouldn't be read by just anyone.

Listing 6.3 iam.tf

```
data "aws_caller_identity" "current" {}

locals {
  principal_arns = var.principal_arns != null ? var.principal_arns :
[data.aws_caller_identity.current.arn]
}

resource "aws_iam_role" "iam_role" {
  name = "${local.namespace}-tf-assume-role"

  assume_role_policy = <<-EOF
    {
      "Version": "2012-10-17",
```

If no principal ARNs are specified, uses the current account

```
      "Statement": [
        {
          "Action": "sts:AssumeRole",
          "Principal": {
              "AWS": ${jsonencode(local.principal_arns)}
          },
          "Effect": "Allow"
        }
      ]
    }
  EOF

  tags = {
    ResourceGroup = local.namespace
  }
}

data "aws_iam_policy_document" "policy_doc" {
  statement {
    actions = [
      "s3:ListBucket",
    ]

    resources = [
      aws_s3_bucket.s3_bucket.arn
    ]
  }

  statement {
    actions = ["s3:GetObject", "s3:PutObject", "s3:DeleteObject"]

    resources = [
      "${aws_s3_bucket.s3_bucket.arn}/*",
    ]
  }

  statement {
    actions = [
      "dynamodb:GetItem",
      "dynamodb:PutItem",
      "dynamodb:DeleteItem"
    ]
    resources = [aws_dynamodb_table.dynamodb_table.arn]
  }
}

resource "aws_iam_policy" "iam_policy" {
  name   = "${local.namespace}-tf-policy"
  path   = "/"
  policy = data.aws_iam_policy_document.policy_doc.json
}

resource "aws_iam_role_policy_attachment" "policy_attach" {
  role       = aws_iam_role.iam_role.name
  policy_arn = aws_iam_policy.iam_policy.arn
}
```

Least-privileged policy to attach to the role

A workspace needs four pieces of information to initialize and deploy against an S3 backend:

- Name of the S3 bucket
- Region the backend was deployed to
- Amazon Resource Name (ARN) of the role that can be assumed
- Name of the DynamoDB table

Since this is not a root module, the outputs need to be bubbled up to be visible after a `terraform apply` (we'll do this later). The outputs are shown next.

Listing 6.4 outputs.tf

```
output "config" {
  value = {
    bucket         = aws_s3_bucket.s3_bucket.bucket
    region         = data.aws_region.current.name
    role_arn       = aws_iam_role.iam_role.arn
    dynamodb_table = aws_dynamodb_table.dynamodb_table.name
  }
}
```

NOTE We don't need a providers.tf because this is a module. The root module will implicitly pass all providers during initialization.

Even though we don't declare providers, it's still a good idea to version lock modules.

Listing 6.5 versions.tf

```
terraform {
  required_version = ">= 0.15"
  required_providers {
      aws = {
          source = "hashicorp/aws"
          version = "~> 3.28"
      }
      random = {
          source = "hashicorp/random"
          version = "~> 3.0"
      }
  }
}
```

Next, we need to create README.md. Believe it or not, having a README.md file is a requirement for registering a module with the Terraform Registry. You have to hand it to HashiCorp for laying down the law about these sorts of things. Let's make a dirt-simple README.md to comply with this requirement (see listing 6.6).

TIP Terraform-docs (https://github.com/segmentio/terraform-docs) is a neat open source tool that automatically generates documentation from your configuration code. I highly recommend it.

Listing 6.6 README.md

You'll probably want to write more documentation, such as what the inputs and outputs are and how to use them.

```
# S3 Backend Module
This module will deploy an S3 remote backend for Terraform
```

Finally, since we'll be uploading this to a GitHub repo, you'll want to create a .gitignore file. A pretty typical one for Terraform modules is shown next.

Listing 6.7 .gitignore

```
.DS_Store
.vscode
*.tfstate
*.tfstate.*
terraform
**/.terraform/*
crash.log
```

6.3 Sharing modules

Great—now we have a module. But how do we share it with friends and coworkers? Although I personally think the Terraform Registry is the best option, there are a number of possible avenues for sharing modules (see figure 6.5). The most common approach is to use GitHub repos, but I've also found S3 buckets to be a good option. In this section, I show you how to publish and source a module two ways: from GitHub and from the Terraform Registry.

> **NOTE** You'll need to upload your code to GitHub even if you wish to use the Terraform Registry because the Terraform Registry sources from public GitHub repos.

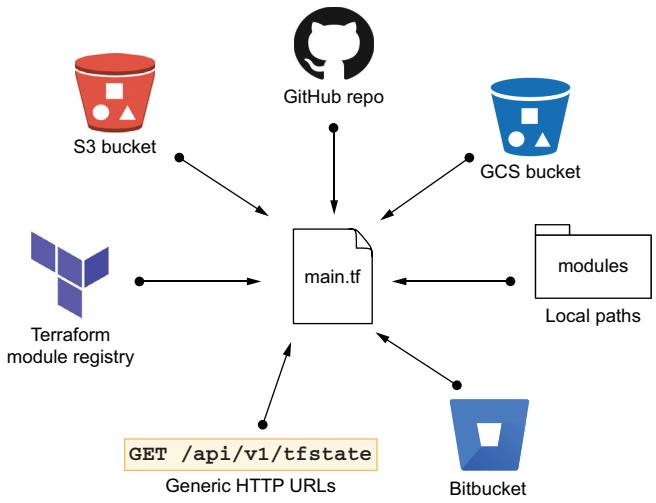


Figure 6.5 Modules can be sourced from multiple possible avenues, including local paths, GitHub repos, and the Terraform Registry.

6.3.1 GitHub

Sourcing modules from GitHub is easy. Just create a repo with a name in the form `terraform-<PROVIDER>-<NAME>`, and put your configuration code there (see figure 6.6). There's no fixed rule about what `PROVIDER` and `NAME` should be, but I typically think of `PROVIDER` as the cloud I am deploying to and `NAME` as a helpful descriptor of the project. Therefore, the module we are deploying will be named `terraform-aws-s3backend`.

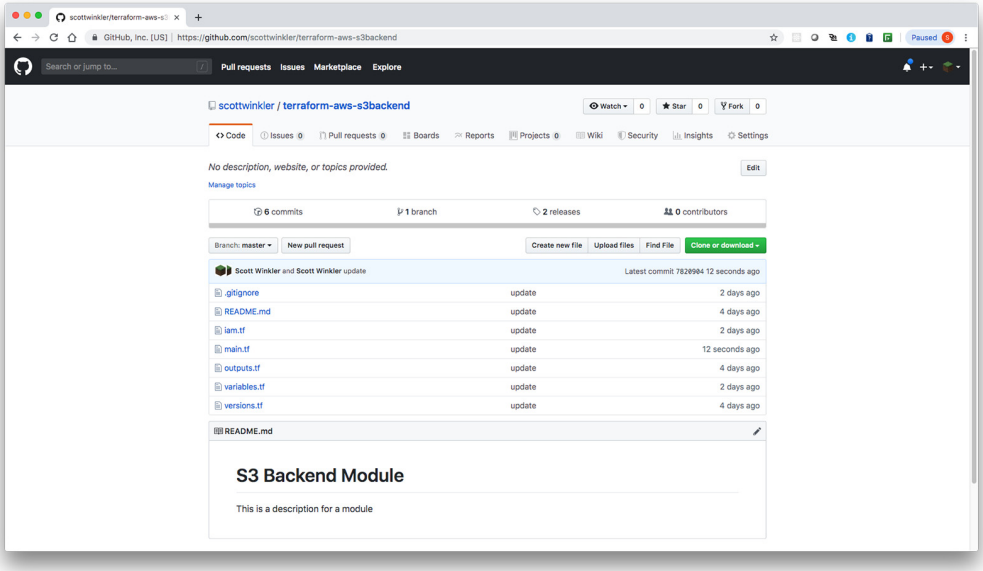


Figure 6.6 Example GitHub repo for the `terraform-aws-s3backend` module

A sample configuration for sourcing a module from a GitHub repo is as follows:

```
module "s3backend" {
    source ="github.com/terraform-in-action/terraform-aws-s3backend"
}
```

> **TIP** You can use a generic Git address to version-control GitHub modules by specifying a branch or tag name. Generic Git URLs are prefixed with the address git::.

6.3.2 Terraform Registry

The Terraform Registry is free and easy to use; all you need is a GitHub account to get started (https://registry.terraform.io). After you sign in, it takes just a few clicks in the UI to register a module so that other people can start using it. Because the Terraform Registry always reads from public GitHub repos, publishing your module in the registry makes your module available to everyone. One of the perks of Terraform Enterprise is

that it lets you have your own private Terraform Registry, which is useful for sharing private modules in large organizations.

> **NOTE** You can also implement the module registry protocol (www.terraform.io/docs/internals/module-registry-protocol.html) if you wish to create your own private module registry.

Implementing the Terraform Registry is not complicated in the least; I think of it as little more than a glorified key-value store that maps source keys to GitHub tags. Its main benefit is that it enforces certain naming conventions and standards based on established best practices for publishing modules. (HashiCorp's best practices for modules can be found at www.terraform.io/docs/modules). It also makes it easy to version-control and search for other people's modules by name or provider. Here's a list of the official rules (www.terraform.io/docs/registry/modules/publish.html):

- Be a public repo on GitHub.
- Have a name in the form `terraform-<PROVIDER>-<NAME>`.
- Have a README.md file (preferably with some example usage code).
- Follow the standard module structure (i.e. have main.tf, variables.tf, and outputs.tf files).
- Use semantic versioned tags for releases (e.g. v0.1.0).

I highly encourage you to try this yourself. In the following figures, you can see how easy it is to do. First, create a release in GitHub using semantic versioning. Next, sign in to the Terraform Registry UI and click the Publish button (figure 6.7). Select

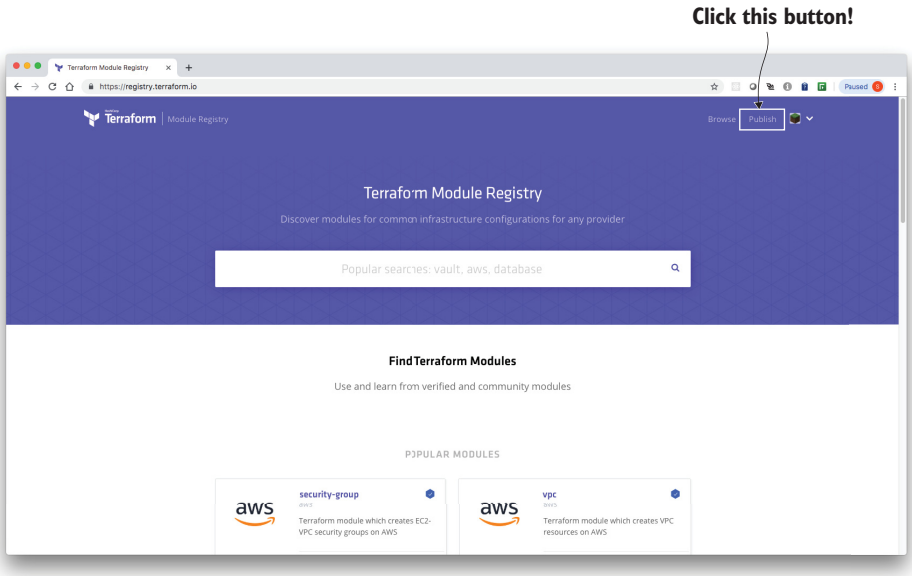


Figure 6.7 Navigate to the Terraform Registry home page.

the GitHub repo you wish to publish (figure 6.8), and wait for it to be published (figure 6.9).

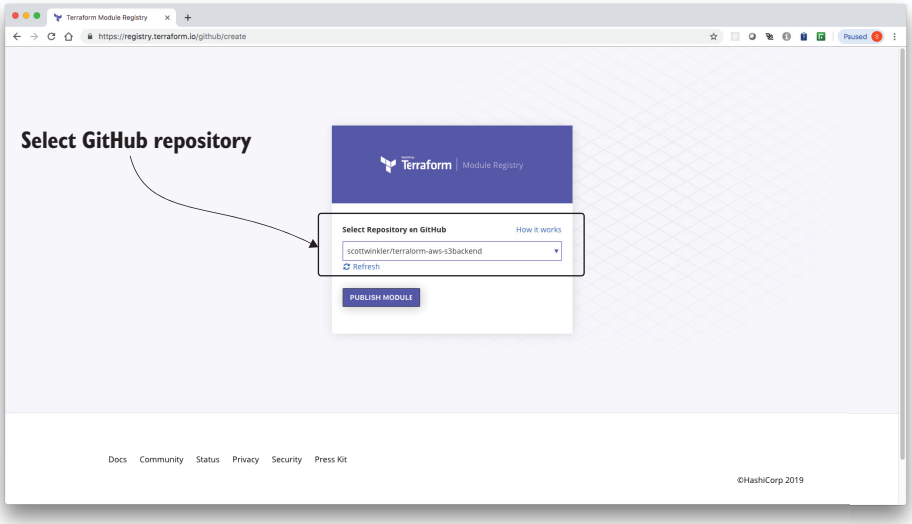


Figure 6.8 Choose a GitHub repo to register as a module.

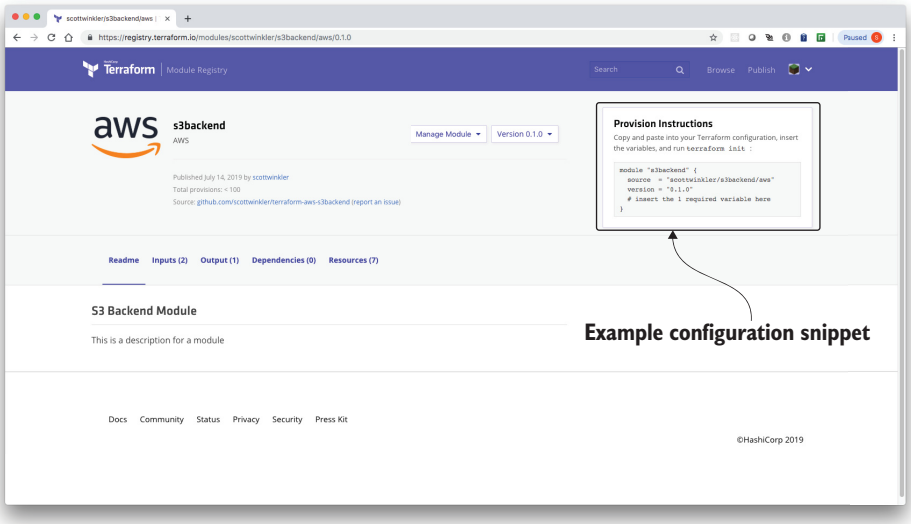


Figure 6.9 Published module in the Terraform Registry

6.4 Everyone gets an S3 backend

Since S3 backends are cheap, especially when using a serverless DynamoDB table like we are, there's no reason not to have lots of them. Deploying one backend per team is a reasonable way to go about partitioning things because you don't want all your state files in one bucket, but you still want to give people enough autonomy to do their job.

> **NOTE** If you are highly disciplined about least-privileged IAM roles, it's fine to have a single backend. That's how Terraform Cloud and Terraform Enterprise work, after all.

Suppose we need to deploy an S3 backend for a motley crew of individuals calling themselves Team Rocket. After we deploy an S3 backend for them, we'll need to verify that we can initialize against it. As part of this process, we'll also cover workspaces and how they can be used to deploy configuration code to multiple environments.

6.4.1 Deploying the S3 backend

We need a root module wrapper for deploying the S3 backend module. If you published the module on GitHub or the Terraform Registry, you can set the source to point to your module; otherwise, you can use the one I've already published. Create a new Terraform project with a file containing the following code.

Listing 6.8 s3backend.tf

```
provider "aws" {
  region = "us-west-2"
}

module "s3backend" {
  source    = "terraform-in-action/s3backend/aws"
  namespace = "team-rocket"
}

output "s3backend_config" {
  value = module.s3backend.config
}
```

You can either update the source to point to your module in the registry or use mine.

Config required to connect to the backend

> **TIP** You can use the `for-each` meta-argument to deploy multiple copies of the `s3backend` module. We talk about how to use for-each on modules in chapter 9.

Start by running `terraform init` followed by `terraform apply`:

```
$ terraform init && terraform apply
...
  # random_string.rand will be created
  + resource "random_string" "rand" {
      + id          = (known after apply)
      + length      = 24
      + lower       = true
```

```
      + min_lower   = 0
      + min_numeric = 0
      + min_special = 0
      + min_upper   = 0
      + number      = true
      + result      = (known after apply)
      + special     = false
      + upper       = false
    }

Plan: 9 to add, 0 to change, 0 to destroy.

Changes to Outputs:
  + config = {
      + bucket         = (known after apply)
      + dynamodb_table = (known after apply)
      + region         = "us-west-2"
      + role_arn       = (known after apply)
    }

Do you want to perform these actions?
  Terraform will perform the actions described above.
  Only 'yes' will be accepted to approve.

  Enter a value:
```

When you're ready, confirm and wait for the resources to be provisioned:

```
...
module.s3backend.aws_iam_policy.iam_policy: Creation complete after 1s
[id=arn:aws:iam::215974853022:policy/tf-policy]
module.s3backend.aws_iam_role_policy_attachment.policy_attach: Creating...
module. s3backend.aws_iam_role_policy_attachment.policy_attach: Creation
complete after 1s [id=tf-assume-role-20190722062228664100000001]

Apply complete! Resources: 9 added, 0 changed, 0 destroyed.

Outputs:

config = {
  "bucket" = "team-rocket-1qh28hgo0g1c-state-bucket"
  "dynamodb_table" = "team-rocket-1qh28hgo0g1c-state-lock"
  "region" = "us-west-2"
  "role_arn" = "arn:aws:iam::215974853022:role/team-rocket-1qh28hgo0g1c-tf-
assume-role"
}
```

Save the `s3backend_config` output value, as we'll need it in the next step.

6.4.2 Storing state in the S3 backend

Now we're ready for the interesting part: initializing against the S3 backend and verifying that it works. Create a new Terraform project with a test.tf file, and configure the backend using the output from the previous section (see the next listing). We have to

create a unique key for the project, which is basically just a prefix to the object stored in S3. This can be anything, so let's call it `jesse/james`.

Listing 6.9 test.tf

```
terraform {
  backend "s3" {
    bucket         = "team-rocket-1qh28hgo0g1c-state-bucket"
    key            = "jesse/james"
    region         = "us-west-2"
    encrypt        = true
    role_arn       = "arn:aws:iam::215974853022:role/team-rocket-
1qh28hgo0g1c-tf-assume-role"
    dynamodb_table = "team-rocket-1qh28hgo0g1c-state-lock"
  }
  required_version = ">= 0.15"
  required_providers {
    null = {
      source  = "hashicorp/null"
      version = "~> 3.0"
    }
  }
}
```

Backends are configured within Terraform settings.

Replace with the values from the previous output.

NOTE You need AWS credentials to assume the role specified by the backend `role_arn` attribute. By design, it looks for environment variables: `AWS_ACCESS_KEY_ID` and `AWS_SECRET_ACCESS_KEY`, or the default profile stored in your AWS credentials file (the same behavior as the AWS provider). There are also options to override the defaults (www.terraform.io/docs/backends/types/s3.html#configuration-variables).

Next, we need a resource with which to test the S3 backend. This can be any resource, but I like to use a special resource offered by the null provider called `null_resource`. You can do lots of cool hacks with `null_resource` and local-exec provisioners (which I'll delve into in the next chapter), but for now, all you need to know is that the following code provisions a dummy resource that prints "gotta catch em all" to the terminal during a `terraform apply`.

NOTE `null_resource` does not create any "real" infrastructure, making it good for testing purposes.

Listing 6.10 test.tf

```
terraform {
  backend "s3" {
    bucket         = "team-rocket-1qh28hgo0g1c-state-bucket"
    key            = "jesse/james"
    region         = "us-west-2"
    encrypt        = true
    role_arn       = "arn:aws:iam::215974853022:role/team-rocket-
```

```
1qh28hgo0g1c-tf-assume-role"
    dynamodb_table = "team-rocket-1qh28hgo0g1c-state-lock"
  }
  required_version = ">= 0.15"
  required_providers {
    null = {
      source  = "hashicorp/null"
      version = "~> 3.0"
    }
  }
}

resource "null_resource" "motto" {
  triggers = {
    always = timestamp()
  }
  provisioner "local-exec" {
    command = "echo gotta catch em all"
  }
}
```

This is where the magic happens.

Run `terraform init`. The CLI output is a little different than what we've seen before, because now it's connecting to the S3 backend as part of the initialization process:

```
$ terraform init

Initializing the backend...

Successfully configured the backend "s3"! Terraform will automatically
use this backend unless the backend configuration changes.
...
```

When Terraform has finished initializing, run `terraform apply -auto-approve`:

```
$ terraform apply -auto-approve
ull_resource.motto: Creating...
null_resource.motto: Provisioning with 'local-exec'...
null_resource.motto (local-exec): Executing: ["/bin/sh" "-c" "echo gotta
catch em all"]
null_resource.motto (local-exec): gotta catch em all
null_resource.motto: Creation complete after 0s [id=1806217872068888379]
Apply complete! Resources: 1 added, 0 changed, 0 destroyed.
```

Prints "gotta catch em all" to stdout

As you can see, the `null_resource` outputs the catchphrase "gotta catch em all" to the terminal. Also, your state file is now safely stored in the S3 bucket created earlier, under the key `jesse/james` (see figure 6.10).

You can download the state file to view its contents or manually upload a new version, although there is no reason to do this under normal circumstances. It's much easier to manipulate the state file with one of the `terraform state` commands. For example:

```
$ terraform state list
null_resource.motto
```

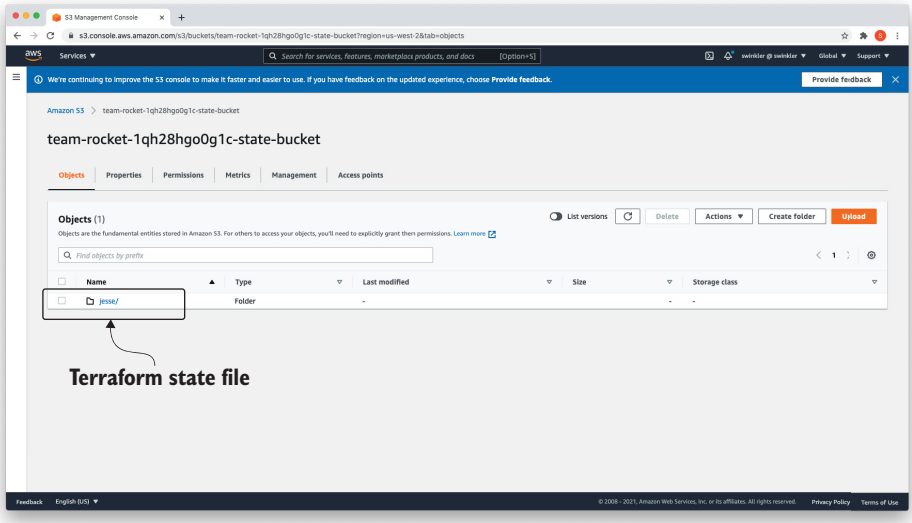


Figure 6.10 The state file is safely stored in the S3 bucket with the key `jesse/james`.

What happens when two people apply at the same time?

In the unlikely event that two people try to deploy against the same remote backend at the same time, only one user will be able to acquire the state lock—the other will fail. The error message received will be as follows:

```
$ terraform apply -auto-approve
Acquiring state lock. This may take a few moments...

Error: Error locking state: Error acquiring the state lock:
ConditionalCheckFailedException: The conditional request failed
    status code: 400, request id:
            PNQMMJD6CTVVTFSUPM537289FFVV4KQNSO5AEMVJF66Q9ASUAAJG
Lock Info:
  ID:        a494a870-6cad-f839-8a6b-9ac288eae7e4
  Path:      pokemon-q56ylfpq6bzrw3dl-state-bucket/jesse/james
  Operation: OperationTypeApply
  Who:       swinkler@OSXSWINKMBP15.local
  Version:   0.12.9
  Created:   2019-11-25 02:47:45.509824 +0000 UTC
  Info:

Terraform acquires a state lock to protect the state from being written
by multiple users at the same time. Please resolve the issue above and try
again. For most commands, you can disable locking with the "-lock=false"
flag, but this is not recommended.
```

After the lock is released, the error message goes away, and subsequent applies will succeed.

6.5 Reusing configuration code with workspaces

Workspaces allow you to have more than one state file for the same configuration code. This means you can deploy to multiple environments without resorting to copying and pasting your configuration code into different folders. Each workspace can use its own variable definitions file to parameterize the environment (see figure 6.11).

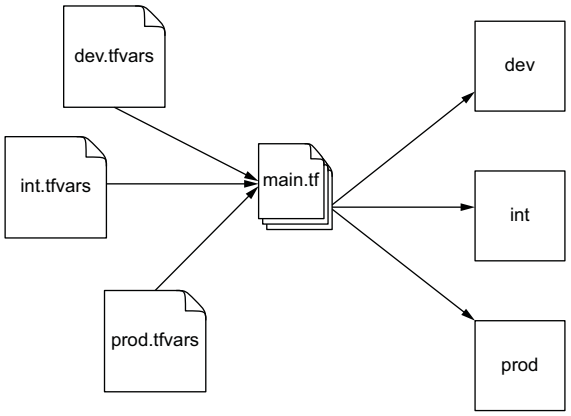


Figure 6.11 Workspaces let you use the same configuration code, parameterized by different variable definitions files, to deploy to multiple environments.

You have already been using workspaces, even if you haven't realized it. Whenever you perform `terraform init`, Terraform creates and switches to a workspace named default. You can prove this by running the command `terraform workspace list`, which lists all workspaces and puts an asterisk next to the one you are currently on:

```
$ terraform workspace list
* default
```

To create and switch to a new workspace other than the default, use the command `terraform workspace select <workspace>`.

Why is this useful, and why do you care? You could have saved your state files under different names, such as dev.tfstate and prod.tfstate, and pointed to them with a command like `terraform apply -state=<path>`. Technically, workspaces are the same as renaming state files. You use workspaces because remote state backends support workspaces and not the `-state` argument. This makes sense when you remember that remote state backends do not store state locally (so there is no state file to point to). I recommend using workspaces even when using a local backend, if only to get in the habit of using them.

6.5.1 Deploying multiple environments

Our null resource deployment is a cute way to test that we can initialize and deploy against the remote stack backend, but it's impractical for describing how to use workspaces effectively. In this section, we try something more real-world-esque: using workspaces to deploy two separate environments, dev and prod. Each environment

will be parameterized by its own variable definitions file to allow us to customize the environment—for example, to deploy to different AWS regions or accounts.

Create a new folder with a main.tf file, as shown in the following listing (replace `bucket`, `profile`, `role_arn`, and `dynamodb_table` as before).

Listing 6.11 main.tf

```
terraform {
  backend "s3" {
    bucket         = "<bucket>"
    key            = "team1/my-cool-project"
    region         = "<region>"
    encrypt        = true
    role_arn       = "<role_arn>"
    dynamodb_table = "<dynamodb_table>"
  }
  required_version = ">= 0.15"
}

variable "region" {
  description = "AWS Region"
  type        = string
}

provider "aws" {
  region  = var.region
}

data "aws_ami" "ubuntu" {
  most_recent = true
  filter {
    name   = "name"
    values = ["ubuntu/images/hvm-ssd/ubuntu-bionic-18.04-amd64-server-*"]
  }
  owners = ["099720109477"]
}

resource "aws_instance" "instance" {
  ami           = data.aws_ami.ubuntu.id
  instance_type = "t2.micro"
  tags = {
    Name = terraform.workspace
  }
}
```

This region is where your remote state backend lives and may be different than the region you are deploying to. Since it is evaluated during initialization, it cannot be configured via a variable.

A special variable, like "path", containing only one attribute: "workspace"

In the current directory, create a folder called environments; and in this directory, create two files: dev.tfvars and prod.tfvars. The contents of these files will set the AWS region to which the EC2 instance will be deployed. An example of the variables definition file for dev.tfvars is shown next.

Listing 6.12 dev.tfvars

```
region = "us-west-2"
```

Next, initialize the workspace as usual:

```
$ terraform init
...
Terraform has been successfully initialized!

You may now begin working with Terraform. Try running "terraform plan" to
see any changes that are required for your infrastructure. All Terraform
commands should now work.

If you ever set or change modules or backend configuration for Terraform,
rerun this command to reinitialize your working directory. If you forget,
other commands will detect it and remind you to do so if necessary.
```

Instead of staying on the default workspace, I suggest immediately switching to a more appropriately named workspace. Most people name workspaces after a GitHub feature branch or deployment environment (such as dev, int, prod, and so on). Let's switch to a workspace called dev to deploy the dev environment:

```
$ terraform workspace new dev
Created and switched to workspace "dev"!

You're now on a new, empty workspace. Workspaces isolate their state,
so if you run "terraform plan" Terraform will not see any existing state
for this configuration.
```

Deploy the configuration code for the dev environment with the dev variables:

```
$ terraform apply -var-file=./environments/dev.tfvars -auto-approve
data.aws_ami.ubuntu: Refreshing state...
aws_instance.instance: Creating...
aws_instance.instance: Still creating... [10s elapsed]
aws_instance.instance: Still creating... [20s elapsed]
aws_instance.instance: Still creating... [30s elapsed]
aws_instance.instance: Creation complete after 38s [id=i-0b7e117464ae7eaa3]

Apply complete! Resources: 1 added, 0 changed, 0 destroyed.
```

The state file has now been created in the S3 bucket under the key `env:/dev/team1/my-cool-project`. Switch to a new prod workspace to deploy the production environment:

```
$ terraform workspace new prod
Created and switched to workspace "prod"!

You're now on a new, empty workspace. Workspaces isolate their state,
so if you run "terraform plan" Terraform will not see any existing state
for this configuration.
```

As we are in the new workspace, the state file is now empty, which we can verify by running a `terraform state list` command and noting that it returns nothing:

```
$ terraform state list
```

Deploying to the prod environment is similar to dev, except now we use prod.tfvars instead of dev.tfvars. I suggest specifying a different region for prod.tfvars, as shown in the following listing.

Listing 6.13 prod.tfvars

```
region = "us-east-1"
```

Deploy to the prod workspace with the prod.tfvars variables definition file:

```
$ terraform apply -var-file=./environments/prod.tfvars -auto-approve
data.aws_ami.ubuntu: Refreshing state...
aws_instance.instance: Creating...
aws_instance.instance: Still creating... [10s elapsed]
aws_instance.instance: Still creating... [20s elapsed]
aws_instance.instance: Still creating... [30s elapsed]
aws_instance.instance: Creation complete after 38s [id=i-042808b20164b509d]

Apply complete! Resources: 1 added, 0 changed, 0 destroyed.
```

NOTE Since we are still using the same configuration code, you do not need to run `terraform init` again.

Now, in S3, we have two state files: one for dev and one for prod (see figure 6.12). You can also inspect the two EC2 instances that were created, named with their workspace names (dev and prod). The states are also stored separately in S3 (see figure 6.13).

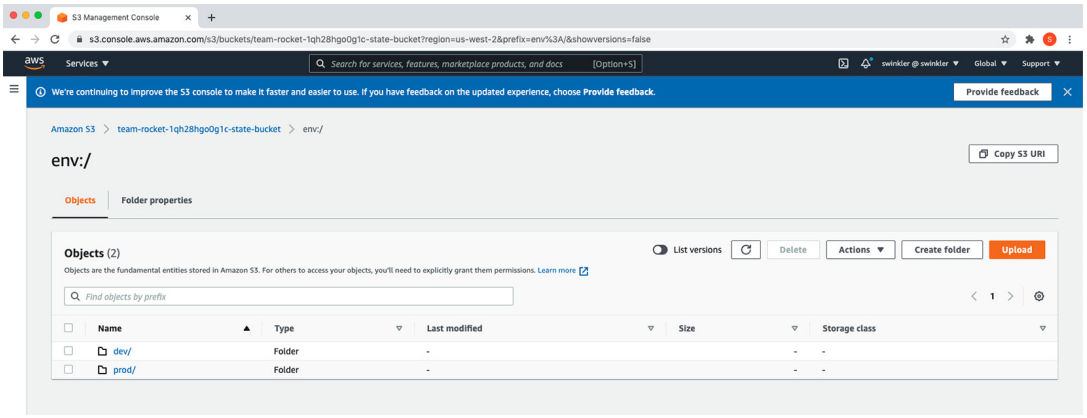


Figure 6.12 There are now two state files under :env corresponding to the dev and prod workspaces.

NOTE I deployed both instances to the same region, rather than different regions, so they would appear in the same screenshot.

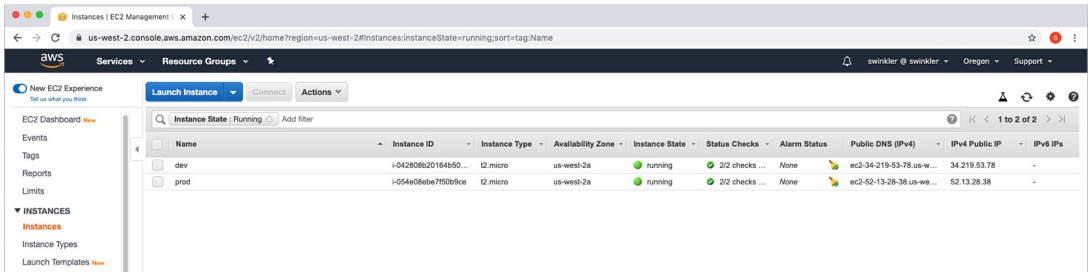


Figure 6.13 Workspaces manage their own state files and their own resources. Here you can see two EC2 instances: one deployed from the dev workspace and one deployed from the prod workspace.

6.5.2 Cleaning up

To clean up, we need to delete the EC2 instances from each environment. Then we can delete the S3 backend.

NOTE You could also delete the EC2 instances through the console.

First, delete the prod deployment:

```
$ terraform destroy -var-file=environments/prodtfvars -auto-approve
data.aws_ami.ubuntu: Refreshing state...
aws_instance.instance: Refreshing state... [id=i-054e08ebe7f50b9ce]
aws_instance.instance: Destroying... [id=i-054e08ebe7f50b9ce]
aws_instance.instance: Still destroying... [id=i-054e08ebe7f50b9ce,
10s elapsed]
aws_instance.instance: Still destroying... [id=i-054e08ebe7f50b9ce,
20s elapsed]
aws_instance.instance: Still destroying... [id=i-054e08ebe7f50b9ce,
30s elapsed]
aws_instance.instance: Destruction complete after 32s

Destroy complete! Resources: 1 destroyed.
Releasing state lock. This may take a few moments...
```

Next, switch into the dev workspace and destroy that:

```
$ terraform workspace select dev
Switched to workspace "dev".

$ terraform destroy -var-file=environments/dev.tfvars -auto-approve
data.aws_ami.ubuntu: Refreshing state...
aws_instance.instance: Refreshing state... [id=i-042808b20164b509d]
aws_instance.instance: Destroying... [id=i-042808b20164b509d]
aws_instance.instance: Still destroying... [id=i-042808b20164b509d,
10s elapsed]
aws_instance.instance: Still destroying... [id=i-042808b20164b509d,
20s elapsed]
aws_instance.instance: Still destroying... [id=i-042808b20164b509d,
30s elapsed]
aws_instance.instance: Destruction complete after 30s
```

```
Destroy complete! Resources: 1 destroyed.
Releasing state lock. This may take a few moments...
```

Finally, switch back into the directory from which you deployed the S3 backend, and run `terraform destroy`:

```
$ terraform destroy -auto-approve
...
module.s3backend.aws_kms_key.kms_key: Still destroying...
[id=16c6c452-2e74-41d4-ae57-067f3b4b8acd, 10s elapsed]
module.s3backend.aws_kms_key.kms_key: Still destroying...
[id=16c6c452-2e74-41d4-ae57-067f3b4b8acd, 20s elapsed]
module.s3backend.aws_kms_key.kms_key: Destruction complete after 24s

Destroy complete! Resources: 8 destroyed.
```

6.6 Introducing Terraform Cloud

Terraform Cloud is the software as a service (SaaS) version of Terraform Enterprise. It has three pricing tiers ranging from free to business (see figure 6.14). The free tier does a lot for you by giving you a free remote state store and enabling VCS/API-driven workflows. Team management, single sign-on (SSO), and Sentinel "policy as code" are some of the bonus features you get when you pay for the higher-tiered offerings. And if you are wondering, the business tier for Terraform Cloud is exactly the same as Terraform Enterprise, except Terraform Enterprise can be run on a private datacenter, whereas Terraform Cloud cannot.

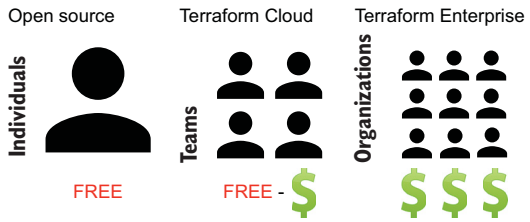


Figure 6.14 The differences between Terraform open source, Terraform Cloud, and Terraform Enterprise

The remote state backend you get from Terraform Cloud does all the same things as an S3 remote backend: it stores state, locks and versions state files, encrypts state files at rest, and allows for fine-grained access control policies. But it also has a nice UI and enables VCS/API-driven workflow.

If you would like to learn more about Terraform Cloud or want to get started, I recommend reading the HashiCorp Learn tutorials on the subject (https://learn.hashicorp.com/collections/terraform/cloud-get-started).

6.7 Fireside chat

We've covered a lot of new information in this chapter. We started by talking about what a remote backend is, why it's important, and how it can be used for collaboration purposes. Then we developed a module for deploying an S3 backend using a flat module design and published it on the Terraform Registry.

After we deployed the S3 backend, we looked at a few examples of how we can use it. The simplest was to deploy a `null_resource`, which didn't really do anything but

verified that the backend was operational. Next, we saw how we can deploy to multiple environments using workspaces. Essentially, you have different variables on your workspace, which configure providers and other environment settings, while your configuration code stays the same. It's also worth mentioning that Terraform Cloud has its own unique take on workspaces, which are heavily inspired by the CLI implementation but are not exactly the same thing.

> **NOTE** Testing is an important part of collaboration and is something we did not get a chance to talk about in this chapter. However, we explore this topic in chapter 10.

Summary

- An S3 backend is used for remotely storing state files. It's made up of four components: a DynamoDB table, an S3 bucket and a KMS key, a least-priviliged IAM role, and housekeeping resources.
- Flat modules organize code by using a lot of little .tf files rather than having nested modules. The pro is that they use less boilerplate, but the con is that it may be harder to reason about the code.
- Modules can be shared through various means including S3 buckets, GitHub repos, and the Terraform Registry. You can also implement your own private module registry if you're feeling adventurous.
- Workspaces allow you to deploy to multiple environments. The configuration code stays the same; the only things that change are the variables and the state file.
- Terraform Cloud is the SaaS version of Terraform Enterprise. Terraform Cloud has lower-priced options with fewer features, if price is a concern for you. But it even gives you a remote state store and allows you to perform VCS driven workflows.

7 CI/CD pipelines as code

This chapter covers

- Designing a CI/CD pipeline as code on GCP
- Two-stage deployments for separating static and dynamic infrastructure
- Iterating over complex types with `for_each` expressions and dynamic blocks
- Implicit vs. explicit providers
- Creating custom resources with local-exec provisioners

CI/CD stands for *continuous integration (CI) / continuous deployment (CD)*. It refers to the DevOps practice of enforcing automation in every step of software delivery. Teams that practice a culture of CI/CD are proven to be more agile and able to deploy code changes more quickly than teams who do not practice a culture of CI/CD. There is also the ancillary benefit of improving software quality, as faster code delivery tends to result in smaller, less risky deployments.

A *CI/CD pipeline* is a process that describes how code gets from version control systems through to end users. Each stage of a CI/CD pipeline performs a discreet task such as building, unit testing, and publishing application source code (see figure 7.1).

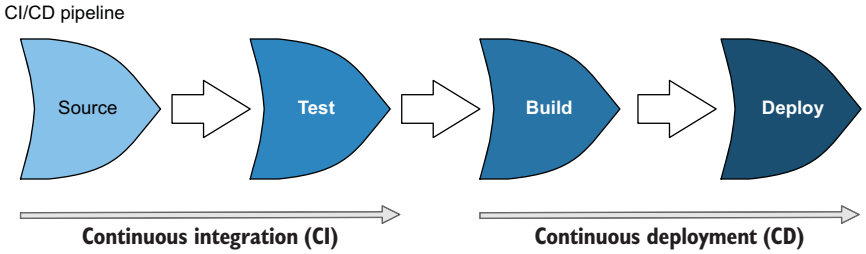


Figure 7.1 A CI/CD pipeline has multiple stages that automate the flow of software delivery.

In this chapter, we deploy a CI/CD pipeline as code. In other words, everything that makes up the pipeline will be deployed and managed with Terraform. We'll use Google Cloud Platform (GCP) as our cloud of choice. GCP is the third largest of the four major clouds (AWS, Azure, GCP, and AliCloud), but it has seen by far the most growth in recent years. There's a lot to like about Google Cloud, from its clean UI to its project-based system, to its managed Kubernetes offerings. But there are some awkward things about it as well, and we see a few examples in this chapter.

We start by covering the last few syntax and expression elements that we haven't introduced previously. Specifically, we introduce `for-each` *expressions*, *dynamic blocks*, and *resource provisioners*. Although we saw dynamic and functional programming back in chapter 3, these new constructs enable writing much more powerful, expressive, and dynamic code than ever before.

Resource provisioners are especially interesting because they are essentially backdoors to the Terraform runtime. Provisioners can execute arbitrary code on either a local or remote machine, which has many obvious security implications, but we will wait until chapter 13 to cover this. You can use provisioners for many tricks. An example we'll see in this chapter is creating custom resources with local-exec provisioners by attaching them to a `null_resource`.

Once our CI/CD pipeline is provisioned, we'll test it by pushing some application code through it and watching as it deploys as a Docker container.

> **NOTE** Docker containers are lightweight, standalone, executable packages of software that include everything needed to run an application: code, runtime, system tools, and settings.

7.1 A tale of two deployments

We've previously deployed applications with Terraform as part of the infrastructure provisioning process. This is convenient because the application can be deployed as part of `terraform apply`, but the process is much slower than it might be otherwise. Applications change frequently—far more frequently than the underlying infrastructure they are deployed onto. If you want to speed up the delivery of applications, the best way to do so is with a CI/CD pipeline.

As much as I love Terraform, it's not well suited for managing things that change frequently, such as application source code. Generating an execution plan in Terraform is downright sluggish, especially if many resources need to be refreshed. This isn't to say that you couldn't use Terraform as part of a CI/CD pipeline (this is the subject of chapter 12, after all), but if your goal is to deploy applications, you shouldn't be afraid to separate *dynamic infrastructure* from *static infrastructure*.

By dynamic infrastructure, I am referring to things that change *a lot*. By the same token, static infrastructure refers to things that only change *a little*. Why make a distinction? Well, managing static infrastructure—resources like virtual machines, load balancers, and so forth—is what Terraform is good at. Terraform is not so great at deploying applications, although there are plenty of examples of people doing exactly that, and we'll see an example in chapter 8. By deploying your static infrastructure with Terraform, you form the foundation on which to deploy everything else.

TIP You could also use Terraform to deploy dynamic infrastructure. For example, you could have a Kubernetes cluster deployed with Terraform and then use a different Terraform workspace to deploy Helm charts onto it.

Figures 7.2 and 7.3 show a comparison between what we've been doing (an all-in-one deployment) and a two-stage deployment.

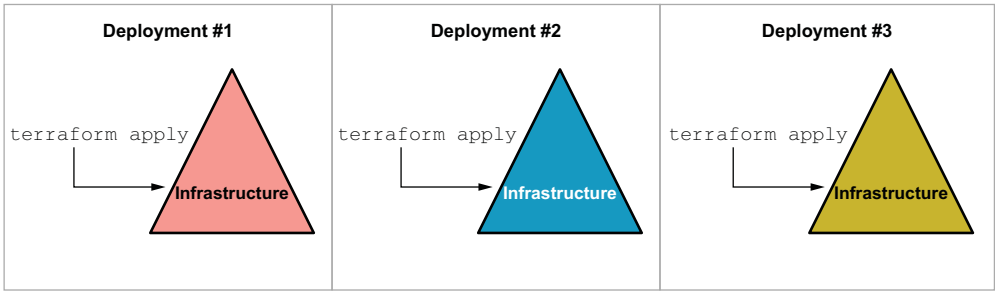


Figure 7.2 Redeploying an entire stack each time you want to make a change is slow.

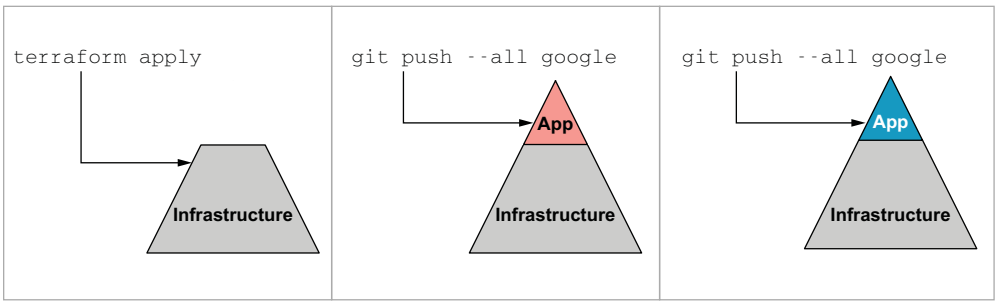


Figure 7.3 By separating your project into what changes a lot vs. what changes a little, you can deploy application code changes more quickly.

7.2 CI/CD for Docker containers on GCP

Docker containers are an excellent way to package your code and ensure that it has all the resources and libraries required to run while still being portable across multiple environments. Because of the enormous popularity of containers, many tools and established architecture patterns exist for setting up a CI/CD pipeline. We'll take advantage of some managed GCP services to deploy a complete CI/CD pipeline for building, unit testing, and deploying Docker containers.

7.2.1 Designing the pipeline

Knative is an abstraction layer over Kubernetes that enables running and managing serverless workloads with ease. It forms the backbone for a GCP service called Cloud Run that automatically scales, load-balances, and resolves DNS for containers. The purpose of using Cloud Run is to simplify this scenario, as it would be a bit more complex to deploy a Kubernetes cluster.

> **NOTE** Cloud Run supports bringing your own compute by enabling Anthos on a Google Kubernetes Engine (GKE) cluster.

As mentioned earlier, CI/CD pipelines for containers generally involve stages for building, unit testing, publishing, and deploying application code. Preferably you would have multiple environments (e.g., dev, staging, prod), but for this scenario, we have only a single environment (prod). We will focus more on CI than CD.

In addition to Cloud Run, we'll use the following managed GCP services to construct the pipeline:

- *Cloud Source Repositories*—A version-controlled Git source repository
- *Cloud Build*—A CI tool for testing, building, publishing, and deploying code
- *Container Registry*—For storing the built container images
- *Cloud Run*—For running serverless containers on a managed Kubernetes cluster

The pipeline we'll build is shown in figure 7.4.

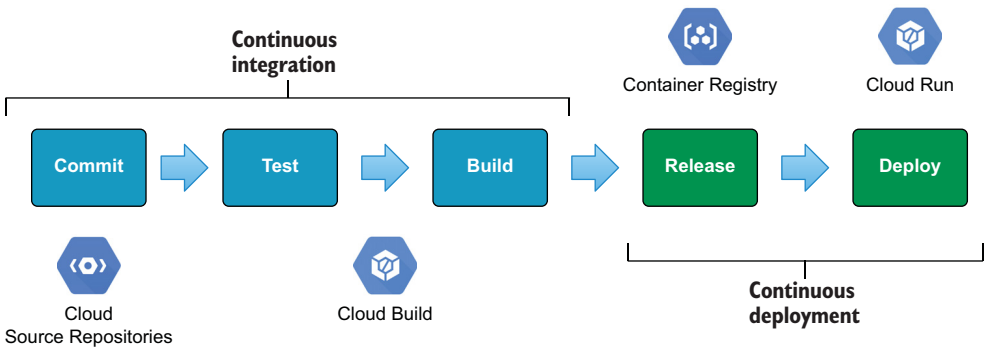


Figure 7.4 CI/CD pipeline for GCP. Commits to Cloud Source Repositories triggers a build in Cloud Build, which then publishes an image to the Container Registry and, finally, kicks off a new deployment to Cloud Run.

7.2.2 Detailed engineering

This project doesn't have much in the way of code, but the code it does have is tricky. Three main components make up the code for the CI/CD pipeline:

- *Enabling APIs*—GCP requires that you explicitly enable the APIs that you wish to use.
- *CI/CD pipeline*—Provisions and wires up the stages for the CI/CD pipeline.
- *Cloud Run service*—Runs the serverless containers on GCP.

Figure 7.5 shows a dependency diagram of the resources we'll provision.

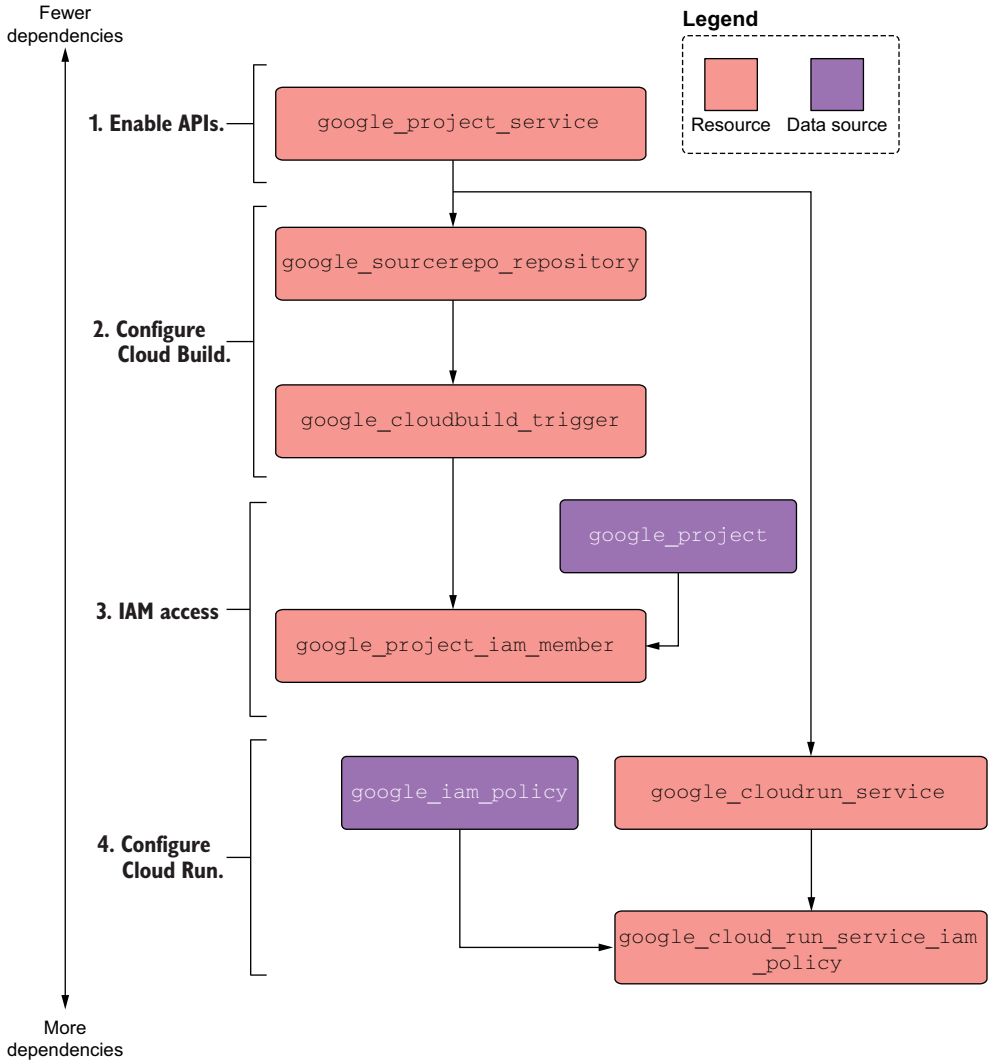


Figure 7.5 There are four sets of components: one for enabling APIs, one for configuring Cloud Build, one for configuring IAM access, and one for configuring the Cloud Run service.

7.3 Initial workspace setup

If you do not already have credentials for GCP, you will need to acquire them. Refer to appendix C for a tutorial on this process.

7.3.1 Organizing the directory structure

This project has two parts: the part deployed with Terraform and the part not deployed with Terraform. Easy, right? Well, how do you organize code that's related to a central project but different enough that it should still be kept separate? Monorepos, of course! This is a subject of much debate (see http://mng.bz/6Nwe), but for this situation, I think it makes sense.

We organize the project into a monorepo by creating a single project directory with two subdirectories: one for all things Terraform related (i.e., static infrastructure) and another for the application code (i.e., dynamic infrastructure). Do this now by creating a project folder, such as gcp-pipelines, with two subfolders, infrastructure and application. When you're done with that, switch into the infrastructure folder, which will be the primary working directory. In the infrastructure folder, create a variables.tf file with the following content.

Listing 7.1 variables.tf

```
variable "project_id" {
  description = "The GCP project id"
  type        = string
}

variable "region" {
  default     = "us-central1"
  description = "GCP region"
  type        = string
}

variable "namespace" {
  description = "The project namespace to use for unique resource naming"
  type        = string
}
```

Next, create a terraform.tfvars file. You can keep `region` and `namespace` the same if you like, but `project_id` should be changed to the ID of your GCP project.

Listing 7.2 terraform.tfvars

```
project_id ="<your_project_id>"
namespace  = "team-rocket"
region     = "us-central1"
```

Your GCP project id goes here.

Notice that `var.namespace` is `team-rocket`. Imagine, if you will, that this isn't just any old pipeline but is going to be used by a group of millennial developers to deploy

their hip new Pokémon-themed app. This reflects the fact that the code is reusable and, if you are an expert in CI/CD, you will always be asked to do work for other people.

Finally, we need to declare the Google provider. Create a providers.tf file with the following contents.

Listing 7.3 providers.tf

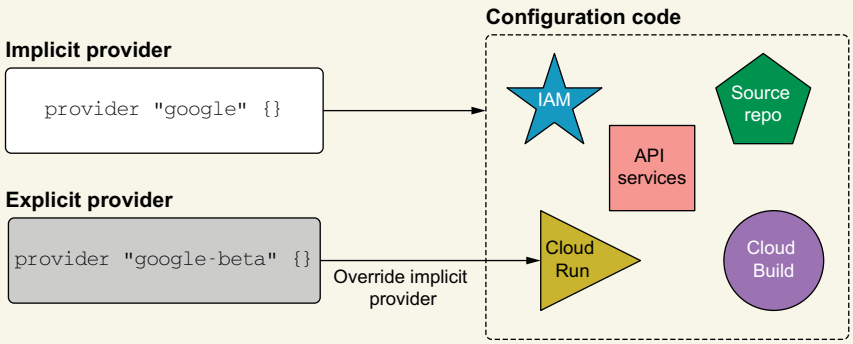
```
provider "google" {
  project = var.project_id
  region  = var.region
}
```

Implicit vs. explicit providers

Google Cloud Platform maintains two provider builds in the provider registry: a Google provider and a Google-beta provider. The beta provider implements newer features that are not present in the production build. For example, until recently, the Cloud Run service was only available as a resource in the Google-beta provider, meaning if you wanted to use it, you had to use the beta provider to do so.

Explicit providers override implicit providers. Most commonly, this is done to orchestrate multi-region deployments. For example, if you wanted to deploy resources simultaneously to us-central1 and us-west2, you could do so with two configurations of the same provider.

Explicit providers get their name because, to use them, you have to explicitly set the `provider` meta argument at the resource or module level. The following figure illustrates how the Google-beta provider overrides the implicit Google provider for a Cloud Run service resource.



Resources and modules have the option to override implicit providers explicitly. Beta services not supported by the Google provider can be provisioned by explicitly setting the `provider` meta argument to the Google-beta provider.

7.4 Dynamic configurations and provisioners

Google is highly opinionated and strict when it comes to matters of Identity and Access Management (IAM). For example, in a new project, you have to enable the services' APIs before you can use them. I am not a fan of this approach and find it inconvenient at best and aggravating at worst. Regardless, there is a Terraform resource that can automate enabling APIs called `google_project_service`. This resource must be created before downstream resources. The code for enabling APIs is shown in listing 7.4.

> **NOTE** There are two syntax features you haven't seen before: `for_each` and `local-exec`. We'll get to these in the next section.

Listing 7.4 main.tf

```
locals {
  services = [                                  <-- List of service APIs to enable
    "sourcerepo.googleapis.com",
    "cloudbuild.googleapis.com",
    "run.googleapis.com",
    "iam.googleapis.com",
  ]
}

resource "google_project_service" "enabled_service" {
  for_each = toset(local.services)
  project  = var.project_id
  service  = each.key

  provisioner "local-exec" {                    <-- Creation-time provisioner
    command = "sleep 60"
  }

  provisioner "local-exec" {                    <-- Destruction-time provisioner
    when    = destroy
    command = "sleep 15"
  }
}
```

7.4.1 for_each vs. count

The `for_each` meta argument accepts as input either a map or a set of strings and outputs an instance for each entry in the data structure. Although analogous to loop constructs in other programming languages, `for_each` does *not* guarantee sequential iteration (because sets and maps are inherently unordered collections). `for_each` is most similar to the meta argument `count` but has several distinct advantages:

- *Intuitive*—`for_each` is a much more natural concept, compared to iterating by index.
- *Less verbose*—syntactically, `for_each` is shorter and more pleasing to the eye.
- *Ease of use*—Instead of storing instances in an array, instances are stored in a map. This makes referencing individual resources easier. Also, if an element in the middle is added or removed, it won't affect references to elements that come after it, as it does with `count`.

`for_each` is the recommended approach to create dynamic configurations. Unless you have a specific reason to access something by index (such as our round-robin approach to creating Mad Lib files in chapter 3), I recommend using `for_each`. The syntax of `for_each` is shown in figure 7.6.

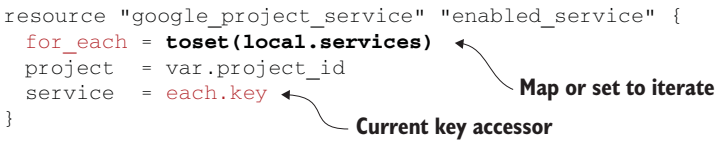


Figure 7.6 Syntax of the `for_each` meta argument and its associated `each` object

In resource blocks where `for_each` is set, an additional `each` object is made available for use by expressions. The `each` object is a reference to the current entry in the iterator and has two accessors:

- `each.key`—The map key or set item corresponding to the entry.
- `each.value`—The map value corresponding to this entry (for sets, this is the same as `each.key`).

I personally found `each` confusing when I first read about it—after all, what do keys and values have to do with sets? What helped me was imagining that Terraform first transforms the set into a list of objects and then iterates over that list (see figure 7.7).

When `for_each` is set, the resource address points to a map of resource instances rather than a single instance (or list of instances, as would be the case with `count`). To

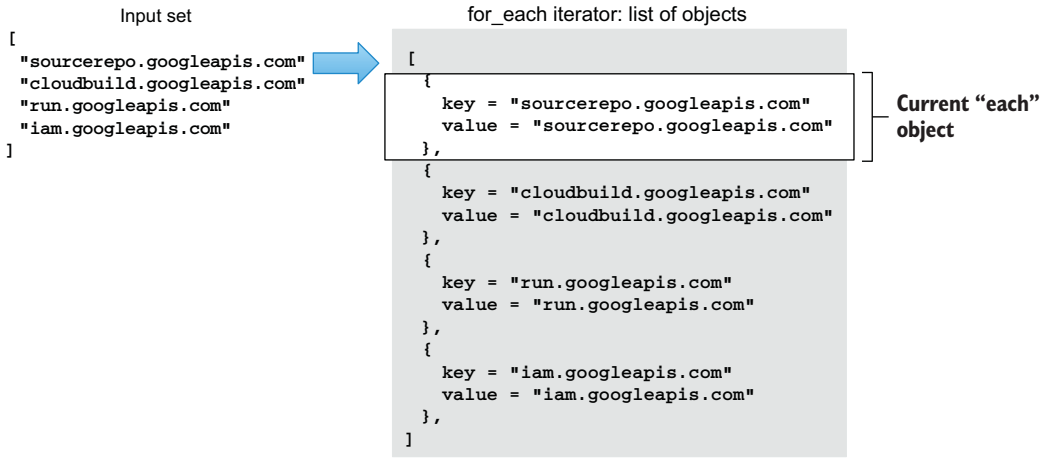


Figure 7.7 The input set is transformed into a list of `each` objects. This new iterator is used by `for_each`.

refer to a specific instance member, simply append the iterator map key after the normal resource address: `<TYPE>.<NAME>.[<KEY>]`. For example, if we wanted to reference the resource instance corresponding to sourcerepo.googleapis.com, we could do so with the following expression:

```
google_project_service.enabled_service["sourcerepo.googleapis.com"]
```

7.4.2 Executing scripts with provisioners

Resource provisioners allow you to execute scripts on local or remote machines as part of resource creation or destruction. They are used for various tasks, such as bootstrapping, copying files, hacking into the mainframe, etc. You can attach a resource provisioner to any resource, but most of the time it doesn't make sense to do so, which is why provisioners are most commonly seen on null resources. Null resources are basically resources that don't do anything, so having a provisioner on one is as close as you can get to having a standalone provisioner.

> **NOTE** Because resource provisioners call external scripts, there is an implicit dependency on the OS interpreter.

Provisioners allow you to dynamically extend functionality on resources by hooking into resource lifecycle events. There are two kinds of resource provisioners:

- Creation-time provisioners
- Destruction-time provisioners

Most people who use provisioners exclusively use creation-time provisioners: for example, to run a script or kick off some miscellaneous automation task. The following example is unusual because it uses both:

```
resource "google_project_service" "enabled_service" {
  for_each = toset(local.services)
  project  = var.project_id
  service = each.key

  provisioner "local-exec" {
    command = "sleep 60"
  }

  provisioner "local-exec" {
    when    = destroy
    command = "sleep 15"
  }
}
```

The "when" attribute defaults to "apply" if not set.

This creation-time provisioner invokes the command `sleep 60` to wait for 60 seconds *after* `Create()` has completed but before the resource is marked as "created" by Terraform (see figure 7.8). Likewise, the destruction-time provisioner waits for 15 seconds *before* `Delete()` is called (see figure 7.9). Both of these pauses (determined experimentally through trial and error) are essential to avoid potential race conditions when enabling/disabling service APIs (see http://mng.bz/oGmZ).

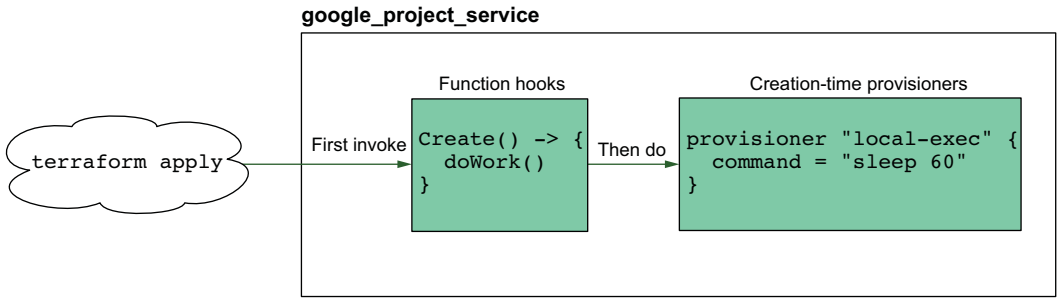


Figure 7.8 The `local-exec` provisioner is called after the `Create()` function hook has exited but before the resource is marked as "created" by Terraform.

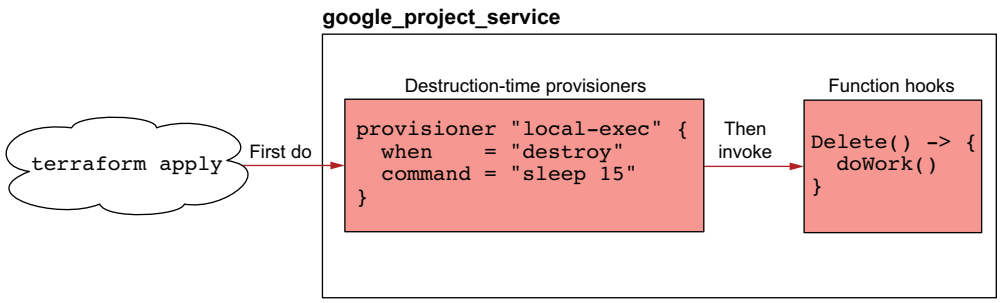


Figure 7.9 The `local-exec` provisioner is called before `Delete()`.

Timing is everything

Why are race conditions happening in the first place? Couldn't this be solved with a well-placed `depends_on`? In an ideal world, yes. Resources should always be in a ready state before they report themselves as created—that way, no race conditions will occur during resource provisioning. Unfortunately, we don't live in an ideal world. Terraform providers are not always perfect. Sometimes resources are marked "created" when actually it takes a few more seconds before they are truly ready. By inserting delays with the `local-exec` provisioner, you can solve many of these strange race condition–style bugs.

If you encounter a bug like this, you should always file an issue with the provider owner. For this specific issue, however, I don't see it being solved anytime soon because of how the Google Terraform team has chosen to implement the GCP provider.

To give you some context, the GCP provider is the only provider I know of that's entirely generated instead of being handcrafted. The secret sauce is an internal code-generation tool called Magic Modules. There are some benefits to this approach, such as speed of delivery; but in my experience, it results in awkwardness and weird edge cases since the Terraform team cannot easily patch broken code.

7.4.3 Null resource with a local-exec provisioner

If both a creation-time and a destruction-time provisioner are attached to the same `null_resource`, you can cobble together a sort of custom Terraform resource. Null resources don't do anything on their own. Therefore, if you have a null resource with a creation-time provisioner that calls a create script and a destruction time provisioner that calls a cleanup script, it wouldn't behave all that differently from a conventional Terraform resource.

The following example code creates a custom resource that prints "Hello World!" on resource creation and "Goodbye cruel world!" on resource deletion. I've spiced it up a bit by using `cowsay`, a CLI tool that prints a picture of an ASCII cow saying the message:

```
resource "null_resource" "cowsay" {
  provisioner "local-exec" {
    command = "cowsay Hello World!"
  }

  provisioner "local-exec" {
    when    = destroy
    command = "cowsay -d Goodbye cruel world!"
  }
}
```

Creation-time provisioner

Destruction-time provisioner

On `terraform apply`, Terraform will run the creation-time provisioner:

```
$ terraform apply -auto-approve
null_resource.cowsay: Creating...
null_resource.cowsay: Provisioning with 'local-exec'...
null_resource.cowsay (local-exec): Executing: ["/bin/sh" "-c" "cowsay Hello
world!"]
null_resource.cowsay (local-exec):  _____________
null_resource.cowsay (local-exec): < Hello World! >
null_resource.cowsay (local-exec):  -------------
null_resource.cowsay (local-exec):         \   ^__^
null_resource.cowsay (local-exec):          \  (oo)\_______
null_resource.cowsay (local-exec):             (__)\       )\/\
null_resource.cowsay (local-exec):                 ||----w |
null_resource.cowsay (local-exec):                 ||     ||
null_resource.cowsay: Creation complete after 0s [id=1729885674162625250]

Apply complete! Resources: 1 added, 0 changed, 0 destroyed.
```

Likewise, on `terraform destroy`, Terraform runs the destruction-time provisioner:

```
$ terraform destroy -auto-approve
null_resource.cowsay: Refreshing state... [id=1729885674162625250]
null_resource.cowsay: Destroying... [id=1729885674162625250]
null_resource.cowsay: Provisioning with 'local-exec'...
null_resource.cowsay (local-exec): Executing: ["/bin/sh" "-c" "cowsay -d
Goodbye cruel world!"]
null_resource.cowsay (local-exec):  _________________________
```

```
null_resource.cowsay (local-exec): < Goodbye cruel world! >
null_resource.cowsay (local-exec):  ----------------------
null_resource.cowsay (local-exec):         \   ^__^
null_resource.cowsay (local-exec):          \  (xx)\_______
null_resource.cowsay (local-exec):             (__)\       )\/\
null_resource.cowsay (local-exec):              U  ||----w |
null_resource.cowsay (local-exec):                 ||     ||
null_resource.cowsay: Destruction complete after 0s

Destroy complete! Resources: 1 destroyed.
```

The dark road of resource provisioners

Resource provisioners should be used only as a method of last resort. The main advantage of Terraform is that it's declarative and stateful. When you make calls out to external scripts, you undermine these core principles.

Some of the worst Terraform bugs I have ever encountered have resulted from an overreliance on resource provisioners. You can't destroy, you can't apply, you're just stuck—and it feels terrible. HashiCorp has publicly stated that resource provisioners are an anti-pattern, and they may even be deprecated in a newer version of Terraform. Some of the lesser-used provisioners have already been deprecated as of Terraform 0.13.

TIP f you are interested in creating custom resources without writing your own provider, I recommend taking a look at the Shell provider (http://mng.bz/n2v5), which is covered in appendix D.

7.4.4 Dealing with repeating configuration blocks

Returning to the main scenario, we need to configure the resources that make up the CI/CD pipeline (see figure 7.10). To start, add the code from listing 7.5 to main.tf. This will provision a version-controlled source repository, which is the first stage of our CI/CD pipeline.

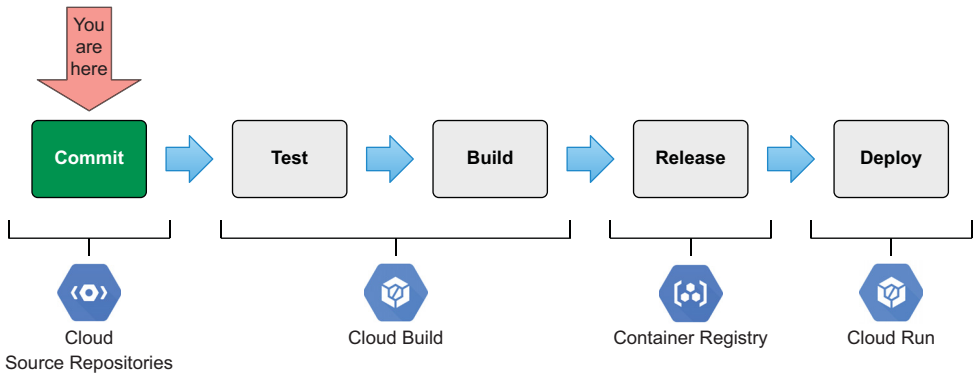


Figure 7.10 CI/CD pipeline: stage 1 of 3

Listing 7.5 main.tf

```
resource "google_sourcerepo_repository" "repo" {
  depends_on = [
    google_project_service.enabled_service["sourcerepo.googleapis.com"]
  ]

  name = "${var.namespace}-repo"
}
```

Next, we need to set up a Cloud Build to trigger a run from a commit to the source repository (see figure 7.11). Since there are several steps in the build process, one way to do this would be to declare a series of repeating configuration blocks, as shown here:

```
resource "google_cloudbuild_trigger" "trigger" {
  depends_on = [
    google_project_service.enabled_service["cloudbuild.googleapis.com"]
  ]

  trigger_template {
    branch_name = "master"
    repo_name   = google_sourcerepo_repository.repo.name
  }

  build {
    step {
      name = "gcr.io/cloud-builders/go"
      args = ["test"]
      env  = ["PROJECT_ROOT=${var.namespace}"]
    }

    step {
      name = "gcr.io/cloud-builders/docker"
      args = ["build", "-t", local.image, "."]
    }

    step {
      name = "gcr.io/cloud-builders/docker"
      args = ["push", local.image]
    }

    step {
      name = "gcr.io/cloud-builders/gcloud"
      args = ["run", "deploy", google_cloud_run_service.service.name,
"--image", local.image, "--region", var.region, "--platform", "managed",
"-q"]
    }
  }
}
```

Repeating configuration blocks for the steps in the build process

As you can see, this works, but it's not exactly flexible or elegant. Having the build steps declared statically doesn't help if you didn't know what those steps were at

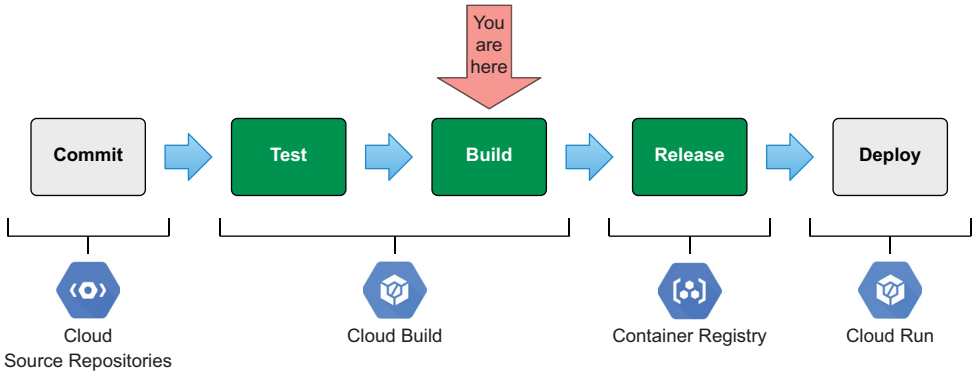


Figure 7.11 CI/CD pipeline: stage 2 of 3

deployment time. Also, this approach is not configurable. To solve this annoying problem, HashiCorp introduced a new expression called *dynamic blocks*.

7.4.5 Dynamic blocks: Rare boys

Dynamic blocks are the rarest of all Terraform expressions, and many people don't even know they exist. They were designed to solve the niche problem of how to create nested configuration blocks dynamically in Terraform. Dynamic blocks can *only* be used within other blocks and *only* when the use of repeatable configuration blocks is supported (surprisingly, not that common). Nevertheless, dynamic blocks are situationally useful, such as when creating rules in a security group or steps in a Cloud Build trigger.

Dynamic nested blocks act much like `for` expressions but produce nested configuration blocks instead of complex types. They iterate over complex types (such as maps and lists) and generate configuration blocks for each element. The syntax for a dynamic nested block is illustrated in figure 7.12.

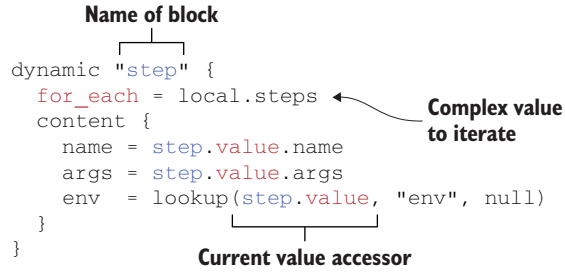


Figure 7.12 Syntax for a dynamic nested block

WARNING Use dynamic blocks sparingly, because they make your code more difficult to understand.

Typically, dynamic nested blocks are combined with local values or input variables (because otherwise, your code would be statically defined, and you wouldn't need to use a dynamic block). In our case, it doesn't matter since we are basically hard-coding the build steps anyway, but it is good practice. I like to declare such local values that

serve only as helpers right above where they are used. You could also put them at the top of the file or in a separate locals.tf file, but in my opinion, doing so makes things more confusing. Append the contents of the following listing to main.tf to provision the Cloud Build trigger and the steps it will employ.

Listing 7.6 main.tf

```
locals {
  image = "gcr.io/${var.project_id}/${var.namespace}"
  steps = [
    {
      name = "gcr.io/cloud-builders/go"
      args = ["test"]
      env  = ["PROJECT_ROOT=${var.namespace}"]
    },
    {
      name = "gcr.io/cloud-builders/docker"
      args = ["build", "-t", local.image, "."]
    },
    {
      name = "gcr.io/cloud-builders/docker"
      args = ["push", local.image]
    },
    {
      name = "gcr.io/cloud-builders/gcloud"
      args = ["run", "deploy", google_cloud_run_service.service.name,
"--image", local.image, "--region", var.region, "--platform", "managed",
"-q"]
    }

  ]
}

resource "google_cloudbuild_trigger" "trigger" {
  depends_on = [
    google_project_service.enabled_service["cloudbuild.googleapis.com"]
  ]

  trigger_template {
    branch_name = "master"
    repo_name   = google_sourcerepo_repository.repo.name
  }

  build {
    dynamic "step" {
      for_each = local.steps
      content {
        name = step.value.name
        args = step.value.args
        env  = lookup(step.value, "env", null)
      }
    }
  }
}
```

Declaring local values right before using them helps with readability.

Not all steps have "env" set. Lookup() returns null if step.value["env"] is not set.

Before we move on to the next section, let's add some IAM-related configuration to main.tf. This will enable Cloud Build to deploy services onto Cloud Run. For that, we need to give Cloud Build the `run.admin` and `iam.serviceAccountUser` roles.

Listing 7.7 main.tf

```
data "google_project" "project" {}

resource "google_project_iam_member" "cloudbuild_roles" {
  depends_on = [google_cloudbuild_trigger.trigger]
  for_each   = toset(["roles/run.admin",
      "roles/iam.serviceAccountUser"])
  project    = var.project_id
  role       = each.key
  member     = "serviceAccount:${data.google_project.project.number}
  ➥ @cloudbuild.gserviceaccount.com"
}
```

Grants the Cloud Build service account these two roles

7.5 Configuring a serverless container

Now we need to configure the Cloud Run service for running our serverless container after it has been deployed with Cloud Build (see figure 7.13). This process has two steps: we need to declare and configure the Cloud Run service, and we need to explicitly enable unauthenticated user access because the default is Deny All.

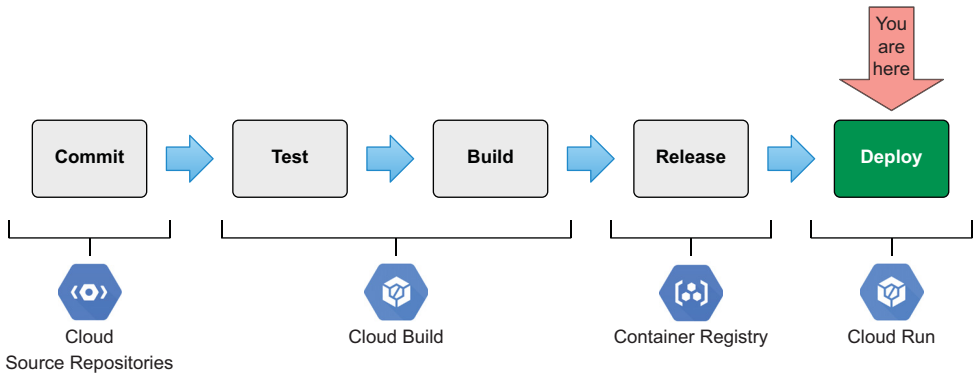


Figure 7.13 CI/CD pipeline: stage 3 of 3

The code for configuring the Cloud Run service is shown in listing 7.8. It's not complicated. The only surprising thing is that we are pointing the container image to a GCP published "Hello" demo image instead of our own. The reason is that our image doesn't yet exist in the Container Registry, so Terraform would throw an error if we tried to `apply`. Since `image` is a required argument, we have to set it to something, but it doesn't really matter what it is because the first execution of Cloud Build will override it.

Listing 7.8 main.tf

```
resource "google_cloud_run_service" "service" {
  depends_on = [
    google_project_service.enabled_service["run.googleapis.com"]
  ]
  name     = var.namespace
  location = var.region

  template {
    spec {
      containers {
        image = "us-docker.pkg.dev/cloudrun/container/hello"
      }
    }
  }
}
```

The Cloud Run service initially uses a demo image that's already in the Container Registry.

To expose the web application to the internet, we need to enable unauthenticated user access. We can do that with an IAM policy that grants all users the `run.invoker` role to the provisioned Cloud Run service. Add the following code to the bottom of main.tf.

Listing 7.9 main.tf

```
data "google_iam_policy" "admin" {
  binding {
    role = "roles/run.invoker"
    members = [
      "allUsers",
    ]
  }
}

resource "google_cloud_run_service_iam_policy" "policy" {
  location    = var.region
  project     = var.project_id
  service     = google_cloud_run_service.service.name
  policy_data = data.google_iam_policy.admin.policy_data
}
```

We are almost done. We just need to address a couple of minor things before finishing: the output values and the provider versions. Create outputs.tf and versions.tf; we will need both of them later. The outputs.tf file will output the URLs from the source repository and Cloud Run service.

Listing 7.10 outputs.tf

```
output "urls" {
  value = {
    repo = google_sourcerepo_repository.repo.url
    app  = google_cloud_run_service.service.status[0].url
  }
}
```

Finally, versions.tf locks in the GCP provider version.

Listing 7.11 versions.tf

```
terraform {
  required_version = ">= 0.15"
  required_providers {
      google = {
          source = "hashicorp/google"
          version = "~> 3.56"
      }
  }
}
```

7.6 Deploying static infrastructure

Remember that there are two parts to this project: the static (aka Terraform) part and the dynamic (or non-Terraform) part. What we have been working on so far only amounts to the static part, which is responsible for laying down the underlying infrastructure that the dynamic infrastructure will run on. We will talk about how to deploy dynamic infrastructure in the next section. For now, we will deploy the static infrastructure. The complete source code of main.tf is shown next.

Listing 7.12 Complete main.tf

```
locals {
  services = [
    "sourcerepo.googleapis.com",
    "cloudbuild.googleapis.com",
    "run.googleapis.com",
    "iam.googleapis.com",
  ]
}

resource "google_project_service" "enabled_service" {
  for_each = toset(local.services)
  project  = var.project_id
  service  = each.key

  provisioner "local-exec" {
    command = "sleep 60"
  }

  provisioner "local-exec" {
    when    = destroy
    command = "sleep 15"
  }
}

resource "google_sourcerepo_repository" "repo" {
  depends_on = [
    google_project_service.enabled_service["sourcerepo.googleapis.com"]
  ]
```

```
  name = "${var.namespace}-repo"
}

locals {
  image = "gcr.io/${var.project_id}/${var.namespace}"
  steps = [
    {
      name = "gcr.io/cloud-builders/go"
      args = ["test"]
      env  = ["PROJECT_ROOT=${var.namespace}"]
    },
    {
      name = "gcr.io/cloud-builders/docker"
      args = ["build", "-t", local.image, "."]
    },
    {
      name = "gcr.io/cloud-builders/docker"
      args = ["push", local.image]
    },
    {
      name = "gcr.io/cloud-builders/gcloud"
      args = ["run", "deploy", google_cloud_run_service.service.name,
"--image", local.image, "--region", var.region, "--platform", "managed",
"-q"]
    }

  ]
}

resource "google_cloudbuild_trigger" "trigger" {
  depends_on = [
    google_project_service.enabled_service["cloudbuild.googleapis.com"]
  ]

  trigger_template {
    branch_name = "master"
    repo_name   = google_sourcerepo_repository.repo.name
  }

  build {
    dynamic "step" {
      for_each = local.steps
      content {
        name = step.value.name
        args = step.value.args
        env  = lookup(step.value, "env", null)
      }
    }
  }
}

data "google_project" "project" {}

resource "google_project_iam_member" "cloudbuild_roles" {
  depends_on = [google_cloudbuild_trigger.trigger]
  for_each   = toset(["roles/run.admin", "roles/iam.serviceAccountUser"])
```

```
  project    = var.project_id
  role       = each.key
  member     = "serviceAccount:${data.google_project.project.number}
  ➥ @cloudbuild.gserviceaccount.com"
}

resource "google_cloud_run_service" "service" {
  depends_on = [
    google_project_service.enabled_service["run.googleapis.com"]
  ]
  name     = var.namespace
  location = var.region

  template {
    spec {
      containers {
        image = "us-docker.pkg.dev/cloudrun/container/hello"
      }
    }
  }
}

data "google_iam_policy" "admin" {
  binding {
    role = "roles/run.invoker"
    members = [
      "allUsers",
    ]
  }
}

resource "google_cloud_run_service_iam_policy" "policy" {
  location    = var.region
  project     = var.project_id
  service     = google_cloud_run_service.service.name
  policy_data = data.google_iam_policy.admin.policy_data
}
```

When you're ready, initialize and deploy the infrastructure to GCP:

```
$ terraform init && terraform apply -auto-approve
...
google_project_iam_member.cloudbuild_roles["roles/iam.serviceAccountUser"]:
Creation complete after 10s [id=tic-
pipelines/roles/iam.serviceAccountUser/serviceaccount:783629414819@cloudbui
ld.gserviceaccount.com]

Apply complete! Resources: 10 added, 0 changed, 0 destroyed.

Outputs:

urls = {
  "app" = "https://team-rocket-oitcosddra-uc.a.run.app"
  "repo" = "https://source.developers.google.com/p/tia-chapter7/r/team-
rocket-repo"
}
```

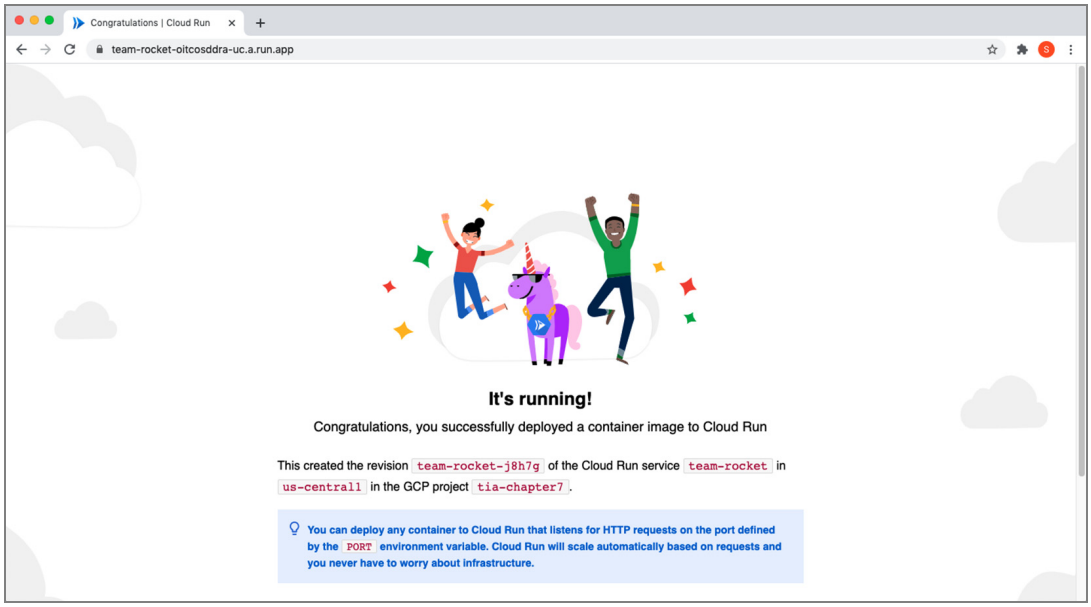


Figure 7.14 The demo Cloud Run service is initially running.

At this point, your Cloud Run service is available at the `urls.app` address, although it is only serving the demo container (see figure 7.14).

7.7 CI/CD of a Docker container

In this section, we deploy a Docker container to Cloud Run through the CI/CD pipeline. The Docker container we'll create is a simple HTTP server that listens on port 8080 and serves a single endpoint. The application code we deploy runs on top of existing static infrastructure (see figure 7.15).

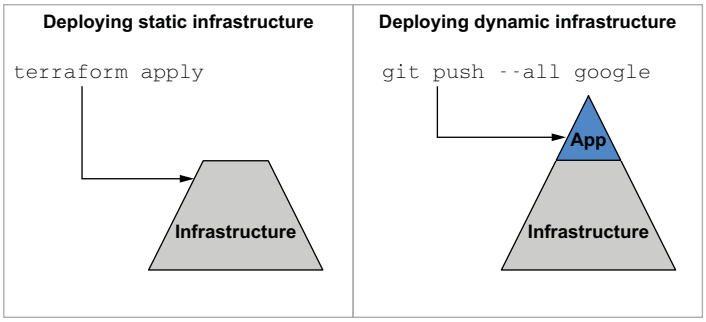


Figure 7.15 Dynamic infrastructure is deployed on top of the static infrastructure.

From section 7.3.1, you should have two folders: application and infrastructure. All the code until now has been in the infrastructure folder. To get started with the application code, switch over to the application folder:

```
$ cd ../application
```

In this directory, create a main.go file that will be the entry point for the server.

Listing 7.13 main.go

```
package main

import (
    "fmt"
    "log"
    "net/http"
)

func IndexServer(w http.ResponseWriter, r *http.Request) {
    fmt.Fprint(w, "Automate all the things!")
}

func main() {
    handler := http.HandlerFunc(IndexServer)
    log.Fatal(http.ListenAndServe(":8080", handler))
}
```

Starts the server on port 8080 and serves the string "Automate all the things!"

Next, write a basic unit test and save it as main_test.go.

Listing 7.14 main_test.go

```
package main

import (
    "net/http"
    "net/http/httptest"
    "testing"
)

func TestGETIndex(t *testing.T) {
    t.Run("returns index", func(t *testing.T) {
        request, _ := http.NewRequest(http.MethodGet, "/", nil)
        response := httptest.NewRecorder()

        IndexServer(response, request)

        got := response.Body.String()
        want := "Automate all the things!"

        if got != want {
            t.Errorf("got '%s', want '%s'", got, want)
        }
    })
}
```

Now create a Dockerfile for packaging the application. The following listing shows the code for a basic multistage Dockerfile that will work for our purposes.

Listing 7.15 Dockerfile

```
FROM golang:1.15 as builder
WORKDIR /go/src/github.com/team-rocket
COPY . .
RUN CGO_ENABLED=0 GOOS=linux go build -v -o app

FROM alpine
RUN apk update && apk add --no-cache ca-certificates
COPY --from=builder /go/src/github.com/team-rocket/app /app
CMD ["/app"]
```

7.7.1 Kicking off the CI/CD pipeline

At this point, we can upload our application code to the source repository, which will kick off the CI/CD pipeline and deploy to Cloud Run. The following commands make this happen. You'll need to substitute in the repo URL from the earlier Terraform output.

Listing 7.16 Git commands

```
git init && git add -A && git commit -m "initial push"
git config --global credential.https://source.developers.google.com.helper
gcloud.sh
git remote add google <urls.repo>
gcloud auth login && git push --all google
```

Insert your source repo URL here.

After you've pushed your code, you can view the build status in the Cloud Build console. Figure 7.16 shows an example of what an in-progress build might look like.

When the build completes, you can navigate to the application URL in the browser (from the `app` output attribute). You should see a spartan website with the words "Automate all the things!" in plain text (see figure 7.17). This means you have succesfullly deployed an app through the pipeline and completed the scenario.

> **WARNING** Don't forget to clean up your static infrastructure with `terraform destroy`. Alternatively, you can manually delete the GCP project from the console.

7.8 Fireside chat

We started by talking about two-stage deployments, where you separate your static infrastructure from your dynamic infrastructure. Static infrastructure doesn't change a lot, which is why it's a good candidate to be provisioned with Terraform. On the other hand, dynamic infrastructure changes far more frequently and typically consists of things like configuration settings and application source code. By making a clear

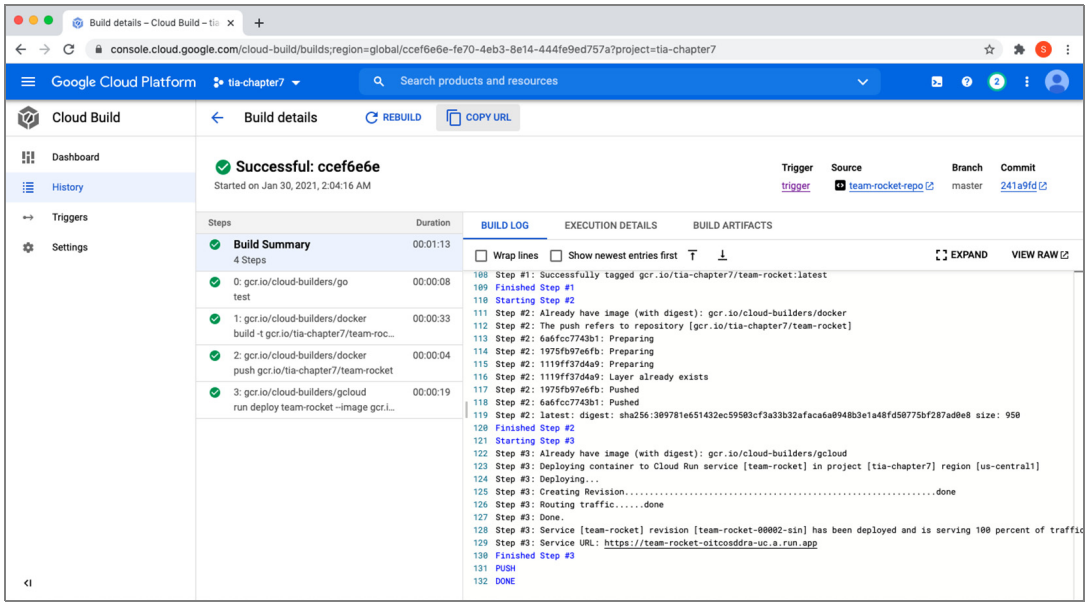


Figure 7.16 Cloud Build triggers a build when you commit to the master branch. This will build, test, publish, and finally deploy the code to Cloud Run.

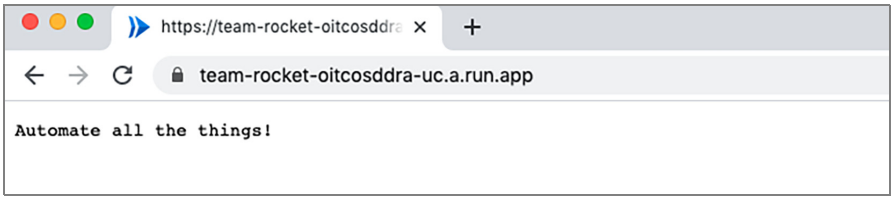


Figure 7.17 Example deployed website

division between static and dynamic infrastructure, you can experience faster, more reliable deployments.

Even though the Terraform code we deployed was for static infrastructure, it was the most expressive code we have seen so far. We introduced `for_each` expressions, dynamic blocks, and even resource provisioners. We only looked at the `local-exec` provisioner, but there are actually three kinds of resource provisioners: see Table 7.1 for a comparison between the different provisioner types.

WARNING Backdoors to Terraform (i.e., resource provisioners) are inherently dangerous and should be avoided. Use them only as a last resort.

Table 7.1 Reference of resource provisioners in Terraform

Name	Description	Example

`file`	Copies files or directories from the machine executing Terraform to the newly created resource.	`provisioner "file" {`
		`  source = "conf/myapp.conf"`
		`  destination = "/etc/myapp.conf"`
		`}`

`local-exec`	Invokes an arbitrary process on the machine running Terraform (not on the resource).	`provisioner "local-exec" {`
		`  command = "echo hello"`
		`}`

`remote-exec`	Invokes a script on a remote resource after it is created. This can be used to run configuration management tools, bootstrap scripts, etc.	`provisioner "remote-exec" {`
		`  inline = [`
		`  "puppet apply",`
		`  ]`
		`}`

Summary

- We designed and deployed a CI/CD pipeline as code on GCP. There are five stages to this pipeline: source, test, build, release, and deploy.
- There are two methods for deploying with Terraform: everything all-in-one and separating static from dynamic infrastructure.
- `for_each` can provision resources dynamically, like `count`, but uses a map instead of a list. Dynamic blocks are similar, except they allow you to generate repeating configuration blocks.
- Providers can be either implicit or explicit. Explicit providers are typically used for multi-region deployments or, in the case of GCP, for using the beta version of the provider.
- Resource provisioners can be either creation-time or destruction-time. If you have both of them on a null resource, this can be a way to create bootleg custom resources. You can also create custom resources with the Shell provider.

8 A multi-cloud MMORPG

This chapter covers

- Deploying a multi-cloud load balancer
- Federating Nomad and Consul clusters with Terraform
- Deploying containerized workloads with the Nomad provider
- Comparing container orchestration architectures with those for managed services

Terraform makes it easy to deploy to the multi-cloud. You can use all the same tools and techniques you've already been using. In this chapter, we build on everything we have done so far to deploy a massively multiplayer online role-playing game (MMORPG) to the multi-cloud.

Multi-cloud refers to any heterogeneous architecture that employs multiple cloud vendors. For example, you may have a Terraform project that deploys resources onto both AWS and GCP; that would be multi-cloud. In comparison, the closely related term *hybrid cloud* is more inclusive: it specifically refers to multi-cloud

where only one of the clouds is private. So, hybrid cloud is a mix of private and public cloud vendors.

The significance of multi-cloud versus hybrid cloud has less to do with nomenclature and more to do with the kinds of problems you may be expected to face. For example, hybrid-cloud companies normally don't want to be hybrid-cloud; they want to be mono-public-cloud. These companies want to migrate legacy applications to the cloud as swiftly as possible so that their private data centers can be shut down. On the other hand, multi-cloud companies are presumably more mature in their journey to the cloud and may already be entirely cloud-native.

As multi-cloud becomes more mainstream, such stereotypes about cloud maturity become less accurate. It's fair to say that most companies, even those that are mature in the cloud, would never adopt a multi-cloud strategy if they were not forced to do so by external factors, such as mergers and acquisitions. For example, if a large enterprise company uses AWS and acquires a smaller startup that uses GCP, the enterprise suddenly has a multi-cloud architecture whether it intended to or not.

Regardless of whether you choose to adopt multi-cloud or are forced into it, there are several advantages compared to the mono-cloud:

- *Flexibility*—You can choose the best-in-class services from any cloud.
- *Cost savings*—Pricing models vary between cloud vendors, so you can save money by choosing the lower-price option.
- *Avoiding vendor lock-in*—It's generally not a good idea to lock yourself into a particular vendor because doing so puts you in a weak negotiating position.
- *Resilience*—Multi-cloud architectures can be designed to automatically fail over from one cloud to the other, making them more resilient than single-cloud architectures.
- *Compliance*—Internal or external factors may play a role. For example, if you want to operate out of China, you are forced to use AliCloud to comply with government regulations.

In this chapter, we investigate several approaches for architecting multi-cloud projects. First, we deploy a hybrid-cloud load balancer that distributes traffic evenly to virtual machines (VMs) located in AWS, Azure, and GCP. This is a fun project meant to demonstrate the ease of deploying multi-cloud or hybrid-cloud projects with Terraform.

Next is my favorite part. We deploy and automatically federate Nomad and Consul clusters onto AWS and Azure. Once the infrastructure is up and running, we deploy a multi-cloud workload for *BrowserQuest*, an MMORPG created by Mozilla. This game is surprisingly fun, especially if you like RPG games. A preview of BrowserQuest is shown in figure 8.1.

Finally, we redesign the MMORPG project to use managed services. Managed services are a great alternative to container orchestration platforms, but they also force you to learn the intricacies of the different clouds.

Figure 8.1 BrowserQuest is a massively multiplayer HTML5 game that you can play through a browser.

8.1 Hybrid-cloud load balancing

We start by deploying a load balancer with a twist. It's a hybrid-cloud load balancer, meaning it will be deployed locally as a Docker container but will load-balance machines residing in AWS, GCP, and Azure. Load balancing is performed with round-robin DNS, so each time the page is refreshed, it takes you to the next machine in the list. Each machine serves HTTP/CSS content with some text and colors letting you know what cloud it's on (see figure 8.2).

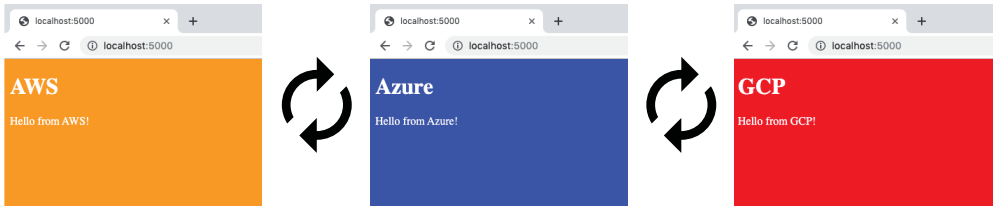


Figure 8.2 Each time the page is refreshed, it cycles to the next machine on the list.

NOTE This scenario is meant to be fun and to demonstrate how easy it is to get started with multi-cloud/hybrid-cloud on Terraform. It's not meant for production use.

8.1.1 Architectural overview

Load balancers distribute traffic across multiple servers, improving the reliability and scalability of applications. As servers come and go, load balancers automatically route traffic to healthy VMs based on routing rules while maintaining a static IP. Typically, all instances that make up the server pool are collocated and networked on the same private subnet (see figure 8.3).

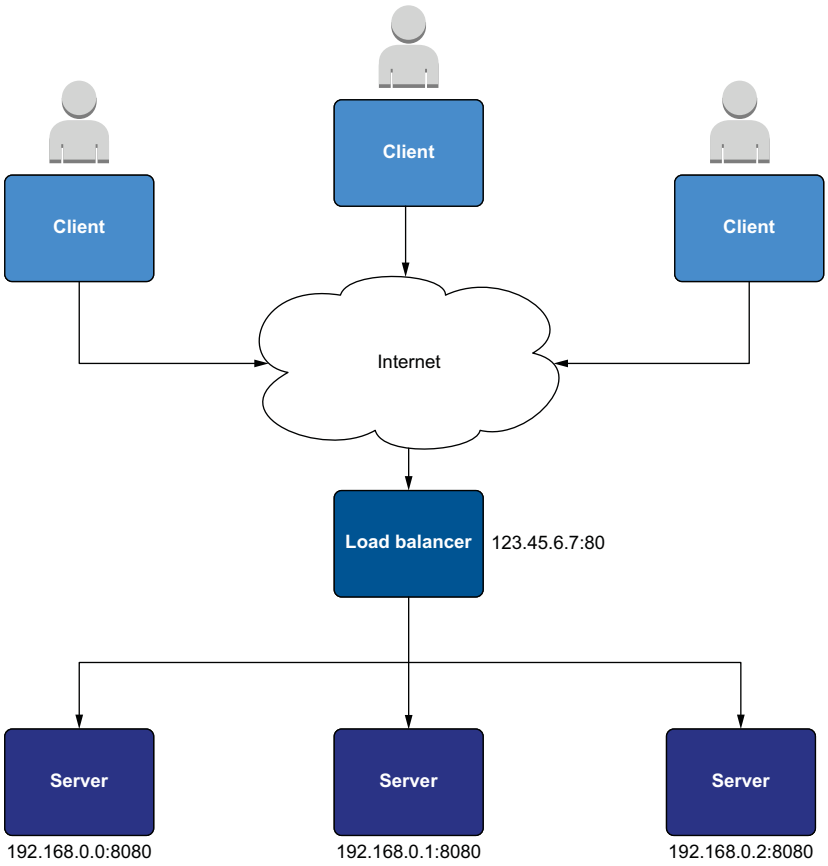


Figure 8.3 A classic load balancer setup. Clients talk to the load balancer over the internet, and all the servers behind the load balancer are on the same private network.

In contrast, the hybrid-cloud load balancer we will deploy is rather unconventional (see figure 8.4). Each server lives in a separate cloud and is assigned a public IP to register itself with the load balancer.

NOTE It's not recommended to assign a public IP address to VMs behind a load balancer. But since the VMs live in different clouds, it's simpler to use a public IP than to tunnel the virtual private clouds together.

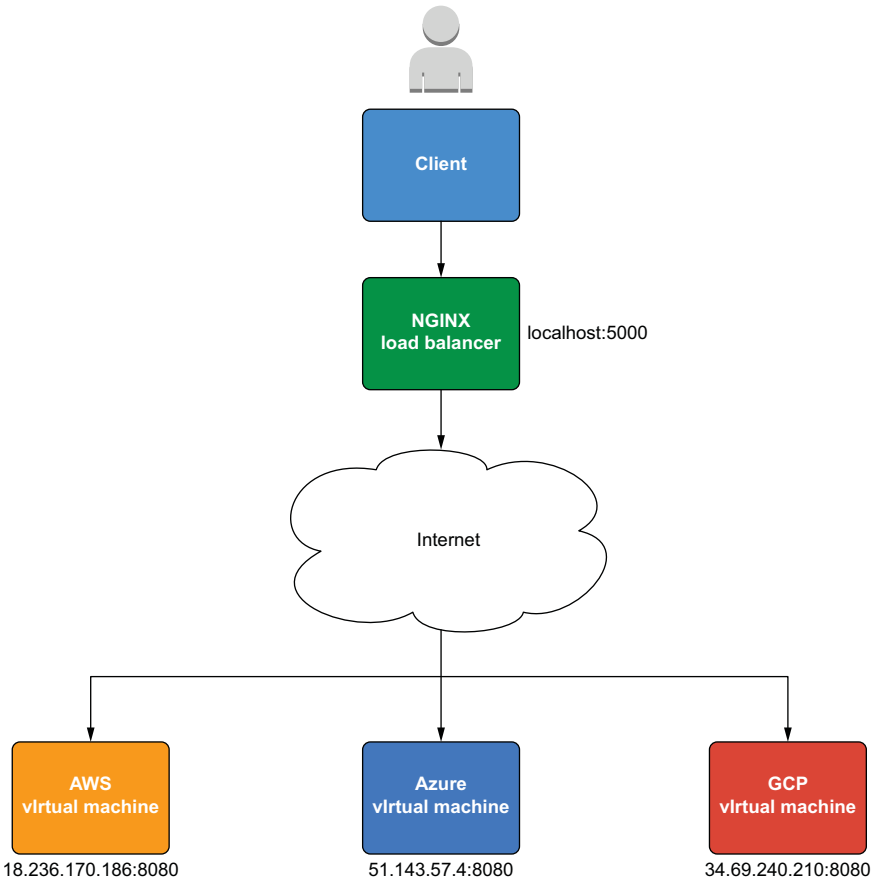


Figure 8.4 Hybrid-cloud load balancing with a private cloud load balancer and public cloud VMs

Although the VMs are in public clouds, the load balancer itself will be deployed as a Docker container on localhost. This makes it a hybrid-cloud load balancer rather than a multi-cloud load balancer. It also gives us an excuse to introduce the Docker provider for Terraform. We'll use a total of five providers, as shown in figure 8.5.

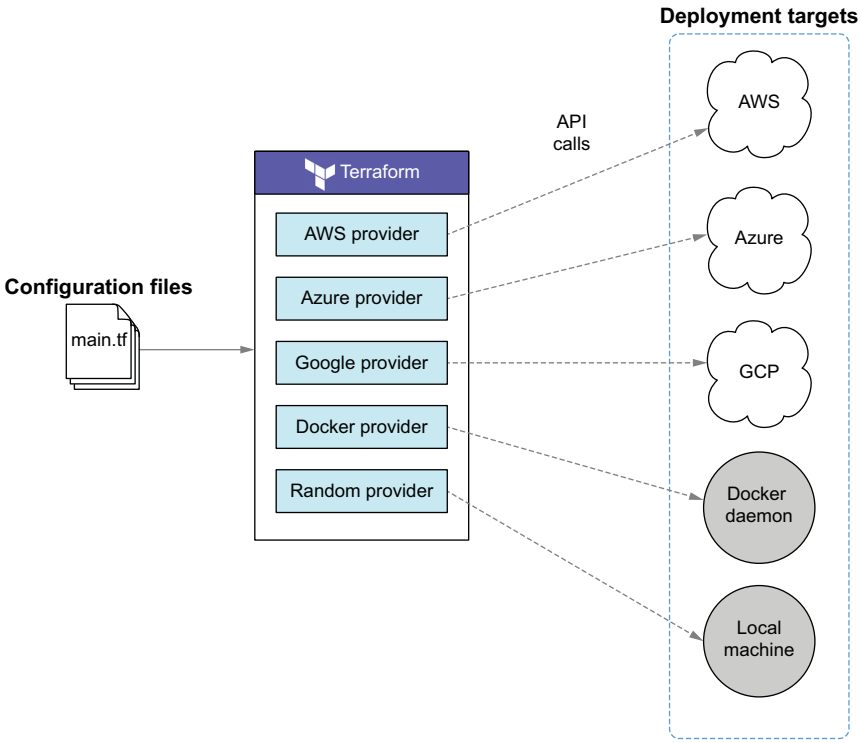


Figure 8.5 The workspace uses five providers to deploy infrastructure onto both public and private clouds.

8.1.2 Code

This scenario's configuration code is short, mainly because most business logic is encapsulated in modules. This is done to simplify the code, because otherwise it would be too long to fit in the chapter. Don't worry, though—you aren't missing anything that we haven't already covered in previous chapters. Of course, you can always take a look at the source code for the modules on GitHub if you want to learn more.

> **TIP** This scenario also works with fewer than three clouds. If you choose not to deploy to all three clouds, simply comment out the configuration code and references to the undesired provider(s) in listing 8.1 and subsequent code listings.

Start by creating a providers.tf file to configure provider information. I will assume you are using the authentication methods described in appendices A, B, and C.

> **NOTE** If you want to authenticate providers using alternative methods, you are more than welcome to. Just because I do things one way doesn't mean you have to do them the same way.

Listing 8.1 providers.tf

```
provider "aws" {
  profile = "<profile>"
  region  = "us-west-2"
}

provider "azurerm" {
  features {}
}

provider "google" {
  project = "<project_id>"
  region  = "us-east1"
}

provider "docker" {}
```

The Docker provider can be configured to connect to local and remote hosts.

The curious Docker provider for Terraform

Once you've been indoctrinated into Terraform, it's natural to want to do everything with Terraform. After all, why not have more of a good thing? The problem is that Terraform simply does not do all tasks well. In my opinion, the Docker provider for Terraform is one such example.

Although you can deploy a Docker container with Terraform, it's probably better to use an orchestration tool like Docker Compose or even CLI commands than a Terraform provider that is no longer owned or maintained by HashiCorp. That being said, the Docker provider is useful in some circumstances.

The relevant code is shown in the following listing. Create a main.tf file with this content.

Listing 8.2 main.tf

```
module "aws" {
  source = "terraform-in-action/vm/cloud//modules/aws"
  environment = {
    name             = "AWS"
    background_color = "orange"
  }
}

module "azure" {
  source = "terraform-in-action/vm/cloud//modules/azure"
  environment = {
    name             = "Azure"
    background_color = "blue"
  }
}
```

Environment variables customize the website.

These modules exist in separate folders of the same GitHub repo.

```
module "gcp" {
  source      = "terraform-in-action/vm/cloud//modules/gcp"
  environment = {
    name             = "GCP"
    background_color = "red"
  }
}

module "loadbalancer" {
  source = "terraform-in-action/vm/cloud//modules/loadbalancer"
  addresses = [
    module.aws.network_address,
    module.azure.network_address,
    module.gcp.network_address,
  ]
}
```

These modules exist in separate folders of the same GitHub repo.

Each VM registers itself with the load balancer using a public IP address.

The outputs are shown in the next listing. This is purely for convenience.

Listing 8.3 outputs.tf

```
output "addresses" {
  value = {
    aws          = module.aws.network_address
    azure        = module.azure.network_address
    gcp          = module.gcp.network_address
    loadbalancer = module.loadbalancer.network_address
  }
}
```

Finally, write the Terraform settings to versions.tf as presented in listing 8.4. This step is required because HashiCorp no longer owns the Docker provider. If you didn't include this block, Terraform wouldn't know where to find the binary for the Docker provider.

Listing 8.4 versions.tf

```
terraform {
  required_providers {
    docker = {
      source  = "kreuzwerker/docker"
      version = "~> 2.11"
    }
  }
}
```

8.1.3 Deploy

Depending on how Docker is installed on your local machine, you may need to configure the `host` or `config_path` attribute in the provider block. Consult the Docker provider documentation (http://mng.bz/8WzZ) for more information. On Mac and Linux operating systems, the defaults should be fine. Windows, however, will need to override at least the `host` attribute.

If you are having difficulties, you can always comment out the Docker provider and module declarations from the preceding code. I show an alternate approach shortly.

> **NOTE** Providers that interact with local APIs must be configured to authenticate to those APIs. This is unique to your environment, so I cannot prescribe a one-size-fits-all approach.

When you are ready to deploy, initialize the workspace with `terraform init` and then run `terraform apply`:

```
$ terraform apply
...
      + owner_id               = (known after apply)
      + revoke_rules_on_delete = false
      + vpc_id                 = "vpc-0904a1543ed8f62a3"
    }

Plan: 20 to add, 0 to change, 0 to destroy.

Changes to Outputs:
  + addresses = {
      + aws          = (known after apply)
      + azure        = (known after apply)
      + gcp          = (known after apply)
      + loadbalancer = "localhost:5000"
    }

Do you want to perform these actions?
  Terraform will perform the actions described above.
  Only 'yes' will be accepted to approve.

  Enter a value:
```

After approving and waiting a few minutes, you get the output addresses for each of the three VMs along with that of the load balancer:

```
module.aws.aws_instance.instance: Creation complete after 16s [id=i-
08fcb1592523ebd73]
module.loadbalancer.docker_container.loadbalancer: Creating...
module.loadbalancer.docker_container.loadbalancer: Creation complete after
1s [id=2e3b541eeb34c95011b9396db9560eb5d42a4b5d2ea1868b19556ec19387f4c2]

Apply complete! Resources: 20 added, 0 changed, 0 destroyed.

Outputs:

addresses = {
  "aws" = "34.220.128.94:8080"
  "azure" = "52.143.74.93:8080"
  "gcp" = "34.70.1.239:8080"
  "loadbalancer" = "localhost:5000"
}
```

If you don't have the load balancer running yet, you can do so by concatenating the three network addresses with a comma delimiter and directly running the Docker container on your local machine:

```
$ export addresses="34.220.128.94:8080,52.143.74.93:8080,34.70.1.239:8080"
$ docker run -p 5000:80 -e ADDRESSES=$addresses -dit swinkler/tia-loadbal-
     ancer
```

When you navigate to the load-balancer address in the browser, you will first hit the AWS VM (see figure 8.6). Each time you refresh the page, you will be served by a VM in a different cloud.

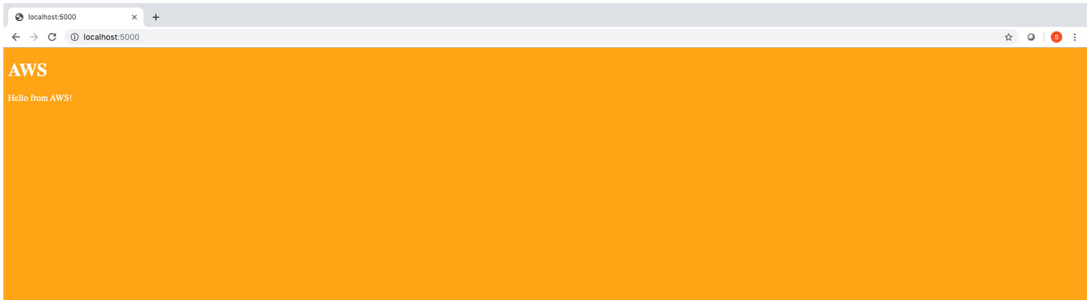


Figure 8.6 An example of the AWS landing page. When you refresh, you will see the Azure page (blue) and then GCP (red).

> **NOTE** It may take a few minutes for all the VMs to start up. Keep refreshing the page until all three appear.

When you are done, remember to clean up with `terraform destroy`:

```
$ terraform destroy -auto-approve
...
module.gcp.google_compute_instance.compute_instance: Still destroying...
[id=gcp-vm, 4m40s elapsed]
module.gcp.google_compute_instance.compute_instance: Still destroying...
[id=gcp-vm, 4m50s elapsed]
module.gcp.google_compute_instance.compute_instance: Destruction complete
after 4m53s
module.gcp.google_project_service.enabled_service["compute.googleapis.com"]
: Destroying... [id=terraform-in-action-lb/compute.googleapis.com]
module.gcp.google_project_service.enabled_service["compute.googleapis.com"]
: Destruction complete after 0s

Destroy complete! Resources: 20 destroyed.
```

> **NOTE** If you ran the Docker container manually on your local machine, you need to manually kill it as well.

8.2 Deploying an MMORPG on a federated Nomad cluster

Clusters are sets of networked machines that operate as a collective unit. Clusters are the backbone of container orchestration platforms and make it possible to run highly parallel and distributed workloads at scale. Many companies rely on container orchestration platforms to manage most, if not all, of their production services.

In this section, we deploy Nomad and Consul clusters onto both AWS and Azure. Nomad is a general-purpose application scheduler created by HashiCorp that also functions as a container orchestration platform. Consul is a general networking tool enabling service discovery and is most similar to Istio (a platform-independent service mesh: www.istio.io).

Each Nomad node (i.e., VM) registers itself with its respective Consul cluster, which can then discover the other clouds' Consul and Nomad nodes via federation. An architecture diagram is shown in figure 8.7.

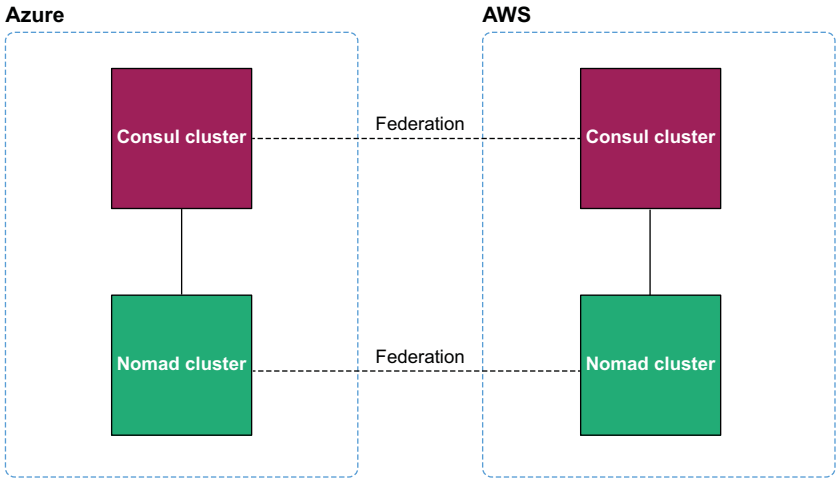


Figure 8.7 Each Nomad cluster registers itself with a local Consul cluster. Federation enables the multi-cloud clusters to behave as a single unit.

Once the infrastructure is up, we will use the Nomad provider for Terraform to deploy the MMORPG service. At the end of this section, we will have a complete and playable multi-cloud game.

8.2.1 Cluster federation 101

Google's Borg paper (https://ai.google/research/pubs/pub43438) was the foundation for all modern cluster technologies: Kubernetes, Nomad, Mesos, Rancher, and Swarm are all implementations of Borg. A key design feature of Borg is that

already-running tasks continue to run even if the Borg master or other tasks (a.k.a. Borglets) go down.

In Borg clusters, nodes may be designated as either client or server. Servers are responsible for managing configuration state and are optimized for consistency in the event of a service outage. Following the *Raft consensus algorithm* (https://raft.github.io), there must be an odd number of servers to achieve a quorum, and one of these servers is elected leader. Client nodes do not have any such restrictions. You can have as many or a few as you like; they simply form a pool of available compute on which to run tasks assigned by servers.

Cluster federation extends the idea of clustering to join multiple clusters, which may exist in different datacenters. Federated Nomad clusters allow you to manage your shared compute capacity from a single control plane.

8.2.2 Architecture

This project deploys a lot of VMs because the Raft consensus algorithm requires a minimum of three servers to establish a quorum, and we have four clusters. This means we need at least 12 VMs plus additional VMs for client nodes.

All the VMs will be part of the Consul cluster, but only a subset of those will be part of the Nomad cluster (see figure 8.8).

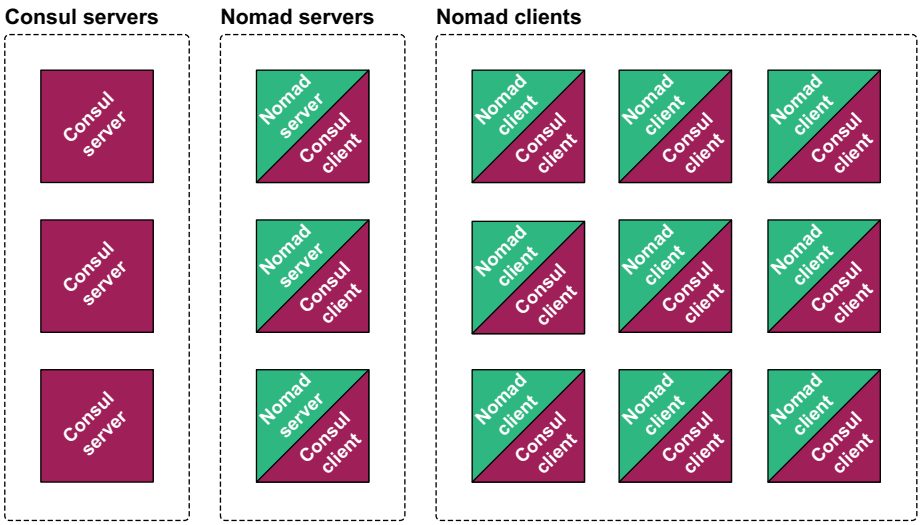


Figure 8.8 There are three groups of VMs: one group runs the Consul server, one group runs the Nomad server, and the third group runs the Nomad client. All of the VMs running Nomad also run the Consul client. Effectively, there is one large Consul cluster, with a subset that is the Nomad cluster.

These three groups of VMs are replicated in both clouds, and like-to-like clusters are federated together. A detailed architecture diagram is shown in figure 8.9.

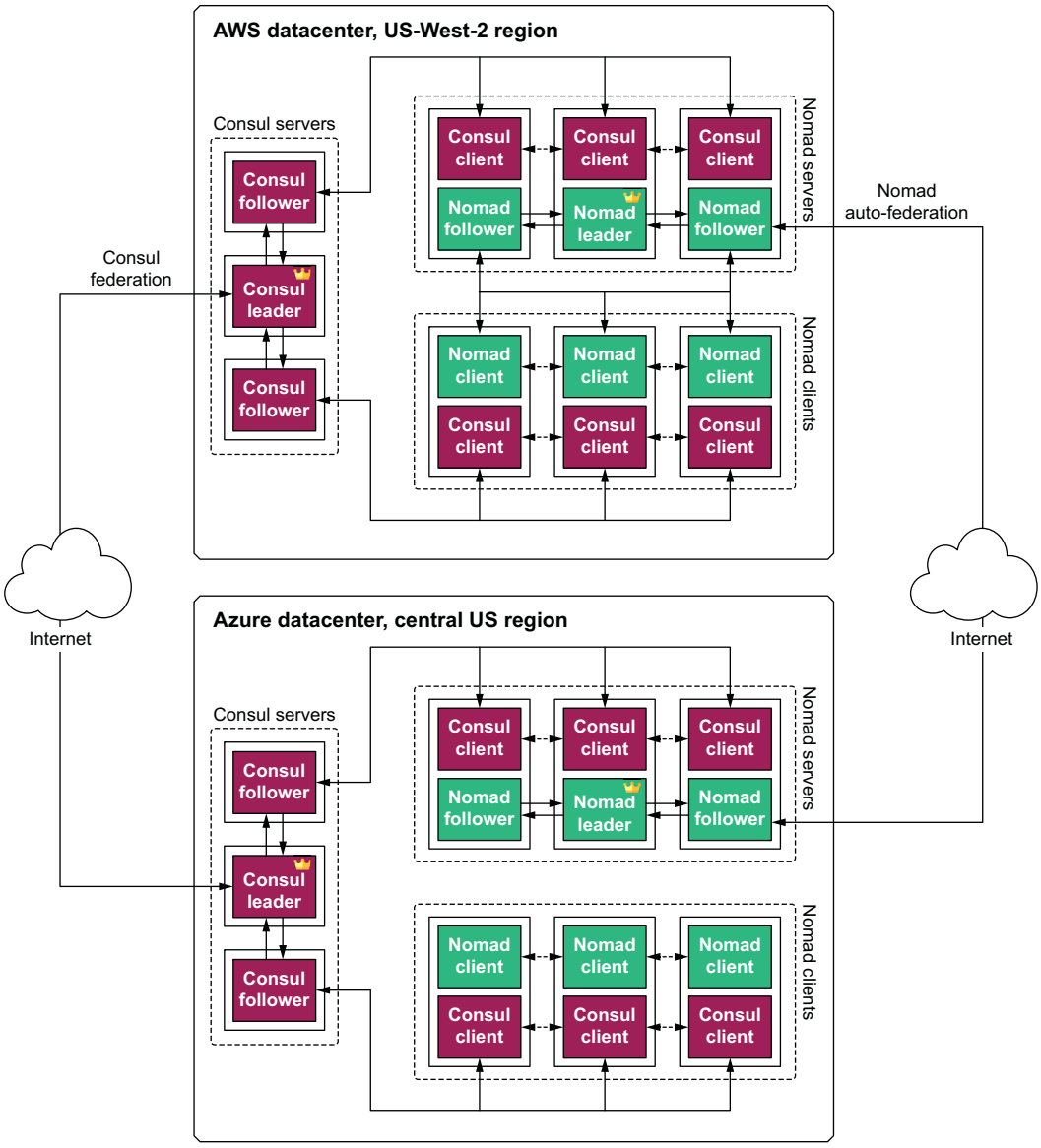


Figure 8.9 Detailed architecture diagram of how federation occurs between the Consul servers and Nomad servers, respectively. The little crowns represent server leaders.

Once the clusters are running and federated together, we will deploy Nomad workloads onto them, following a two-stage deployment technique described in chapter 7 (see figure 8.10). The only difference is that the second stage will be deployed using Terraform rather than a separate CI/CD pipeline.

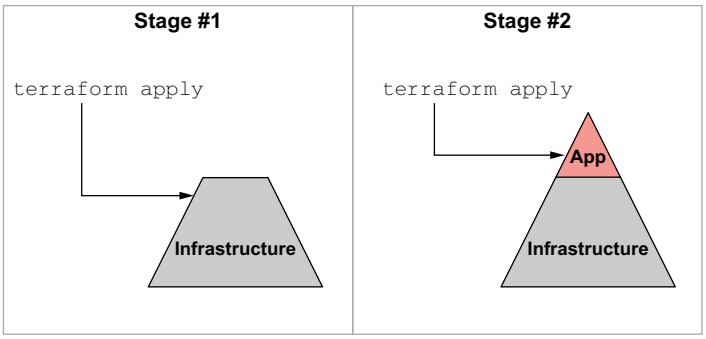


Figure 8.10 Deployment is done in two stages. First the static infrastructure is provisioned, and then the dynamic infrastructure is provisioned on top of that.

Figure 8.11 shows a detailed network topology for the application layer (stage 2). The application layer is composed of two Docker containers: one for the web app and one for the Mongo database. The web app runs on AWS, and the Mongo database runs on Azure. Each Nomad client runs a Fabio service for application load balancing/routing.

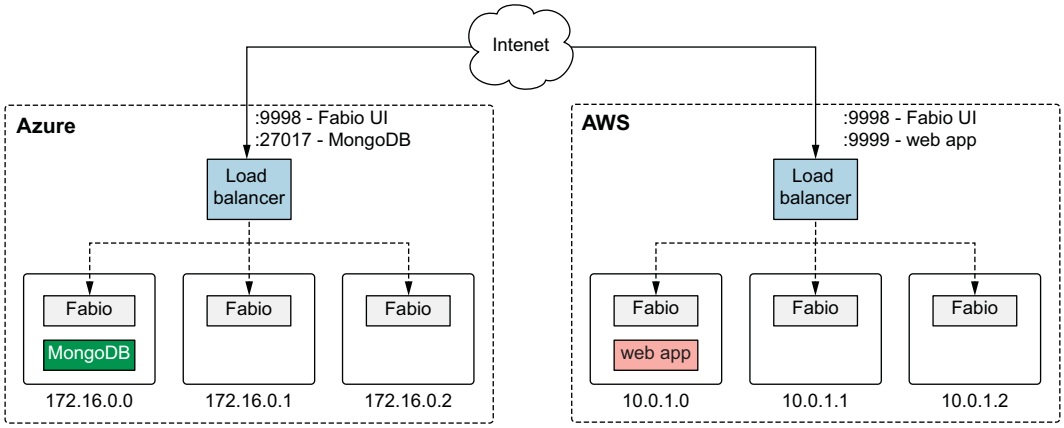


Figure 8.11 Network topology for the application layer. The web app runs in AWS, MongoDB runs on Azure, and Fabio runs on every Nomad client for application load balancing.

Fabio is exposed to the outside world through an external network load balancer that was deployed as part of stage 1.

> **NOTE** Fabio (https://fabiolb.net) is an HTTP and TCP reverse proxy that configures itself with data from Consul.

8.2.3 Stage 1: Static infrastructure

Now that we have the background and architecture out of the way, let's start writing the infrastructure code for stage 1. As before, we make heavy use of modules. This is mainly because the complete source code would be long and fairly uninteresting—we covered most of it in chapter 4. Again, if you would like to know more, feel free to peruse the source code on GitHub. The complete code is shown in the following listing.

Listing 8.5 main.tf

```
terraform {
  required_version = ">= 0.15"
  required_providers {
    azurerm = {
      source  = "hashicorp/azurerm"
      version = "~> 2.47"
    }
    aws = {
      source  = "hashicorp/aws"
      version = "~> 3.28"
    }
    random = {
      source  = "hashicorp/random"
      version = "~> 3.0"
    }
  }
}

provider "aws" {
  profile = "<profile>"
  region  = "us-west-2"
}

provider "azurerm" {
  features  {}
}

module "aws" {
  source               = "terraform-in-action/nomad/aws"
  associate_public_ips = true

  consul = {
    version              = "1.9.2"
    servers_count        = 3
    server_instance_type = "t3.micro"
  }
```

Because we do not have a VPN tunnel between Azure and AWS, we have to assign public IP addresses to the client nodes to join the clusters.

```
  nomad = {
    version              = "1.0.3"
    servers_count        = 3
    server_instance_type = "t3.micro"
    clients_count        = 3
    client_instance_type = "t3.micro"
  }
}

module "azure" {
  source               = "terraform-in-action/nomad/azure"
   location = "Central US"
  associate_public_ips = true
  join_wan             = module.aws.public_ips.consul_servers

  consul = {
    version              = "1.9.2"
    servers_count        = 3
    server_instance_size = "Standard_A1"
  }

  nomad = {
    version              = "1.0.3"
    servers_count        = 3
    server_instance_size = "Standard_A1"
    clients_count        = 3
    client_instance_size = "Standard_A1"
  }
}

output "aws" {
  value = module.aws
}
output "az" {
  value = module.azure
}
```

Because we do not have a VPN tunnel between Azure and AWS, we have to assign public IP addresses to the client nodes to join the clusters.

The Azure Consul cluster federates itself with the AWS Consul cluster using a public IP address.

WARNING These modules expose Consul and Nomad over insecure HTTP. Production use necessitates encrypting traffic with SSL/TLS certificates.

Let's now provision the static infrastructure. Initialize the workspace with `terraform init`, and run `terraform apply`:

```
$ terraform apply
...
Plan: 96 to add, 0 to change, 0 to destroy.

Changes to Outputs:
  + aws = {
      + addresses  = {
          + consul_ui = (known after apply)
          + fabio_lb  = (known after apply)
          + fabio_ui  = (known after apply)
          + nomad_ui  = (known after apply)
```

```
        }
      + public_ips = {
          + consul_servers = (known after apply)
          + nomad_servers  = (known after apply)
        }
    }
  + az  = {
      + addresses = {
          + consul_ui = (known after apply)
          + fabio_db  = (known after apply)
          + fabio_ui  = (known after apply)
          + nomad_ui  = (known after apply)
        }
    }

Do you want to perform these actions?
  Terraform will perform the actions described above.
  Only 'yes' will be accepted to approve.

  Enter a value:
```

After you approve the `apply` and wait 10–15 minutes for it to complete, the output will include your AWS and Azure addresses for Consul, Nomad, and Fabio:

```
...
module.azure.module.consul_servers.azurerm_role_assignment.role_assignment:
Still creating... [20s elapsed]
module.azure.module.consul_servers.azurerm_role_assignment.role_assignment:
Creation complete after 23s [id=/subscriptions/47fa763c-d847-4ed4-bf3f-
1d2ed06f972b/providers/Microsoft.Authorization/roleAssignments/9ea7d897-
b88e-d7af-f28a-a98f0fbecfa6]

Apply complete! Resources: 96 added, 0 changed, 0 destroyed.

Outputs:

aws = {
  "addresses" = {
    "consul_ui" = "http://terraforminaction-5g7lul-consul-51154501.us-west-
2.elb.amazonaws.com:8500"
    "fabio_lb" = "http://terraforminaction-5g7lul-fabio-
8ed59d6269bc073a.elb.us-west-2.amazonaws.com:9999"
    "fabio_ui" = "http://terraforminaction-5g7lul-fabio-
8ed59d6269bc073a.elb.us-west-2.amazonaws.com:9998"
    "nomad_ui" = "http://terraforminaction-5g7lul-nomad-728741357.us-west-
2.elb.amazonaws.com:4646"
  }
  "public_ips" = {
    "consul_servers" = tolist([
      "54.214.122.191",
      "35.161.158.133",
      "52.41.144.132",
    ])
    "nomad_servers" = tolist([
      "34.219.30.131",
```

```
      "34.222.26.195",
      "34.213.132.122",
    ])
  }
}
az = {
  "addresses" = {
    "consul_ui" = "http://terraforminaction-vyyoqu-
consul.centralus.cloudapp.azure.com:8500"
    "fabio_db" = "tcp://terraforminaction-vyyoqu-
fabio.centralus.cloudapp.azure.com:27017"
    "fabio_ui" = "http://terraforminaction-vyyoqu-
fabio.centralus.cloudapp.azure.com:9998"
    "nomad_ui" = "http://terraforminaction-vyyoqu-
nomad.centralus.cloudapp.azure.com:4646"
  }
}
```

NOTE Although Terraform has been applied successfully, it will still take a few minutes for the clusters to finish bootstrapping.

Verify that Consul is running by copying the URL from either `aws.addresses.consul_ui` or `azure.addresses.consul_ui` into the browser (since they are federated, it does not matter which you use). You will get a page that looks like figure 8.12.

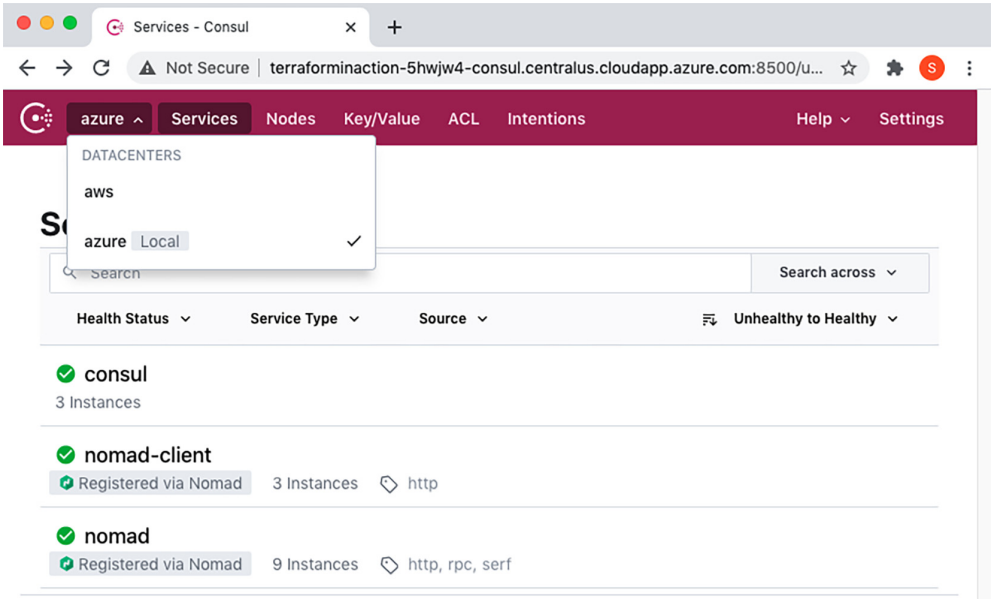


Figure 8.12 AWS Consul has started up and been federated with the Azure Consul, and Nomad servers and clients have automatically registered themselves. Clicking the Services tab lets you toggle between the AWS and Azure datacenters.

Once the Nomad servers are registered, you can view the Nomad control plane by copying the URL for either `aws.addresses.nomad_ui` or `azure.addresses.nomad_ui` into the browser. You can verify the clients are ready by clicking the Clients tab (see figure 8.13).

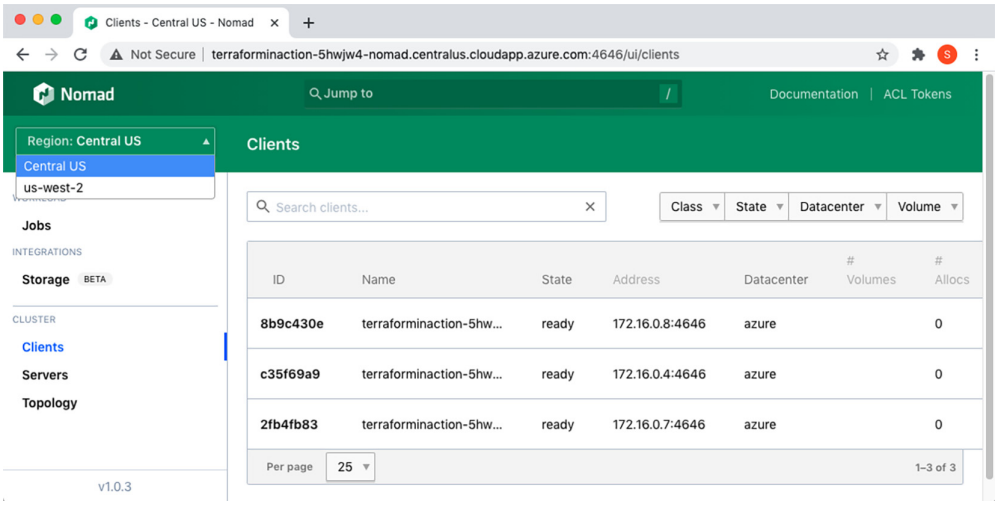


Figure 8.13 Nomad clients have joined the cluster and are ready to work. At top left, you can click the Regions tab to switch to the AWS datacenter.

8.2.4 Stage 2: Dynamic infrastructure

We are ready to deploy the MMORPG services onto Nomad. We'll use the Nomad provider for Terraform, although it is more of a teaching opportunity than a real-world solution. In practice, I recommend deploying Nomad or Kubernetes workloads with the SDK, CLI, or API as part of an automated CI/CD pipeline.

Create a new Terraform workspace with a single file called nomad.tf containing the code in the following listing. You will need to populate it with some of the addresses from the previous section.

Listing 8.6 nomad.tf

```
terraform {
  required_version = ">= 0.15"
  required_providers {
    nomad = {
      source  = "hashicorp/nomad"
      version = "~> 1.4"
    }
  }
}
```

```
provider "nomad" {
  address = "<aws.addresses.nomad_ui>"
  alias   = "aws"
}

provider "nomad" {
  address = "<azure.addresses.nomad_ui>"
  alias   = "azure"
}

module "mmorpg" {
  source   = "terraform-in-action/mmorpg/nomad"
  fabio_db = "<azure.addresses.fabio_db>"
  fabio_lb = "<aws.addresses.fabio_lb>"

  providers = {
    nomad.aws   = nomad.aws
    nomad.azure = nomad.azure
  }
}

output "browserquest_address" {
  value = module.mmorpg.browserquest_address
}
```

The Nomad provider needs to be declared twice because of an oddity in how the API handles jobs.

The module needs to know the address of the database and load balancer to initialize. Consul could be used for service discovery, but that would require the two clouds to have a private network tunnel to each other.

The providers meta-argument allows providers to be explicitly passed to modules.

Next, initialize Terraform and run an `apply`:

```
$ terraform apply
...
      + type                      = "service"
    }

Plan: 4 to add, 0 to change, 0 to destroy.

Changes to Outputs:
  + browserquest_address = "http://terraforminaction-5g7lul-fabio-
8ed59d6269bc073a.elb.us-west-2.amazonaws.com:9999"

Do you want to perform these actions?
  Terraform will perform the actions described above.
  Only 'yes' will be accepted to approve.

  Enter a value:
```

Confirm the `apply`, and deploy the services onto Nomad:

```
...
module.mmorpg.nomad_job.aws_browserquest: Creation complete after 0s
[id=browserquest]
module.mmorpg.nomad_job.azure_fabio: Creation complete after 0s [id=fabio]
module.mmorpg.nomad_job.azure_mongo: Creation complete after 0s [id=mongo]

Apply complete! Resources: 4 added, 0 changed, 0 destroyed.

Outputs:

browserquest_address = "http://terraforminaction-5g7lul-fabio-
8ed59d6269bc073a.elb.us-west-2.amazonaws.com:9999"
```

The Nomad services are now deployed and have registered themselves with Consul and Fabio (see figures 8.14–8.16).

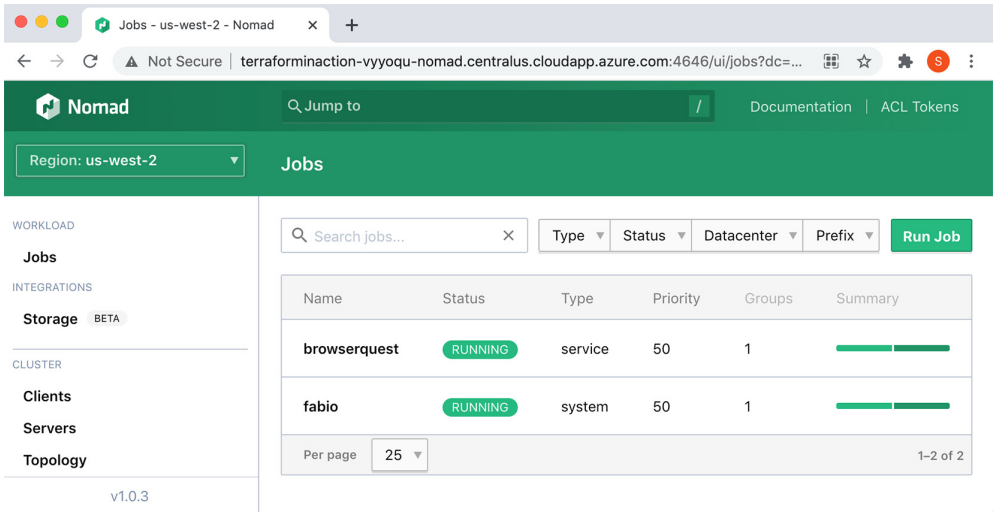


Figure 8.14 In the Nomad UI, you can see that BrowserQuest and Fabio are currently running in the AWS region. Click the Regions tab to switch to the Azure region and view Fabio and MongoDB running there.

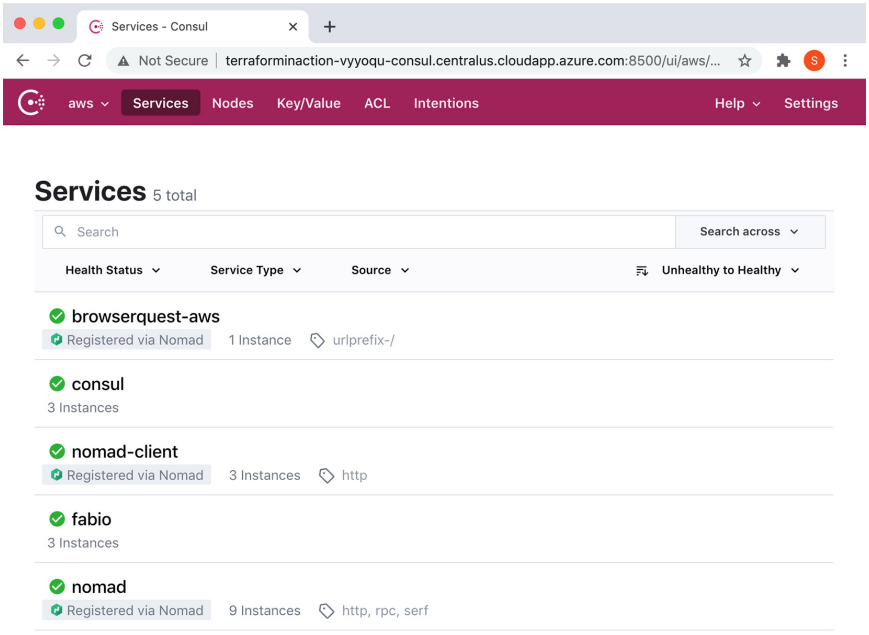


Figure 8.15 Jobs register themselves as services with Consul, which can be seen in the Consul UI.

Figure 8.16 After the services are marked as healthy by Consul, they can be detected by Fabio. In AWS, Fabio routes HTTP traffic to the dynamic port that BrowserQuest is running on. In Azure, Fabio routes TCP traffic to the dynamic port MongoDB is running on.

8.2.5 *Ready player one*

After verifying the health of the services, you are ready to play! Copy the `browserquest_address` output into your browser, and you will be presented with a screen asking to create a new character (see figure 8.17). Anyone who has this address can join the game and play too.

> **NOTE** The title screen says Phaser Quest instead of BrowserQuest because it is a re-creation of the original BrowserQuest game using the Phaser game engine for JavaScript. Credit goes to Jerenaux (www.github.com/Jerenaux/phaserquest).

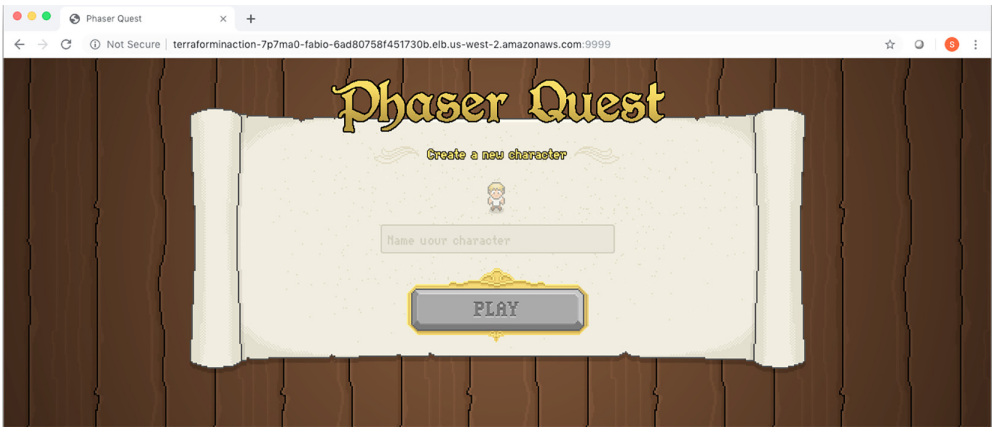


Figure 8.17 Welcome screen for the BrowserQuest MMORPG. You can now create a character, and anyone who has the link can play with you.

When you are done, tear down the static infrastructure before proceeding (it does not matter whether you destroy the Nomad workloads):

```
$ terraform destroy -auto-approve
...
module.azure.module.resourcegroup.azurerm_resource_group.resource_group:
Destruction complete after 46s
module.azure.module.resourcegroup.random_string.rand: Destroying...
[id=t2ndbvgi4ayw2qmhvl7mw1bu]
module.azure.module.resourcegroup.random_string.rand: Destruction complete
after 0s

Destroy complete! Resources: 93 destroyed.
```

8.3 Re-architecting the MMORPG to use managed services

Think of this as a bonus section. I could have ended the chapter with the previous section, but I feel the overall story would have been incomplete. The magical thing about multi-cloud is that it's whatever you want it to be. Multi-cloud doesn't have to involve VMs or federating container orchestration platforms; it can also mix and match managed services.

By *managed services*, I mean anything that isn't raw compute or heavy on the operations side of things; both SaaS and serverless qualify under this definition. Managed services are unique to each cloud. Even the same kind of managed service will differ in implementation across cloud providers (in terms of APIs, features, pricing, etc.). These differences can be perceived either as obstacles or as opportunities. I prefer the latter.

In this section, we re-architect the MMORPG to run on managed services in AWS and Azure. Specifically, we use AWS Fargate to deploy the app as a serverless container and Azure Cosmos DB as a managed MongoDB instance. Figure 8.18 shown an architecture diagram.

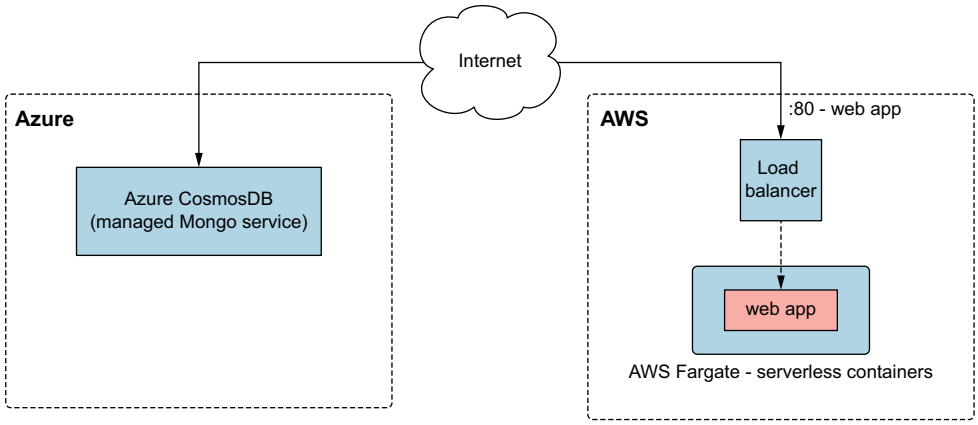
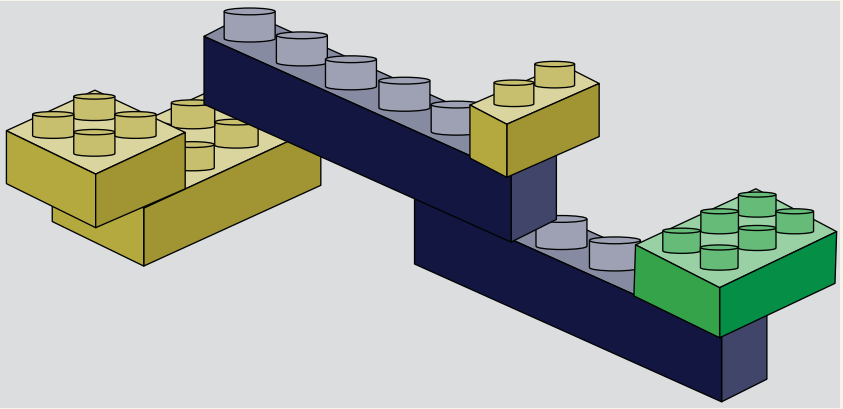


Figure 8.18 Architecture for the multi-cloud deployment of the MMORPG using managed services

Building-blocks metaphor

In many ways, developing with Terraform is like constructing with building blocks. Terraform has many different providers that, much like individual block sets, give you a huge assortment of pieces to work with. You don't need any specialized tools to assemble building blocks—they just fit together, because that's how they were designed.



Combining resources from various cloud providers is like playing with building blocks.

Naturally, building something new is always the challenging part. Sometimes you have more blocks than you know what to do with, or some of the blocks you need are missing (and you don't even know which ones). Also, the instructions may be completely or partially absent, but you still have to build that Millennium Falcon. Given the sheer number of blocks at hand, it's inevitable that there are good and less-good ways to combine blocks.

I am not suggesting that it is always a good idea to mix and match resources between various cloud providers—that would be foolhardy. My intent is merely to encourage you to keep an open mind. The "best" design may not always be the most obvious one.

8.3.1 Code

The chapter is already long, so I will make this quick. You need to create only one file, and it has everything required to deploy this scenario. Create a new workspace with a player2.tf file.

Listing 8.7 player2.tf

```
terraform {
  required_version = ">= 0.15"
  required_providers {
```

```
    azurerm = {
      source  = "hashicorp/azurerm"
      version = "~> 2.47"
    }
    aws = {
      source  = "hashicorp/aws"
      version = "~> 3.28"
    }
    random = {
      source  = "hashicorp/random"
      version = "~> 3.0"
    }
  }
}

provider "aws" {
  profile = "<profile>"
  region = "us-west-2"
}

provider "azurerm" {
  features {}
}

module "aws" {
  source = "terraform-in-action/mmorpg/cloud//aws"
  app = {
    image   = "swinkler/browserquest"
    port    = 8080
    command = "node server.js --connectionString
    ➥ ${module.azure.connection_string}"
  }
}

module "azure" {
  source    = "terraform-in-action/mmorpg/cloud//azure"
  namespace = "terraforminaction"
  location  = "centralus"
}

output "browserquest_address" {
  value = module.aws.lb_dns_name
}
```

8.3.2 Ready player two

We are ready to deploy! Wasn't that easy? Initialize the workspace with `terraform init` followed by `terraform apply`. The result of `terraform apply` is as follows:

```
$ terraform apply
...
      + owner_id               = (known after apply)
      + revoke_rules_on_delete = false
      + vpc_id                 = (known after apply)
    }
```

```
Plan: 37 to add, 0 to change, 0 to destroy.

Changes to Outputs:
  + browserquest_address = (known after apply)

Do you want to perform these actions?
  Terraform will perform the actions described above.
  Only 'yes' will be accepted to approve.

  Enter a value:
```

Confirm, and wait until Terraform finishes applying:

```
...
module.aws.aws_ecs_task_definition.ecs_task_definition: Creation complete
after 1s [id=terraforminaction-ebfes6-app]
module.aws.aws_ecs_service.ecs_service: Creating...
module.aws.aws_ecs_service.ecs_service: Creation complete after 0s
[id=arn:aws:ecs:us-west-2:215974853022:service/terraforminaction-ebfes6-
ecs-service]

Apply complete! Resources: 37 added, 0 changed, 0 destroyed.

Outputs:

browserquest_address = terraforminaction-ebfes6-lb-444442925.us-west-
2.elb.amazonaws.com
```

Copy the `browserquest_address` into the browser, and you are ready to play (see figure 8.19)! Be patient, though, because it can take a few minutes for the services to finish bootstrapping.

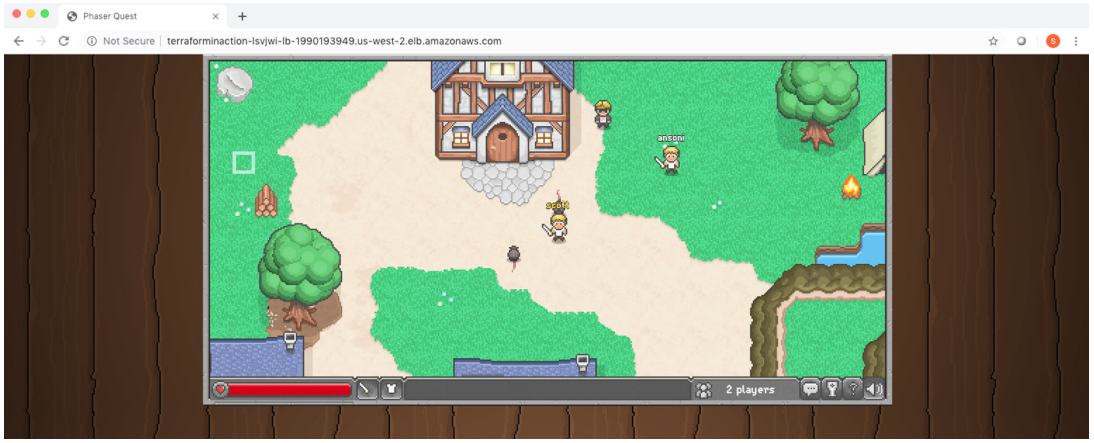


Figure 8.19 Multi-cloud means multiplayer!

TIP Remember to tear down the infrastructure with `terraform destroy` to avoid incurring additional costs!

8.4 Fireside chat

Terraform is the glue that binds multi-cloud architectures together. We started by deploying a hybrid-cloud load balancer with VMs in AWS, GCP, and Azure. This was as easy as declaring a few provider and module blocks. Multi-cloud architectures don't have to be complex; they can be as simple as deploying an app using Heroku and configuring DNS with Cloudflare.

The next scenario we looked at involved a two-stage deployment to launch a container-orchestration platform and deploy services on top of that. Our container-orchestration platform consisted of two Nomad clusters federated together and using Consul for service discovery. Federated clusters are a practical way to approach multi-cloud because they allow you to treat compute like a commodity. Applications can be deployed without concern for the underlying infrastructure or cloud. Furthermore, by using a networking tool like Consul, it's possible to improve resiliency by performing automated failovers via dynamic routing.

We followed up the container-orchestration scenario by redesigning our MMORPG app to use managed services. The frontend was deployed as a serverless container onto AWS and connected to a managed MongoDB instance on Azure. The point was that you don't have to go all in on Kubernetes or Nomad if you don't want to. Managed services are a fantastic alternative to container-orchestration platforms because of their reduced operational overhead.

Summary

- Terraform can orchestrate multi-cloud and hybrid-cloud deployments with ease. From a user perspective, it is not much different than deploying to a single cloud.
- Not all Terraform providers are worthwhile. For example, the Docker and Nomad providers for Terraform offer questionable value at best. It may be easier to call the APIs directly than to incorporate these providers into your workflows.
- Cluster federation can be performed automatically as part of `terraform apply`, although the clusters won't necessarily be ready when Terraform finishes applying. This is because the applications running on the clusters may still be bootstrapping.
- Terraform can deploy containerized services, whether in the traditional sense—via container orchestration platforms—or using managed services.

Part 3

Mastering Terraform

Mastering anything is difficult and circuitous, and Terraform is no exception. Until now, the overall narrative has been fairly linear. We started with the basics of Terraform, moved on to design patterns and principles, and rounded out the discussion with a few real-world scenarios. Progressing further, however, first requires us to take a step back and ask bigger questions: How does Terraform fit into the overall technology landscape? How do you manage, automate, and integrate Terraform with other continuous deployment technologies? All this, and more, is the subject of part 3.

Chapter 9 is all about zero-downtime deployments. We examine two methods for performing Blue/Green deployments with Terraform before finally asking, "Is Terraform the right tool for the job?" As it turns out, Terraform and Ansible might be better together.

Chapter 10 explores case studies in testing and refactoring Terraform configuration. Everyone has to deal with refactoring at some point, but it's tricky with Terraform because you have to deal with migrating state. Automated testing helps to some extent since it gives you greater confidence that functionality is preserved and nothing has broken.

Chapter 11 is when we finally extend Terraform by writing a custom provider. Writing custom providers is fun because it allows you the greatest control over how Terraform behaves. We write a bare-bones provider for a Petstore API and use Terraform to deploy a managed pet resource to it.

Chapter 12 considers the problem of running Terraform in automation. Terraform Cloud and Terraform Enterprise are proprietary solutions that address this problem, but they may not fit your requirements. We walk through what it

takes to build your own CI/CD pipeline for running Terraform in automation and discuss potential improvements.

Chapter 13 is about security and secrets management in Terraform. Topics covered include how to secure state and log files, how to manage static and dynamic secrets, and how to enforce policy as code with Sentinel. There are many ways Terraform can leak secrets, and it's important to know what they are so you can protect against them.

9 Zero-downtime deployments

This chapter covers

- Customizing resource lifecycles with the `create_before_destroy` flag
- Performing Blue/Green deployments with Terraform
- Combining Terraform with Ansible
- Generating SSH key pairs with the TLS provider
- Installing software on VMs with `remote-exec` provisioners

Traditionally, there has been a window of time during software deployments when servers are incapable of serving production traffic. This window is typically scheduled for early morning off-hours to minimize downtime, but it still impacts availability. *Zero-downtime deployment* (ZDD) is the practice of keeping services always running and available to customers, even during software updates. If a ZDD is executed well, users should not be aware when changes are being made to the system.

In this chapter, we investigate three approaches to achieving ZDDs with Terraform. First, we use the `create_before_destroy` meta attribute to ensure that an application is running and passing health checks before we tear down the old

instance. The `create_before_destroy` meta attribute alters how *force-new* updates are handled internally by Terraform. When it's set to `true`, interesting and unexpected behavior can result.

Next, we examine one of the oldest and most popular ways to achieve ZDD: *Blue/Green deployments*. This technique uses two separate environments (one "Blue" and the other "Green") to rapidly cut over from one software version to another. Blue/Green is popular because it is fairly easy to implement and enables rapid rollback. Furthermore, Blue/Green is a stepping stone toward more advanced forms of ZDD, such as rolling Blue/Green and canary deployments.

Finally, we offload the responsibilities of ZDD to another, more suitable technology: Ansible. Ansible is a popular configuration management tool that allows you to rapidly deploy applications onto existing infrastructure. By provisioning all your static infrastructure with Terraform, Ansible can be used to deploy the more dynamic applications.

9.1 Lifecycle customizations

Consider a resource that provisions an instance in AWS that starts a simple HTTP server running on port 80:

```
resource "aws_instance" "instance" {
  ami           = var.ami
  instance_type = var.instance_type

  user_data = <<-EOF                                  <-- Starts a simple HTTP webserver
    #!/bin/bash
    mkdir -p /var/www && cd /var/www
    echo "App v${var.version}" >> index.html
    python3 -m http.server 80
  EOF
}
```

If one of the force-new attributes (`ami`, `instance_type`, `user_data`) was modified, then during a subsequent `terraform apply`, the existing resource would be destroyed before the new one was created. This is Terraform's default behavior. The drawback is that there is downtime between when the old resource is destroyed and the replacement resource is provisioned (see figure 9.1). This downtime is not negligible and can be anywhere from five minutes to an hour or more, depending on the upstream API.

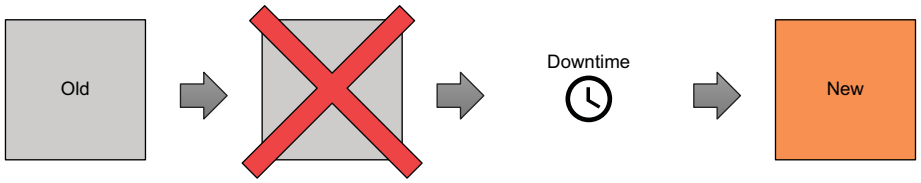


Figure 9.1 By default, any force-new update on a resource results in downtime. This is because the old resource must be destroyed before a new resource can be created.

To avoid downtime, the `lifecycle` meta argument allows you to customize the resource lifecycle. The `lifecycle` nested block is present on all resources. You can set the following three flags:

- `create_before_destroy` (bool)—When set to `true`, the replacement object is created before the old object is destroyed.
- `prevent_destroy` (bool)—When set to `true`, Terraform will reject any plan that would destroy the infrastructure object associated with the resource with an explicit error.
- `ignore_changes` (list of attribute names)—Specifies a list of resource attributes that Terraform should ignore when generating execution plans. This allows a resource to have some measure of configuration drift without forcing updates to occur.

These three flags let you override the default behavior for resource creation, destruction, and updates and should be used with extreme caution because they alter Terraform's fundamental behavior.

9.1.1 Zero-downtime deployments with create_before_destroy

The most intriguing parameter on the `lifecycle` block is `create_before_destroy`. This flag switches the order in which Terraform performs a force-new update. When this parameter is set to `true`, the new resource is provisioned alongside the existing resource. Only after the new resource has successfully been created is the old resource destroyed. This concept is shown in figure 9.2.

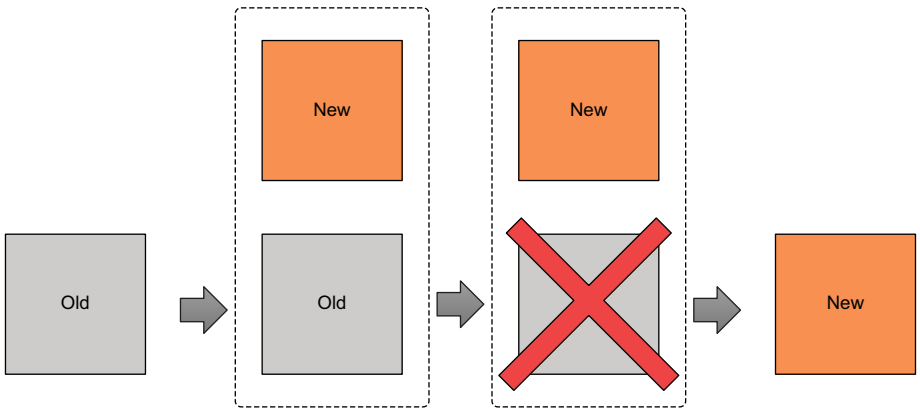


Figure 9.2 When `create_before_destroy` is set to `true`, the replacement resource is created before the old resource is destroyed. This means you don't experience any downtime during force-new updates.

NOTE `create_before_destroy` doesn't default to `true` because many providers do not allow two instances of the same resource to exist simultaneously. For example, you can't have two S3 buckets with the same name.

Paul Hinzie, director of engineering at HashiCorp, suggested back in 2015 that the `create_before_destroy` flag could be used to enable ZDDs (see http://mng.bz/EV1o). Consider the following snippet, which modifies the lifecycle of an `aws_instance` resource by setting the `create_before_destroy` flag to `true`:

```
resource "aws_instance" "instance" {
  ami           = var.ami
  instance_type = "t3.micro"

  lifecycle {
    create_before_destroy = true
  }

  user_data = <<-EOF
    #!/bin/bash
    mkdir -p /var/www && cd /var/www
    echo "App v${var.version}" >> index.html
    python3 -m http.server 80
  EOF
}
```

As before, any changes to one of the force-new attributes will trigger a force-new update—but because `create_before_destroy` is now set to `true`, the replacement resource will be created before the old one is destroyed. This applies only to managed resources (i.e., not data sources).

Suppose `var.version`, a variable denoting the application version, were incremented from 1.0 to 2.0. This change would trigger a force-new update on `aws_instance` because it alters `user_data`, which is a force-new attribute. Even with `create_before_destroy` set to `true`, however, we cannot guarantee that the HTTP server will be running after the resource has been marked as created. In fact, it probably won't be, because Terraform manages things that it knows about (the EC2 instance) and not the application that runs on that instance (the HTTP server).

We can circumvent this limitation by taking advantage of resource provisioners. Due to the way provisioners were implemented, a resource is not marked as created or destroyed unless all creation-time and destruction-time provisioners have executed with no errors. This means we can use a `local-exec` provisioner to perform creation-time health checks to ensure that the instance has been created and the application is healthy and serving HTTP traffic:

```
resource "aws_instance" "instance" {
  ami           = var.ami
  instance_type = "t3.micro"

  lifecycle {
    create_before_destroy = true
  }

  user_data = <<-EOF
    #!/bin/bash
```

```
    mkdir -p /var/www && cd /var/www
    echo "App v${var.version}" >> index.html
    python3 -m http.server 80
  EOF

  provisioner "local-exec" {
    command = "./health-check.sh ${self.public_ip}"
  }
}
```

Application health check. The script file health-check.sh is presumed to exist.

NOTE The `self` object within a `local-exec` provisioner is a reference to the current resource the provisioner is attached to.

9.1.2 Additional considerations

Although it would appear that `create_before_destroy` is an easy way to perform ZDDs, it has a number of quirks and shortcomings that you should keep in mind:

- *Confusing*—Once you start messing with Terraform's default behavior, it's harder to reason about how changes to your configuration files and variables will affect the outcome of an `apply`. This is especially true when `local-exec` provisioners are thrown in the mix.
- *Redundant*—Everything you can accomplish with `create_before_destroy` can also be done with two Terraform workspaces or modules.
- *Namespace collisions*—Because both the new and old resources must exist at the same time, you have to choose parameters that will not conflict with each other. This is often awkward and sometimes even impossible, depending on how the parent provider implemented the resource.
- *Force-new vs. in place*—Not all attributes force the creation of a new resource. Some attributes (like tags on AWS resources) are updated in place, which means the old resource is never actually destroyed but merely altered. This also means any attached resource provisioners won't be triggered.

TIP I do not use `create_before_destroy` as I have found it to be more trouble than it is worth.

9.2 Blue/Green deployments

During a Blue/Green deployment, you switch between two production environments: one called *Blue* and one called *Green*. Only one production environment is live at any given time. A router directs traffic to the live environment and can be either a load balancer or a DNS resolver. Whenever you want to deploy to production, you first deploy to the idle environment. Then, when you are ready, you switch the router from pointing to the live server to pointing to the idle server—which is already running the latest version of the software. This switch is referred to as a *cutover* and can be done manually or automatically. When the cutover completes, the idle server becomes the new live server, and the former live server is now the idle server (see figure 9.3).

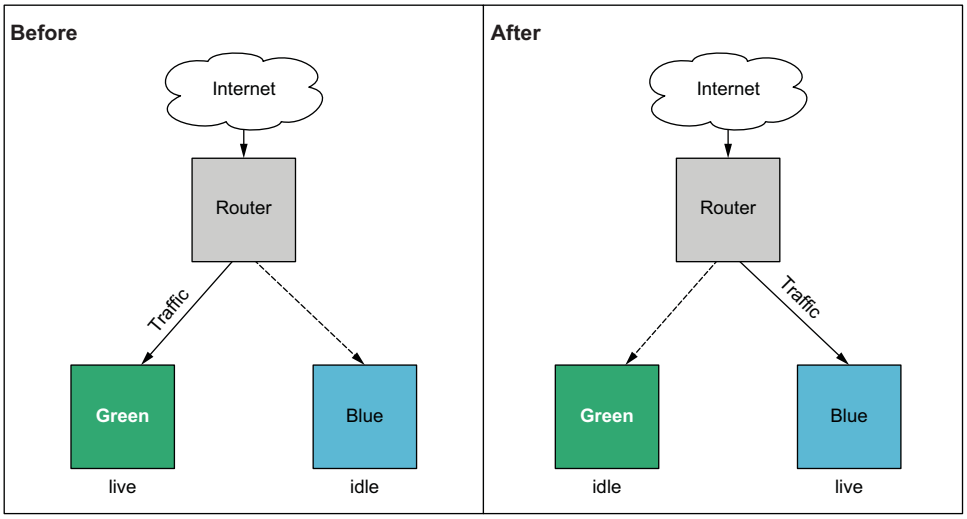


Figure 9.3 Blue/Green deployments have two production environments: one live and serving production traffic and the other idle. Changes are always made first to the idle environment. After cutover, the idle environment becomes the new live environment and begins receiving production traffic.

Video graphics analogy

Suppose you had to draw a picture on the screen pixel by pixel or line by line. If you drew such an image on the screen directly, you would immediately be disappointed by how long it took. This is because there is a hard limit on how fast changes can be propagated to the screen—usually between 60 and 120 Hz (cycles per second). Most programmers use a technique called *double buffering* to combat this problem. Double buffering is the act of writing to an in-memory data structure called a *back buffer* and then drawing the image from the back buffer to the screen in a single operation. This technique is significantly faster than drawing pixels one at a time and is good enough for most applications.

However, for some particularly graphics-intensive applications—namely, video games—double buffering is still too slow. There is still downtime, as the graphics card cannot write to the back buffer at the same time the screen is reading from it (and vice versa). A clever workaround is to use not one but *two* back buffers. One back buffer is reserved for the screen, while the other is reserved for the graphics card. After a predefined period, the back buffers are swapped (i.e., the screen pointer is cut over from one back buffer to the other). This technique, called *page flipping*, is a fun analogy for how Blue/Green deployment works.

Blue/Green deployments are the oldest and most popular way to achieve ZDDs. More advanced implementations of ZDD include rolling Blue/Green and/or canary deployments.

Rolling Blue/Green and canary deployments

Rolling Blue/Green is similar to regular Blue/Green, except instead of moving 100% of the traffic at once, you slowly replace one server at a time. Suppose you have a set of production servers running the old version of your software and wish to update to the new version. To commence rolling Blue/Green, you launch a new server running the new version, ensure that it passes health checks, and then kill one of the old servers. You do this incrementally, one server at a time, until all the servers are migrated over and running the latest version of the software. This is more complicated from an application standpoint as you have to ensure the application can support running two versions concurrently. Applications with a data layer may have trouble with data corruption if the schema changes from one version to the next while read/writes are still taking place.

Canary deployments are also about deploying an application in small, incremental steps but have more to do with people than servers. As with rolling Blue/Green, some people get one version of your software while others get another version. Unlike rolling Blue/Green, this approach has nothing to do with migrating servers one at a time. Often, a canary deployment serves a small percentage of your total traffic to the new application, monitors performance, and slowly increases the percentage over time until all traffic is receiving the new application. If an error or performance issue is encountered, the percentage can be immediately decreased to perform fast rollbacks. Canary deployments may also rely on a feature toggle that turns new features on or off based on specific criteria (such as age, gender, and country of origin).

While it is certainly possible to do rolling Blue/Green and canary deployments with Terraform, much of the challenge depends on the kind of service you are deploying. Some managed services make this easy because the logic is baked right into the resource (such as with Azure virtual machine scale sets), while other resources need you to implement this logic yourself (such as with AWS Route 53 and AWS application load balancers). This section sticks with the classic, and more general, Blue/Green deployment problem.

9.2.1 Architecture

Going back to the definition of Blue/Green, we need two copies of the production environment: Blue and Green. We also need some common infrastructure that is independent of the environment, such as the load balancer, VPC, and security groups. For the purposes of this exercise, I refer to this common infrastructure as the *base* because it forms the foundation layer onto which the application will be deployed, similar to what we did with the two-stage deployment technique in chapters 7 and 8.

> **NOTE** Managing stateful data for Blue/Green deployments is notoriously tricky. Many people recommend including databases in the base layer so that all production data is shared between Blue and Green.

We will deploy version 1.0 of our software onto Green and version 2.0 onto Blue. Initially, Green will be the live server while Blue is idle. Next, we will manually cut over from Green to Blue so that Blue becomes the new live server while Green is idle. From the user's perspective, the software update from version 1.0 to 2.0 happens instantaneously. The overarching deployment strategy is illustrated by figure 9.4. Figure 9.5 shows a detailed architecture diagram.

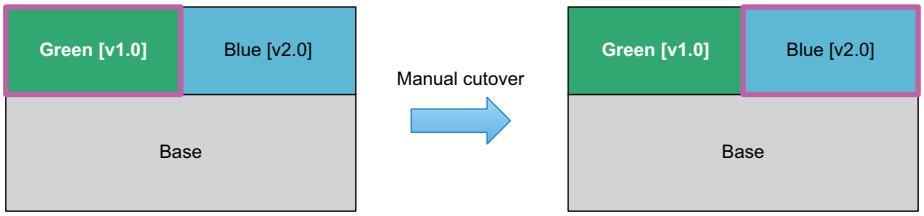


Figure 9.4 The shared, or base, infrastructure is deployed first. Initially, Green will be the live server, while Blue is idle. Then a manual cutover will take place so that Blue becomes the new live server. The end result is that the customer experiences an instantaneous software update from version 1.0 to 2.0.

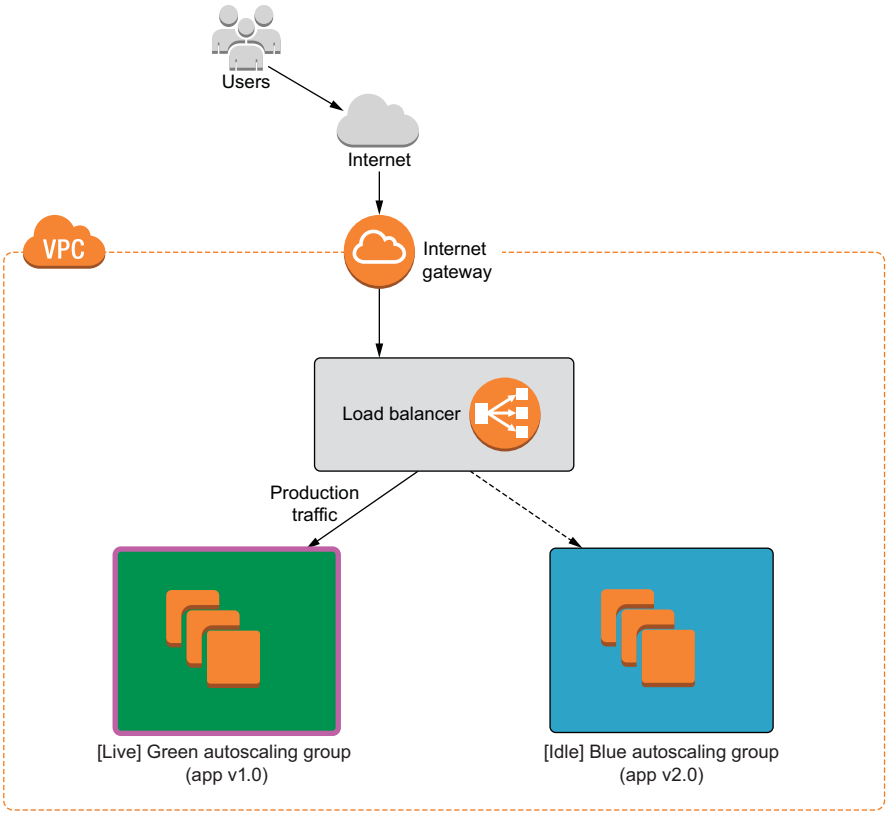


Figure 9.5 We will deploy a load balancer with two autoscaling groups: Green and Blue. The load balancer serves production traffic to the current live environment.

9.2.2 Code

We will use premade modules so we can focus on the big picture. Create a new Terraform workspace, and copy the code from the following listing into a file named blue_green.tf.

Listing 9.1 blue_green.tf

```
provider "aws" {
  region  = "us-west-2"
}

variable "production" {
  default = "green"
}

module "base" {
  source     = "terraform-in-action/aws/bluegreen//modules/base"
  production = var.production
}

module "green" {
  source      = "terraform-in-action/aws/bluegreen//modules/autoscaling"
  app_version = "v1.0"
  label       = "green"
  base        = module.base
}

module "blue" {
  source      = "terraform-in-action/aws/bluegreen//modules/autoscaling"
  app_version = "v2.0"
  label       = "blue"
  base        = module.base
}

output "lb_dns_name" {
  value = module.base.lb_dns_name
}
```

TIP You can also use feature flags to enable/disable Blue/Green environments. For example, you could have a boolean variable called `enable_green_application` that set the `count` attribute on a resource to either 1 or 0 (i.e., `count = var.enable_green_application ? 1 : 0`).

9.2.3 Deploy

Initialize the Terraform workspace with `terraform init`, and follow it up with `terraform apply`. The result of the execution plan is as follows:

```
$ terraform apply
...
  + resource "aws_iam_role_policy" "iam_role_policy" {
      + id     = (known after apply)
      + name   = (known after apply)
      + policy = jsonencode(
            {
```

```
            + Statement = [
                + {
                    + Action   = "logs:*"
                    + Effect   = "Allow"
                    + Resource = "*"
                    + Sid      = ""
                  },
              ]
            + Version   = "2012-10-17"
          }
      )
    + role   = (known after apply)
  }

Plan: 39 to add, 0 to change, 0 to destroy.

Changes to Outputs:
  + lb_dns_name = (known after apply)

Do you want to perform these actions?
  Terraform will perform the actions described above.
  Only 'yes' will be accepted to approve.

  Enter a value:
```

Confirm, and wait until Terraform finishes creating the resources (approximately 5–10 minutes). The output of the `apply` will contain the address of the load balancer, which can be used to access the current live autoscaling group. Recall that in this case, it is Green:

```
module.green.aws_autoscaling_group.webserver: Still creating... [40s elapsed]
module.green.aws_autoscaling_group.webserver: Creation complete after 42s
[id=terraforminaction-v7t08a-green-asg]
module.blue.aws_autoscaling_group.webserver: Creation complete after 48s
[id=terraforminaction-v7t08a-blue-asg]

Apply complete! Resources: 39 added, 0 changed, 0 destroyed.

Outputs:

lb_dns_name = terraforminaction-v7t08a-lb-369909743.us-west-2.elb.ama-
     zonaws.com
```

Navigate to the address in the browser to pull up a simple HTML site running version 1.0 of the application on Green (see figure 9.6).

Figure 9.6 The application load balancer currently points to the Green autoscaling group, which hosts version 1.0 of the application.

9.2.4 Blue/Green cutover

Now we are ready for the manual cutover from Green to Blue. Blue is already running version 2.0 of the application, so the only thing we need to do is update the load-balancer listener to point from Green to Blue. In this example, it's as easy as changing `var.production` from `"green"` to `"blue"`.

Listing 9.2 blue_green.tf

```
provider "aws" {
  region  = "us-west-2"
}

variable "production" {
  default = "blue"
}

module "base" {
  source     = "terraform-in-action/aws/bluegreen//modules/base"
  production = var.production
}

module "green" {
  source      = "terraform-in-action/aws/bluegreen//modules/autoscaling"
  app_version = "v1.0"
  label       = "green"
  base        = module.base
}

module "blue" {
  source      = "terraform-in-action/aws/bluegreen//modules/autoscaling"
  app_version = "v2.0"
  label       = "blue"
  base        = module.base
}

output "lb_dns_name" {
  value = module.base.lb_dns_name
}
```

Now run an apply again.

```
$ terraform apply
...
      ~ action {
            order            = 1
          ~ target_group_arn = "arn:aws:elasticloadbalancing:us-west-
    2:215974853022:targetgroup/terraforminaction-v7t08a-blue/
    7e1fcf9eb425ac0a" -> "arn:aws:elasticloadbalancing:us-west-
    2:215974853022:targetgroup/terraforminaction-v7t08a-green/
    80db7ad39adc3d33"
            type             = "forward"
        }

        condition {
            field  = "path-pattern"
```

```
            values = [
                "/stg/*",
            ]
        }
    }
```

```
Plan: 0 to add, 2 to change, 0 to destroy.

Do you want to perform these actions?
  Terraform will perform the actions described above.
  Only 'yes' will be accepted to approve.

  Enter a value:
```

After you confirm the `apply`, it should take only a few seconds for Terraform to complete the action. Again, from the user's perspective, the change happens instantaneously with no discernable downtime. The load-balancer address has not changed: all that has happened is that the load balancer is now serving traffic to the Blue autoscaling group rather than Green. If you refresh the page, you will see that version 2.0 of the application is now in production and is served by the Blue environment (see figure 9.7).

Figure 9.7 The load balancer now points to the Blue autoscaling group, which hosts version 2.0 of the application.

9.2.5 Additional considerations

We have demonstrated a simple example of how to do Blue/Green deployments with Terraform. You should take the following additional considerations into account before implementing Blue/Green for your deployments:

- *Cost savings*—The idle group does not need to be exactly the same as the active group. You can save money by scaling down the instance size or the number of nodes when not needed. All you have to do is scale up right before you make the cutover.
- *Reducing the blast radius*—Instead of having the load balancer and autoscaling groups all in the same Terraform workspace, it may be better to have three workspaces: one for Blue, one for Green, and one for the base. When performing the manual cutover, you mitigate risk by not having all your infrastructure in the same workspace.

- *Canary deployments*—With AWS Route 53, you can perform canary deployments by having two load balancers and routing a percentage of the production traffic to each. Note that this may require executing a series of incremental Terraform deployments.

WARNING Remember to take down your infrastructure with `terraform destroy` before proceeding, to avoid incurring ongoing costs!

9.3 Configuration management

Occasionally, it's important to step back and ask, "Is Terraform the right tool for the job?" In many cases, the answer is no. Terraform is great, but only for the purpose it was designed for. For application deployments on VMs, you would be better served with a configuration management tool.

The further you move up the application stack, the more frequently changes occur. At the bottom is the infrastructure, which is primarily static and unchanging. By comparison, applications deployed onto that infrastructure are extremely volatile. Although Terraform can deploy applications (as we have seen in previous chapters), it isn't particularly good at continuous deployment. By design, Terraform is an infrastructure-provisioning tool and is too slow and cumbersome to fit this role. Instead, a container-orchestration platform or configuration-management tool would be more appropriate. Since we examined application delivery with containers in the preceding two chapters, let's now consider configuration management.

Configuration management (CM) enables rapid software delivery onto existing servers. Some CM tools can perform a degree of infrastructure provisioning, but none are particularly good at the task. Terraform is much better at infrastructure provisioning than any existing CM tool. Nevertheless, it's not a competition: you can achieve great results by combining the infrastructure-provisioning capabilities of Terraform with the best parts of CM.

Superficially, it might seem that the innate mutability of CM clashes with the innate immutability of Terraform, but this isn't so. First, we know that Terraform is not as immutable as it claims to be: in-place updates and `local-exec` provisioners are examples to the contrary. Second, CM is not as mutable as you might be led to believe. Yes, CM relies on mutable infrastructure, but applications can be deployed onto that infrastructure immutably.

Terraform and CM tools do not have to be competitive and can be integrated effectively into a common workflow. When you use the two-stage deployment technique, Terraform can provision the infrastructure, and CM can handle application delivery (see figure 9.8).

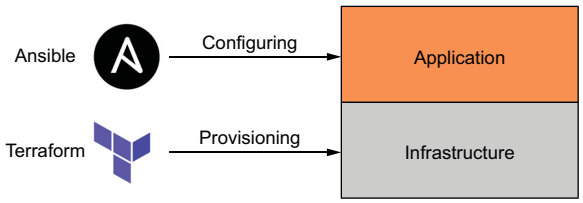


Figure 9.8 A two-stage deployment, with Terraform deploying the base-level infrastructure and Ansible configuring the application

9.3.1 Combining Terraform with Ansible

Ansible and Terraform make a great pair, and HashiCorp has even publicly stated that they are "better together" (see http://mng.bz/N8eN). But how can these two disparate tools be successfully integrated in practice? It works like this:

1. Provision a VM, or a fleet of VMs, with Terraform.
2. Run an Ansible playbook to configure the machines and deploy new applications.

This process is illustrated in figure 9.9 when the target cloud is AWS and the VM in question is an EC2 instance.

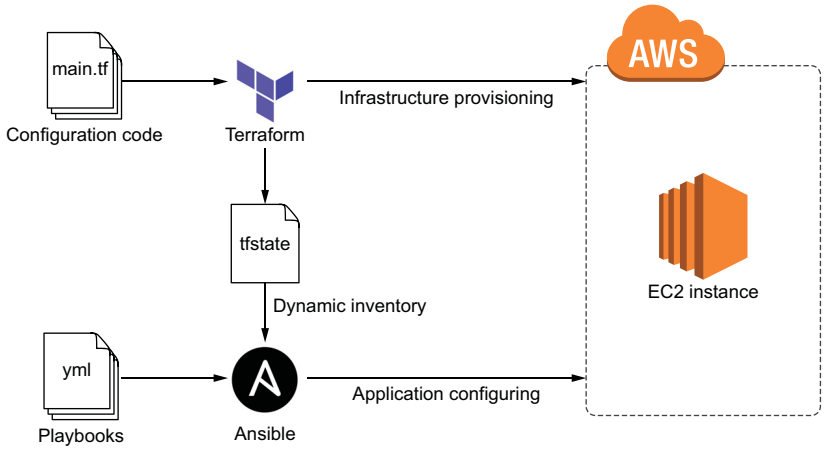


Figure 9.9 Terraform provisions an EC2 instance, and Ansible configures it with an Ansible playbook.

NOTE Chef, Puppet, and SaltStack could be incorporated in a similar manner.

For this scenario, we are going to provision a single EC2 instance with Terraform. The EC2 instance will have Ansible preinstalled on it and will be configured with an SSH key pair generated through Terraform. Once the server is up and running, we will deploy an Nginx application onto it with Ansible. Finally, we will update the application to simulate a new application deployment.

9.3.2 Code

Jumping right in, we'll start by declaring the AWS provider. In a new project directory, create a main.tf file with the AWS provider declared at the top.

Listing 9.3 main.tf

```
provider "aws" {
  region  = "us-west-2"
}
```

Next, we'll generate the SSH key pair that we'll use to configure the EC2 instance. The TLS provider makes this easy. After that, we'll write the private key to a local file and upload the public key to AWS (see listing 9.4).

NOTE Ansible requires SSH access to push software updates. Instead of creating a new SSH key pair, you could reuse an existing one, but it's good to know how to do this with Terraform, regardless.

Listing 9.4 main.tf

```
...
resource "tls_private_key" "key" {
  algorithm = "RSA"
}

resource "local_file" "private_key" {
  filename          = "${path.module}/ansible-key.pem"
  sensitive_content = tls_private_key.key.private_key_pem
  file_permission   = "0400"
}

resource "aws_key_pair" "key_pair" {
  key_name   = "ansible-key"
  public_key = tls_private_key.key.public_key_openssh
}
```

Configuring SSH means we need to create a security group with access to port 22. Of course, we also need port 80 open to serve HTTP traffic. The configuration code for the AWS security group is shown next.

Listing 9.5 main.tf

```
...
data "aws_vpc" "default" {
  default = true
}

resource "aws_security_group" "allow_ssh" {
  vpc_id = data.aws_vpc.default.id

  ingress {
    from_port   = 22
    to_port     = 22
    protocol    = "tcp"
    cidr_blocks = ["0.0.0.0/0"]
  }

  ingress {
    from_port   = 80
    to_port     = 80
    protocol    = "tcp"
    cidr_blocks = ["0.0.0.0/0"]
  }
```

```
  egress {
    from_port   = 0
    to_port     = 0
    protocol    = "-1"
    cidr_blocks = ["0.0.0.0/0"]
  }
}
```

We also need to get the latest Ubuntu AMI so that we can configure the EC2 instance. This code should be familiar.

Listing 9.6 main.tf

```
...
data "aws_ami" "ubuntu" {
  most_recent = true

  filter {
    name   = "name"
    values = ["ubuntu/images/hvm-ssd/ubuntu-focal-20.04-amd64-server-*"]
  }

  owners = ["099720109477"]
}
```

And now we can configure the EC2 instance.

Listing 9.7 main.tf

```
...

resource "aws_instance" "ansible_server" {
  ami                    = data.aws_ami.ubuntu.id
  instance_type          = "t3.micro"
  vpc_security_group_ids = [aws_security_group.allow_ssh.id]
  key_name               = aws_key_pair.key_pair.key_name

  tags = {
    Name = "Ansible Server"
  }

  provisioner "remote-exec" {
    inline = [
      "sudo apt update -y",
      "sudo apt install -y software-properties-common",
      "sudo apt-add-repository --yes --update ppa:ansible/ansible",
      "sudo apt install -y ansible"
]

    connection {
      type        = "ssh"
      user        = "ubuntu"
      host        = self.public_ip
      private_key = tls_private_key.key.private_key_pem
```

Installs Ansible

```
    }
  }

  provisioner "local-exec" {
    command = "ansible-playbook -u ubuntu --key-file ansible-key.pem -T 300
    ➥ -i '${self.public_ip},', app.yml"
  }
}
```

Runs the initial playbook

NOTE The `remote-exec` provisioner is exactly like a `local-exec` provisioner, except it first connects to a remote host.

A case for provisioners

I do not usually advocate using resource provisioners because executing arbitrary code from Terraform is generally a bad idea. However, I feel that this is one situation where an exception could be made. Instead of prebaking an image or invoking a user-init script, a `remote-exec` provisioner performs direct inline commands to update the system and install preliminary software. You also get the logs piped back into Terraform stdout. It's quick and easy, especially since we already have an SSH key pair on hand.

But that's not the only advantage of using a `remote-exec` provisioner in this case. Since resource provisioners execute sequentially, we can guarantee that the `local-exec` provisioner running the playbook does not execute until after the `remote-exec` provisioner succeeds. Without a `remote-exec` provisioner, there would be a race condition.

Finally, we need to output the `public_ip` and the Ansible command for running the playbook.

Listing 9.8 main.tf

```
...
output "public_ip" {
 value = aws_instance.ansible_server.public_ip
}

output "ansible_command" {
    value = "ansible-playbook -u ubuntu --key-file ansible-key.pem -T 300
    ➥ -i '${aws_instance.ansible_server.public_ip},', app.yml"
}
```

At this point, the Terraform is done, but we still need a couple more files for Ansible. In particular, we need a playbook file (app.yml) and an index.html file that will serve as our sample application.

NOTE If you do not already have Ansible installed on your local machine, you should install it at this point. The Ansible documentation describes how to do this: http://mng.bz/D1Nn.

Create a new app.yml playbook file with the contents from the next listing. This is a simple Ansible playbook that ensures that Nginx is installed, adds an index.html page, and starts the Nginx service.

Listing 9.9 app.yml

```
---
    - name: Install Nginx
      hosts: all
      become: true

      tasks:
      - name: Install Nginx
        yum:
          name: nginx
          state: present

      - name: Add index page
        template:
          src: index.html
          dest: /var/www/html/index.html

      - name: Start Nginx
        service:
          name: nginx
          state: started
```

And here is the HTML page we'll be serving.

Listing 9.10 index.html

```
<!DOCTYPE html>
<html>
<style>
    body {
        background-color: green;
        color: white;
    }
</style>

<body>
    <h1>green-v1.0</h1>
</body>

</html>
```

Your current directory now contains the following files:

```
.
├── app.yml
├── index.html
├── main.tf
```

For reference, here are the complete contents of main.tf.

Listing 9.11 Complete main.tf

```
provider "aws" {
  region  = "us-west-2"
}

resource "tls_private_key" "key" {
  algorithm = "RSA"
}

resource "local_file" "private_key" {
  filename          = "${path.module}/ansible-key.pem"
  sensitive_content = tls_private_key.key.private_key_pem
  file_permission   = "0400"
}

resource "aws_key_pair" "key_pair" {
  key_name   = "ansible-key"
  public_key = tls_private_key.key.public_key_openssh
}

data "aws_vpc" "default" {
  default = true
}

resource "aws_security_group" "allow_ssh" {
  vpc_id = data.aws_vpc.default.id

  ingress {
    from_port   = 22
    to_port     = 22
    protocol    = "tcp"
    cidr_blocks = ["0.0.0.0/0"]
  }

  ingress {
    from_port   = 80
    to_port     = 80
    protocol    = "tcp"
    cidr_blocks = ["0.0.0.0/0"]
  }

  egress {
    from_port   = 0
    to_port     = 0
    protocol    = "-1"
    cidr_blocks = ["0.0.0.0/0"]
  }
}

data "aws_ami" "ubuntu" {
  most_recent = true
```

```
  filter {
    name   = "name"
    values = ["ubuntu/images/hvm-ssd/ubuntu-focal-20.04-amd64-server-*"]
  }

  owners = ["099720109477"]
}

resource "aws_instance" "ansible_server" {
  ami                    = data.aws_ami.ubuntu.id
  instance_type          = "t3.micro"
  vpc_security_group_ids = [aws_security_group.allow_ssh.id]
  key_name               = aws_key_pair.key_pair.key_name

  tags = {
    Name = "Ansible Server"
  }

  provisioner "remote-exec" {
    inline = [
      "sudo apt update -y",
      "sudo apt install -y software-properties-common",
      "sudo apt-add-repository --yes --update ppa:ansible/ansible",
      "sudo apt install -y ansible"
]

    connection {
      type        = "ssh"
      user        = "ubuntu"
      host        = self.public_ip
      private_key = tls_private_key.key.private_key_pem
    }
  }

  provisioner "local-exec" {
    command = "ansible-playbook -u ubuntu --key-file ansible-key.pem -T 300
    ➥ -i '${self.public_ip},', app.yml"
  }
}

output "public_ip" {
 value = aws_instance.ansible_server.public_ip
}

output "ansible_command" {
    value = "ansible-playbook -u ubuntu --key-file ansible-key.pem -T 300
    ➥ -i '${aws_instance.ansible_server.public_ip},', app.yml"
}
```

9.3.3 Infrastructure deployment

We are now ready to deploy!

WARNING Ansible (v2.9 or later) must be installed on your local machine or the `local-exec` provisioner will fail!

Initialize Terraform, and perform a `terraform apply`:

```
$ terraform init && terraform apply -auto-approve
...
aws_instance.ansible_server: Creation complete after 2m7s
[id=i-06774a7635d4581ac]

Apply complete! Resources: 5 added, 0 changed, 0 destroyed.

Outputs:

ansible_command = ansible-playbook -u ubuntu --key-file ansible-key.pem -T
300 -i '54.245.143.100,', app.yml
public_ip = 54.245.143.100
```

Now that the EC2 instance has been deployed and the first Ansible playbook has run, we can view the web page by navigating to the public IP address in the browser (see figure 9.10).

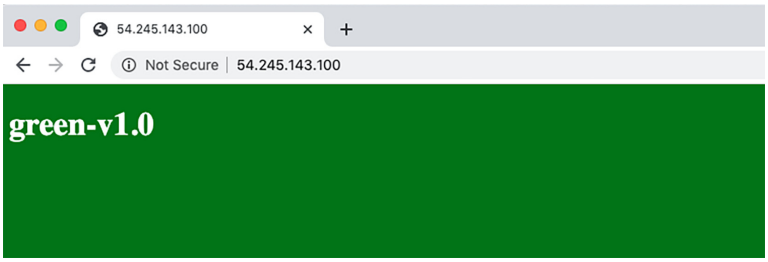


Figure 9.10 Green application deployment performed with Ansible

9.3.4 Application deployment

We did not need to use a `local-exec` provisioner to deploy the initial Ansible playbook, but it was a good example of when `local-exec` provisioners might be useful. Usually, application updates are deployed independently, perhaps as the result of a CI trigger. To simulate an application change, let's modify index.html as shown next.

Listing 9.12

```
<!DOCTYPE html>
<html>
<style>
    body {
        background-color: blue;
        color: white;
    }
</style>
```

```
<body>
    <h1>blue-v2.0</h1>
</body>

</html>
```

By re-running the Ansible playbook, we can update the application layer without touching the underlying infrastructure (see figure 9.11).

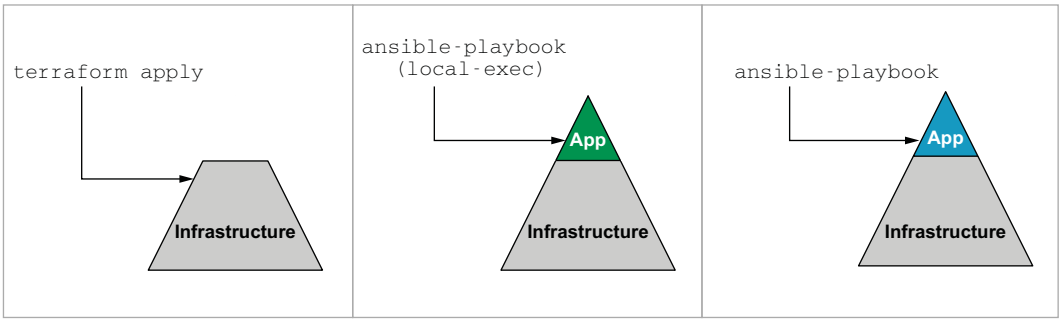


Figure 9.11 Terraform provisions initial infrastructure, while Ansible deploys applications onto that infrastructure.

Let's deploy the update now by running the `ansible-playbook` command from the Terraform output:

```
$ ansible-playbook -u ubuntu --key-file ansible-key.pem -T 300 -i
'54.245.143.100,', app.yml

PLAY [Install Nginx]
**********************************************************************
**********************************************************************
**********************************************************

TASK [Gathering Facts]
**********************************************************************
**********************************************************************
**********************************************************
ok: [54.245.143.100]

TASK [Install Nginx]
**********************************************************************
**********************************************************************
**********************************************************
ok: [54.245.143.100]

TASK [Add index page]
**********************************************************************
**********************************************************************
**********************************************************
changed: [54.245.143.100]
```

```
TASK [Start Nginx]
*********************************************************************
*********************************************************************
*************************************************************
ok: [54.245.143.100]

PLAY RECAP
*********************************************************************
*********************************************************************
*********************************************************************
54.245.143.100             : ok=4    changed=1    unreachable=0    failed=0
skipped=0    rescued=0    ignored=0
```

> **TIP** If you have more than one VM, it's better to write the addresses to a dynamic inventory file. Terraform can generate this file for you by way of string templates and the Local provider.

Now that Ansible has redeployed our application, we can verify that the changes have propagated by refreshing the web page (see figure 9.12).

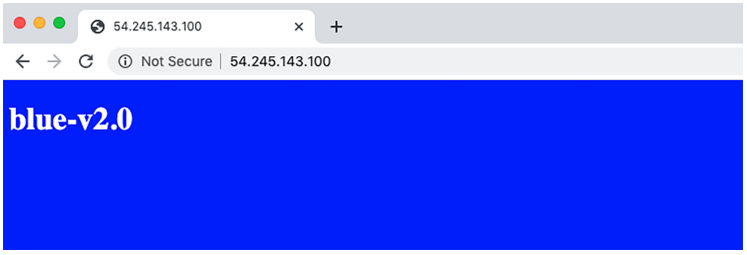


Figure 9.12 Blue application deployment performed by Ansible

We have demonstrated how to combine Terraform with Ansible. Instead of worrying about how to perform ZDD with Terraform, we have offloaded the responsibility to Ansible—and we can do the same thing with any other configuration-management or application-delivery technology.

> **WARNING** Don't forget to clean up with `terraform destroy`!

9.4 Fireside chat

This chapter focused on zero-downtime deployment and what that means from a Terraform perspective. We started by talking about the `lifecycle` block and how it can be used alongside `local-exec` health checks to ensure that a new service is running before we tear down the old service. The `lifecycle` block is the last of the resource meta attributes; the complete list is as follows:

- `depends_on`—Specifies hidden dependencies
- `count`—Creates multiple resource instances, indexable with bracket notation

- `for_each`—Creates multiple instances from a map or set of strings
- `provider`—Selects a non-default provider configuration
- `lifecycle`—Performs lifecycle customizations
- `provisioner` and `connection`—Takes extra actions after resource creation

Traditionally, ZDD refers to application deployments: Blue/Green, rolling Blue/Green, or canary deployments. Although it's possible to use the `lifecycle` block to mimic the behavior of Blue/Green deployments, doing so is confusing and not recommended. Instead, we used feature flags to switch between environments with Terraform.

Finally, we explored how to offload the responsibilities of ZDD to other, more suitable technologies (specifically, Ansible). Yes, Terraform can deploy your entire application stack, but this isn't always convenient or prudent. Instead, it may be beneficial to use Terraform only for infrastructure provisioning and a proven CM tool for application delivery. Of course, there isn't one right choice. It all depends on what you are deploying and what serves your customers the best.

Summary

- The `lifecycle` block has many flags that allow for customizing resource lifecycles. Of these, the `create_before_destroy` flag is certainly the most drastic, as it completely overhauls the way Terraform behaves.
- Performing Blue/Green deployments in Terraform is more a technique than a first-class feature. We covered one way to do Blue/Green using feature flags to toggle between the Green and Blue environments.
- Terraform can be combined with Ansible by using a two-stage deployment technique. In the first stage, Terraform deploys the static infrastructure; in the second stage, Ansible deploys applications on top of that infrastructure.
- The TLS provider makes it easy to generate SSH key pairs. You can even write out the private key to a .pem file using the Local provider.
- `remote-exec` provisioners are no different than `local-exec` provisioners, except they run on a remote machine instead of the local machine. They output to normal Terraform logs and can be used in place of `user_init` data or prebaked AMIs.

10 Testing and refactoring

This chapter covers

- Tainting and rotating AWS access keys provisioned by Terraform
- Refactoring module expansions
- Migrating state with `terraform mv` and `terraform state`
- Importing existing resources with `terraform import`
- Testing IaC with `terraform-exec`

The ancient Greek philosopher Heraclitus is famous for positing that "Life is flux." In other words, change is inevitable, and to resist change is to resist the essence of our existence. Perhaps nowhere is change more pronounced than in the software industry. Due to changing customer requirements and shifting market conditions, software is guaranteed to change. If not actively maintained, software degrades over time. Refactoring and testing are steps that developers take to keep software current.

Refactoring is the art of improving the design of code without changing existing behavior or adding new functionality. Benefits of refactoring include the following:

- *Maintainability*—The ability to quickly fix bugs and address problems faced by customers.
- *Extensibility*—How easy it is to add new features. If your software is extensible, then you are more agile and able to respond to marketplace changes.
- *Reusability*—The ability to remove duplicated and highly coupled code. Reusable code is readable and easier to maintain.

Even a minor code refactoring should be thoroughly tested to ensure that the system operates as intended. There are (at least) three levels of software testing to consider: unit tests, integration tests, and system tests. From a Terraform perspective, we typically do not worry about unit tests because they are already implemented at the provider level. We also don't care much about developing system tests because they are not as well defined when it comes to infrastructure as code (IaC). What we do care about are *integration tests*. In other words, for a given set of inputs, does a subsystem of Terraform (i.e., a module) deploy without errors and produce the expected output?

In this chapter, we begin by writing configuration code to self-service and rotate AWS access keys (with `terraform taint`). There are problems with the code's maintainability, which we improve on in the next section using *module expansions*. Module expansions are a Terraform 0.13 feature allowing the use of `count` and `for_each` on modules. They are quite powerful, and a lot of old code could benefit from their use.

To deploy the code into production, we need to migrate state. State migration is tedious and somewhat tricky, but as we'll see, with the proper use of `terraform mv`, `terraform state`, and `terraform import`, it's achievable.

The last thing we investigate is how to test Terraform code with terraform-exec (https://github.com/hashicorp/terraform-exec). Terraform-exec is a HashiCorp golang library that makes it possible to programmatically execute Terraform commands. It's most similar to Gruntwork's Terratest (https://terratest.gruntwork.io) and lets us write integration tests for Terraform modules. Let's get started.

10.1 Self-service infrastructure provisioning

Self-service is all about enabling customers to service themselves. Terraform, being a human-readable configuration language, is ideal for self-service infrastructure provisioning. With Terraform, customers can service themselves by making pull requests (PRs) against repositories (see figure 10.1).

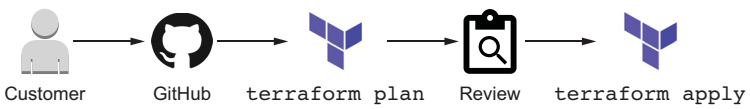


Figure 10.1 Customers make PRs against a version-controlled source repository. This PR triggers a plan, which is reviewed by a management team. When the PR is merged, an `apply` runs and the resources are deployed.

But wait, haven't we been doing self-service infrastructure provisioning all along? In a way, yes—but also no. This whole time, we've been looking at IaC more from a developer or operations perspective rather than a customer perspective. Remember that not everyone has equal experience with Terraform. Creating a successful self-service model is as much designing an easy-to-use workflow as it is choosing a technology.

Self-service infrastructure provisioning sounds great on paper, but in practice, it quickly becomes chaos if rules aren't established about what can and cannot be provisioned. You have to make life easy for the customer, and you also have to make life easy for yourself.

Suppose you are part of a public cloud team responsible for gating AWS access to teams and service accounts within the company. In this arrangement, employees are not allowed to provision AWS Identity and Access Management (IAM) users, policies, or access keys themselves; everything must be approved by the public cloud team. In the past, such requests may have come through an internal IT ticketing system, but that approach is slower and (of course) not self-service. By storing your infrastructure as code, customers can directly make PRs with the changes they want. Reviewers only need to examine the result of `terraform plan` before approving. In chapter 13, we see how even this minuscule governance task can be automated with Sentinel policies. For now, we'll assume this is a purely manual process.

10.1.1 Architecture

Let's make a self-service IAM platform. It needs to provision AWS IAM users, policies, and access keys with Terraform and output a valid AWS credentials file. The module structure we'll go with is a flat module design, meaning there will be many little files and no nested modules. Each service will get its own file for declaring resources, and shared code will be put in auxiliary files (see figure 10.2).

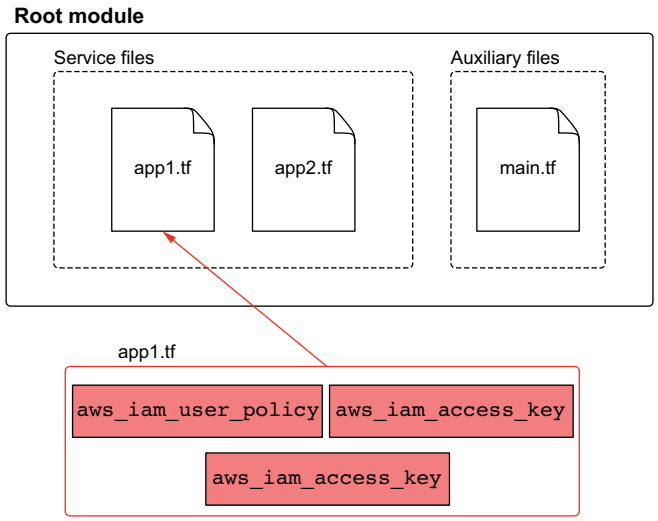


Figure 10.2 The module has two kinds of files: service and auxiliary. Service files keep all managed IAM resources together for a particular service. Auxiliary files are supporting files that organize and configure the module as a whole.

10.1.2 Code

We'll jump right into writing the code. Create a new directory with three files: app1.tf, app2.tf, and main.tf. The first file, app1.tf, contains the code for deploying an AWS IAM user called app1-svc-account, attaches an inline policy, and provisions AWS access keys.

Listing 10.1 app1.tf

```
resource "aws_iam_user" "app1" {
  name          = "app1-svc-account"
  force_destroy = true
}

resource "aws_iam_user_policy" "app1" {
  user   = aws_iam_user.app1.name
  policy = <<-EOF
    {
      "Version": "2012-10-17",
      "Statement": [
        {
          "Action": [
            "ec2:Describe*"
          ],
          "Effect": "Allow",
          "Resource": "*"
        }
      ]
    }
  EOF
}

resource "aws_iam_access_key" "app1" {
  user = aws_iam_user.app1.name
}
```

The second file, app2.tf, is similar, except it creates an IAM user called app2-svc-account with a policy that allows it to list S3 buckets.

Listing 10.2 app2.tf

```
resource "aws_iam_user" "app2" {
  name          = "app2-svc-account"
  force_destroy = true
}

resource "aws_iam_user_policy" "app2" {
  user   = aws_iam_user.app1.name
  policy = <<-EOF
    {
      "Version": "2012-10-17",
      "Statement": [
        {
```

```
          "Action": [
            "s3:List*"
          ],
          "Effect": "Allow",
          "Resource": "*"
        }
      ]
    }
  EOF
}

resource "aws_iam_access_key" "app2" {
  user = aws_iam_user.app2.name
}
```

In main.tf, we have a `local_file` resource that creates a valid AWS credentials file (see http://mng.bz/rmrB).

Listing 10.3 main.tf

```
terraform {
  required_version = ">= 0.15"
  required_providers {
    aws = {
      source = "hashicorp/aws"
      version = "~> 3.28"
    }
    local = {
      source = "hashicorp/local"
      version = "~> 2.0"
    }
  }
}

provider "aws" {
    profile = "<profile>"
    region = "us-west-2"
}

resource "local_file" "credentials" {          <-- Outputs a valid AWS credentials file
  filename           = "credentials"
  file_permission    = "0644"
  sensitive_content  = <<-EOF
    [${aws_iam_user.app1.name}]
    aws_access_key_id = ${aws_iam_access_key.app1.id}
    aws_secret_access_key = ${aws_iam_access_key.app1.secret}

    [${aws_iam_user.app2.name}]
    aws_access_key_id = ${aws_iam_access_key.app2.id}
    aws_secret_access_key = ${aws_iam_access_key.app2.secret}
  EOF
}
```

NOTE Provider declarations are usually put in providers.tf, and Terraform settings are usually put in versions.tf. Here we have not done so, to conserve space.

10.1.3 Preliminary deployment

Deployment is easy. Initialize with `terraform init`, and deploy with `terraform apply`:

```
$ terraform apply -auto-approve
...
aws_iam_access_key.app2: Creation complete after 3s
[id=AKIATESI2XGPIHJZPZFB]
local_file.credentials: Creating...
local_file.credentials: Creation complete after 0s
[id=e726f407ee85ca7fedd178003762986eae1d7a27]

Apply complete! Resources: 7 added, 0 changed, 0 destroyed.
```

After the `apply` completes, you will have two new sets of IAM users with inline policies and access keys (see figure 10.3).

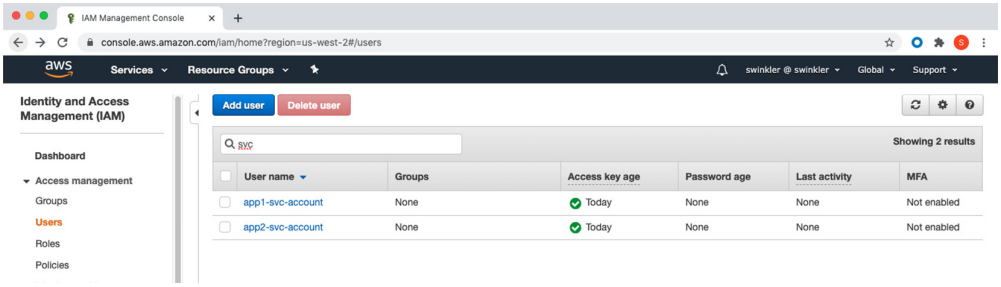


Figure 10.3 Terraform has provisioned two new IAM users with inline policies and created access keys for those users.

An AWS credentials file has also been generated using `local_file`. The credentials file can be used to authenticate to the AWS CLI:

```
$ cat credentials
[app1-svc-account]
aws_access_key_id = AKIATESI2XGPIUSUHWUV
aws_secret_access_key = 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

[app2-svc-account]
aws_access_key_id = AKIATESI2XGPIHJZPZFB
aws_secret_access_key = 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
```

> **NOTE** Instead of writing secrets in plain text to a credentials file, it's better to store these values in a centralized secrets management tool like HashiCorp Vault or AWS Secrets Manager. We cover this in more depth in chapter 13.

Terraform is managing only two service accounts at the moment, but it's easy to imagine how more service accounts could be provisioned. All that needs to be done is to

create a new service file and update `local_file`. Although the code works, some problems emerge when scaling up. Before we discuss what improvements could be made, let's first rotate access keys with `terraform taint`.

10.1.4 Tainting and rotating access keys

Regular secrets rotation is a well-known security best practice. Even the ancient Romans knew this; sentries would change camp passwords once a day. Since access keys allow service accounts to provision resources in AWS accounts, it's a good idea to rotate these as frequently as possible (at least once every 90 days).

Although we could rotate access keys by performing `terraform destroy` followed by `terraform apply`, sometimes you wouldn't want to do this. For example, if there was a permanent resource fixture, such as a Relational Database Service (RDS) database or S3 bucket included as part of the deployment, `terraform destroy` would delete these and result in data loss.

We can target the destruction and re-creation of individual resources with the `terraform taint` command. During the next `apply`, the resource will be destroyed and created anew. We use the command as follows:

```
terraform taint [options] address
```

> **NOTE** `address` is the *resource address* (see http://mng.bz/VGgP) that uniquely identifies a resource within a given configuration.

To rotate access keys, we first list the resources in the state file to obtain resource addresses. The command `terraform state list` does this for us:

```
$ terraform state list
aws_iam_access_key.app1
aws_iam_access_key.app2
aws_iam_user.app1
aws_iam_user.app2
aws_iam_user_policy.app1
aws_iam_user_policy.app2
local_file.credentials
```

It looks like our two resource addresses are `aws_iam_access_key.app1` and `aws_iam_access_key.app2`. Go ahead and taint these resources so they can be re-created during the next `apply`:

```
$ terraform taint aws_iam_access_key.app1
Resource instance aws_iam_access_key.app1 has been marked as tainted.
$ terraform taint aws_iam_access_key.app2
Resource instance aws_iam_access_key.app2 has been marked as tainted.
```

When we run `terraform plan`, we can see that the `aws_access_key` resources have been marked as tainted and will be re-created:

```
$ terraform plan
...
Terraform will perform the following actions:
```

```
  # aws_iam_access_key.app1 is tainted, so must be replaced
-/+ resource "aws_iam_access_key" "app1" {
      + encrypted_secret  = (known after apply)
      ~ id                = "AKIATESI2XGPIUSUHWUV" -> (known after apply)
      + key_fingerprint   = (known after apply)
      ~ secret            = "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" ->
(known after apply)
      ~ ses_smtp_password = "AiLTGCR7lNIM1u8Pl3cTOHu10Ni5JbhxULGdb+4z6inL"
-> (known after apply)
      ~ status            = "Active" -> (known after apply)
        user              = "app1-svc-account"
    }
...
Plan: 3 to add, 0 to change, 3 to destroy.
```

> **NOTE** If you ever taint the wrong resource, you can always undo your mistake with the complementary command: `terraform untaint`.

If we apply changes, the access keys are re-created without affecting anything else (except, of course, dependent resources like `local_file`). Apply changes now by running `terraform apply`:

```
$ terraform apply -auto-approve
...
aws_iam_access_key.app1: Creation complete after 0s [id=AKIATESI2XGPIQGHRH5W]
local_file.credentials: Creating...
local_file.credentials: Creation complete after 1s
[id=ea6994e2b186bbd467cceee89ff39c10db5c1f5e]

Apply complete! Resources: 3 added, 0 changed, 3 destroyed.
```

We can verify that the access keys have indeed been rotated by `cat`-ing the credentials file and observing that it has new access and secret access keys:

```
$ cat credentials
[app1-svc-account]
aws_access_key_id = AKIATESI2XGPIQGHRH5W
aws_secret_access_key = 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

[app2-svc-account]
aws_access_key_id = AKIATESI2XGPLJNKW5FC
aws_secret_access_key = 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
```

10.2 Refactoring Terraform configuration

While the code may be suitable for the current use case, there are deficiencies that will result in long-term maintainability issues:

- *Duplicated code*—As new users and policies are provisioned, correspondingly more service files are required. This means a lot of copy/paste.
- *Name collisions*—Because of all the copy/paste, name collisions on resources are practically inevitable. You'll waste time resolving silly name conflicts.

- *Inconsistency*—As the codebase grows, it becomes harder and harder to maintain uniformity, especially if PRs are being made by people who aren't Terraform experts.

To alleviate these concerns, we need to refactor.

10.2.1 Modularizing code

The biggest refactoring improvement we can make is to put reusable code into modules. Not only does this solve the problem of duplicated code (i.e., resources in modules only have to be declared once), but it also solves the problems of name collisions (resources do not conflict with resources in other modules) and inconsistency (it's difficult to mess up a PR if not much code is being changed).

The first step to modularizing an existing workspace is to identify opportunities for code reuse. Comparing app1.tf with app2.tf, the same three resources are declared in both: an IAM user, an IAM policy, and an IAM access key. Here is app1.tf:

```
resource "aws_iam_user" "app1" {
    name          = "app1-svc-account"
    force_destroy = true
  }

  resource "aws_iam_user_policy" "app1" {
    user   = aws_iam_user.app1.name
    policy = <<-EOF
      {
        "Version": "2012-10-17",
        "Statement": [
          {
            "Action": [
              "ec2:Describe*"
            ],
            "Effect": "Allow",
            "Resource": "*"
          }
        ]
      }
    EOF
  }

  resource "aws_iam_access_key" "app1" {
    user = aws_iam_user.app1.name
  }
```

And here is app2.tf:

```
resource "aws_iam_user" "app2" {
  name          = "app2-svc-account"
  force_destroy = true
}

resource "aws_iam_user_policy" "app2" {
  user   = aws_iam_user.app1.name
```

```
  policy = <<-EOF
    {
      "Version": "2012-10-17",
      "Statement": [
        {
          "Action": [
            "s3:List*"
          ],
          "Effect": "Allow",
          "Resource": "*"
        }
      ]
    }
  EOF
}

resource "aws_iam_access_key" "app2" {
  user = aws_iam_user.app2.name
}
```

There are slight differences between the policy configurations, of course, but they can be easily parameterized. We'll move the three resources into a common module called `iam` (see figure 10.4).

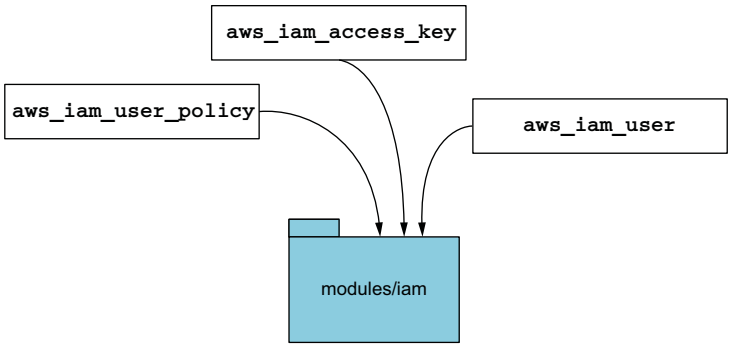


Figure 10.4 Consolidating common IAM resources in a Terraform module

Next, we need to clean up main.tf. This file is responsible for provisioning a credentials text document containing the AWS access and secret access keys, but the way it does so is inefficient as it requires explicitly referencing each resource:

```
resource "local_file" "credentials" {
  filename           = "credentials"
  file_permission    = "0644"
  sensitive_content  = <<-EOF
    [${aws_iam_user.app1.name}]
    aws_access_key_id = ${aws_iam_access_key.app1.id}
    aws_secret_access_key = ${aws_iam_access_key.app1.secret}
```

Explicitly references app1 resources

```
    [${aws_iam_user.app2.name}]
    aws_access_key_id = ${aws_iam_access_key.app2.id}
    aws_secret_access_key = ${aws_iam_access_key.app2.secret}
  EOF
}
```

Explicitly references app2 resources

Each time a new IAM user is provisioned, you'll need to update this file. At first, this may not seem like a big deal, but it becomes a hassle over time. This would be a good place to use template strings. A three-line snippet with the profile name, AWS access key ID, and AWS secret access key can be produced by the IAM module and dynamically joined with other such snippets to form a credentials document.

10.2.2 Module expansions

Consider what the interface for the IAM module should be. At the very least, it should accept two input parameters: one to assign a service name and another to attach a list of policies. Accepting a list of policies is better than how we previously had it—we were only able to attach a single policy. Our module will also produce output with a three-line template string that we can join with other strings (see figure 10.5).

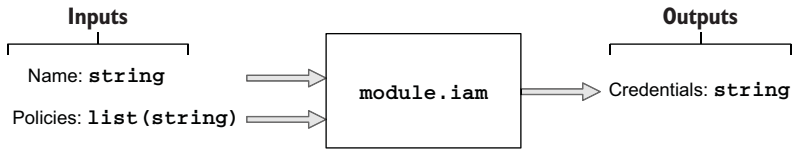


Figure 10.5 Inputs and outputs for the IAM module

Until recently, we would have had to declare each instance of a module like this separately:

```
module "iam-app1" {
  source   = "./modules/iam"
  name     = "app1"
  policies = [file("./policies/app1.json")]
}

module "iam-app2" {       #A
  source   = "./modules/iam"
  name     = "app2"
  policies = [file("./policies/app2.json")]
}
```

Two instances of the same module used to have to be declared separately.

This isn't terrible, but it also isn't ideal. Even though we modularized the code, we would still have to copy/paste each time we wanted a new module instance. It diminished a lot of the benefit of using nested modules and was a major reason many people favored using flat modules.

Fortunately, there is now a solution. With the advent of Terraform 0.13, a new feature was released called *module expansions*. Module expansions make it possible to use `count` and `for_each` on a module the same way you can for a resource. Instead of declaring a module multiple times, now you only have to declare it once. For example, assuming we had a map of configuration stored in a `local.policy_mapping` value, figure 10.6 shows how a single module declaration could expand into multiple instances.

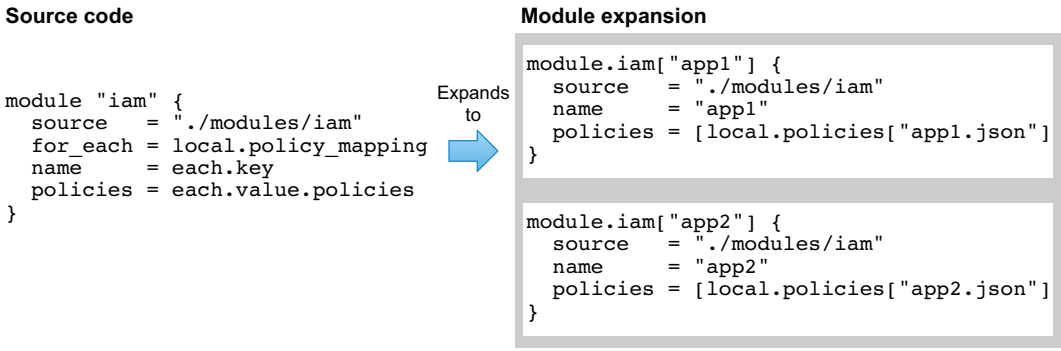


Figure 10.6 Expanding a Terraform module with `for_each`

Like `for_each` on resources, `for_each` on a module requires providing configuration via either a set or a map. Here we will use a map, with the keys being the `name` attribute and the values being an object with a single attribute called `policies`. Policies are of type `list(string)` and contain the JSON policy documents for each policy that will be attached to the IAM user.

Listing 10.4 main.tf

```
locals {
  policy_mapping = {
    "app1" = {
      policies = [local.policies["app1.json"]],
    },
    "app2" = {
      policies = [local.policies["app2.json"]],
    },
  }
}

module "iam" {
  source   = "./modules/iam"
  for_each = local.policy_mapping
  name     = each.key
  policies = each.value.policies
}
```

Module expansion creates a separate instance for each element of for_each.

Why not use sets?

I recommend using maps instead of sets whenever more than one attribute needs to be set on a module. Maps allow you to pass entire objects, whereas sets do not. Moreover, you can only pass in a set of type `set(string)`, so if you wanted to pass more than a single attribute's worth of data, you would have to awkwardly encode data in the form of a JSON string and then decode it with `jsondecode()`. This approach is cumbersome and results in a messier plan because it spits out a lot of unnecessary information and makes resource addresses (strings that reference a specific resource) longer than they should be.

Of course, you could choose to use `count` with set, but `count` indices have their own problems. Overall, I cannot recommend using sets with module expansions unless only a single attribute needs to be set.

10.2.3 Replacing multi-line strings with local values

We are refactoring an existing Terraform workspace to aid readability and maintainability. One of the key aspects is how to make it easy for someone to configure the workspace inputs. Remember that we have two module inputs: `name` (pretty self-explanatory) and `policies` (which needs further explanation). In this case, `policies` is an input variable of type `list(string)` designed to accept a list of JSON policy documents to attach to an individual IAM user. We have a choice about how to do this; we can either embed the policy documents inline as string literals (which is what we've been doing) or read the policy documents from an external file (the better option of the two).

Embedding string literals, especially multi-line string literals, is generally a bad idea because it hurts readability. Having too many string literals in Terraform configuration makes it messy and hard to find what you're looking for. It is better to keep this information in a separate file and read from it using either `file()` or `fileset()`. The following listing uses a `for` expression to produce a map of key-value pairs containing the filename and contents of each policy file. That way, policies can be stored together in a common directory and fetched by filename.

Listing 10.5 main.tf

```
locals {
  policies = {
    for path in fileset(path.module, "policies/*.json") : basename(path) =>
file(path)
  }
  policy_mapping = {
    "app1" = {
      policies = [local.policies["app1.json"]],
    },
    "app2" = {
      policies = [local.policies["app2.json"]],
    },
```

```
  }
}

module "iam" {
  source   = "./modules/iam"
  for_each = local.policy_mapping
  name     = each.key
  policies = each.value.policies
}
```

To give you an idea of what the fancy `for` expression does, the calculated value of `local.policies`, which is the result of the `for` expression, is shown here:

```
{
  "app1.json" = "{\n    \"Version\": \"2012-10-17\",\n    \"Statement\":
[\n      {\n        \"Action\": [\n          \"ec2:Describe*\"\n
],\n        \"Effect\": \"Allow\",\n        \"Resource\": \"*\"\n      }\n
]\n  }\n  "
  "app2.json" = "{\n   \"Version\": \"2012-10-17\",\n   \"Statement\": [\n
    {\n            \"Action\": [\n                \"s3:List*\"\n
],\n          \"Effect\": \"Allow\",\n          \"Resource\": \"*\"\n
}\n    ]\n}\n"
}
```

As you can see, we can now reference the JSON policy documents for individual policies by filename. For example, `local.policies["app1.json"]` would return the contents of app1.json. Now all we need to do is make sure these files actually exist.

Create a policies folder in the current working directory. In this folder, create two new files, app1.json and app2.json, with the contents shown in listings 10.6 and 10.7, respectively.

Listing 10.6 app1.json

```
{
  "Version": "2012-10-17",
  "Statement": [
    {
      "Action": [
        "ec2:Describe*"
      ],
      "Effect": "Allow",
      "Resource": "*"
    }
  ]
}
```

Listing 10.7 app2.json

```
{
    "Version": "2012-10-17",
    "Statement": [
        {
            "Action": [
                "s3:List*"
            ],
```

```
            "Effect": "Allow",
            "Resource": "*"
        }
    ]
}
```

10.2.4 Looping through multiple module instances

Remember how the IAM module returns a `credentials` output? This is a little three-line string that can be appended with other such strings to produce a complete and valid AWS credentials file. The `credentials` string has this form:

```
[app1-svc-account]
aws_access_key_id = AKIATESI2XGPIQGHRH5W
aws_secret_access_key = 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
```

If each module instance produces its own output, we can join them together with the built-in `join()` function. The following `for` expression loops through each instance of the `module.iam` expansion, accesses the credentials output, and joins them with a newline:

```
join("\n", [for m in module.iam : m.credentials])
```

> **Splat expressions operate only on lists**
>
> A *splat expression* is syntactic sugar allowing you to concisely express simple `for` expressions. For example, if you had a list of objects, each with the `id` attribute, you could extract all IDs in a new list of strings with the following expression: `[for v in var.list : v.id]`. In contrast, the splat expression `var.list[*].id` is far more concise (the special `[*]` symbol indicates iterating over all elements of a list).
>
> Although convenient, splat expressions are less useful than they could be since they only operate on lists. If they could operate on maps, you could use them to reference resources or modules created with `for_each`. For instance, the preceding `for` expression `[for m in module.iam : m.credentials]` could be replaced with `module.iam[*].credentials`. Other than for historical reasons, I am not sure why this isn't already possible. It's disappointing that splat expressions don't work the same for maps as they do for lists.

The complete main.tf code, with the included Terraform settings block and provider declarations, is as follows.

Listing 10.8 main.tf

```
terraform {
  required_version = ">= 0.15"
  required_providers {
    aws = {
      source = "hashicorp/aws"
      version = "~> 3.28"
    }
    local = {
```

```
      source = "hashicorp/local"
      version = "~> 2.0"
    }
  }
}

provider "aws" {
    profile = "<profile>"
    region = "us-west-2"
}

locals {
  policies = {
    for path in fileset(path.module, "policies/*.json") : basename(path) =>
file(path)
  }
  policy_mapping = {
    "app1" = {
      policies = [local.policies["app1.json"]],
    },
    "app2" = {
      policies = [local.policies["app2.json"]],
    },
  }
}

module "iam" {
  source   = "./modules/iam"
  for_each = local.policy_mapping
  name     = each.key
  policies = each.value.policies
}

resource "local_file" "credentials" {
  filename = "credentials"
  content  = join("\n", [for m in module.iam : m.credentials])
}
```

The IAM module doesn't exist yet, but it will soon.

10.2.5 New IAM module

Now it's time to implement the IAM module that will deploy three IAM resources (user, policy, and access key). This module will have two input variables (`name` and `policy`) and one output value (`credentials`). Create a file with relative path ./modules/iam/main.tf, and insert the code from listing 10.9.

NOTE A standard module structure would have code split into main.tf, variables.tf, and outputs.tf; again, for the sake of brevity, I have not done this.

Listing 10.9 main.tf

```
variable "name" {
  type = string
}

variable "policies" {
```

```
  type = list(string)
}

resource "aws_iam_user" "user" {
  name          = "${var.name}-svc-account"
  force_destroy = true
}

resource "aws_iam_policy" "policy" {
  count  = length(var.policies)
  name        = "${var.name}-policy-${count.index}"
  policy      = var.policies[count.index]
}

resource "aws_iam_user_policy_attachment" "attachment" {
    count  = length(var.policies)
  user       = aws_iam_user.user.name
  policy_arn = aws_iam_policy.policy[count.index].arn
}

resource "aws_iam_access_key" "access_key" {
  user = aws_iam_user.user.name
}

output "credentials" {
  value = <<-EOF
    [${aws_iam_user.user.name}]
    aws_access_key_id = ${aws_iam_access_key.access_key.id}
    aws_secret_access_key = ${aws_iam_access_key.access_key.secret}
  EOF
}
```

Support for attaching multiple policies

Three-line template string

At this point, we are code complete. Your completed project should contain the following files:

```
.
├── credentials
├── main.tf
├── modules
│   └── iam
│       └── main.tf
├── policies
│   ├── app1.json
│   └── app2.json
└── terraform.tfstate

3 directories, 6 files
```

10.3 Migrating Terraform state

After reinitializing the workspace with `terraform init`, calling `terraform plan` reveals that Terraform intends to destroy and re-create all resources during the subsequent `terraform apply`:

```
$ terraform plan
...
```

```
  # module.iam["app2"].aws_iam_user.user will be created
  + resource "aws_iam_user" "user" {
      + arn           = (known after apply)
      + force_destroy = true
      + id            = (known after apply)
      + name          = "app2-svc-account"
      + path          = "/"
      + unique_id     = (known after apply)
    }

  # module.iam["app2"].aws_iam_user_policy_attachment.attachment[0] will be
created
  + resource "aws_iam_user_policy_attachment" "attachment" {
      + id         = (known after apply)
      + policy_arn = (known after apply)
      + user       = "app2-svc-account"
}

Plan: 9 to add, 0 to change, 7 to destroy.

------------------------------------------------------------------------
```

All resources will be destroyed and re-created.

This happens because Terraform does not know that resources declared in the IAM module are the same as previously provisioned resources. Often, it isn't an issue of resources being destroyed and re-created; it's an issue of data loss. For example, if you had a deployed database, you would certainly want to avoid deleting it. For the IAM scenario, we do not have any databases; but let's says we want to avoid deleting IAM users because the associated AWS CloudWatch logs are important. We'll skip migrating IAM policies or access keys because there is nothing special about them.

Unfortunately for us, Terraform state migration is rather difficult and tedious. It's difficult because it requires intimate knowledge about how state is stored, and it's tedious because—although it isn't entirely manual—it would take a long time to migrate more than a handful of resources.

> **NOTE** HashiCorp has announced that improved imports could be a deliverable of Terraform 1.0 (see http://mng.bz/xGWW). Hopefully, this will alleviate the worst sufferings of state migration.

10.3.1 State file structure

Let's now consider what goes into Terraform state. If you recall from chapter 2, state contains information about what is currently deployed and is automatically generated from configuration code as part of `terraform apply`. To migrate state, we need to move or import resources into a correct destination resource address (see figure 10.7).

There are three options when it comes to migrating state:

- Manually editing the state file (not recommended)
- Moving stateful data with `terraform state mv`
- Deleting old resources with `terraform state rm` and reimporting with `terraform import`

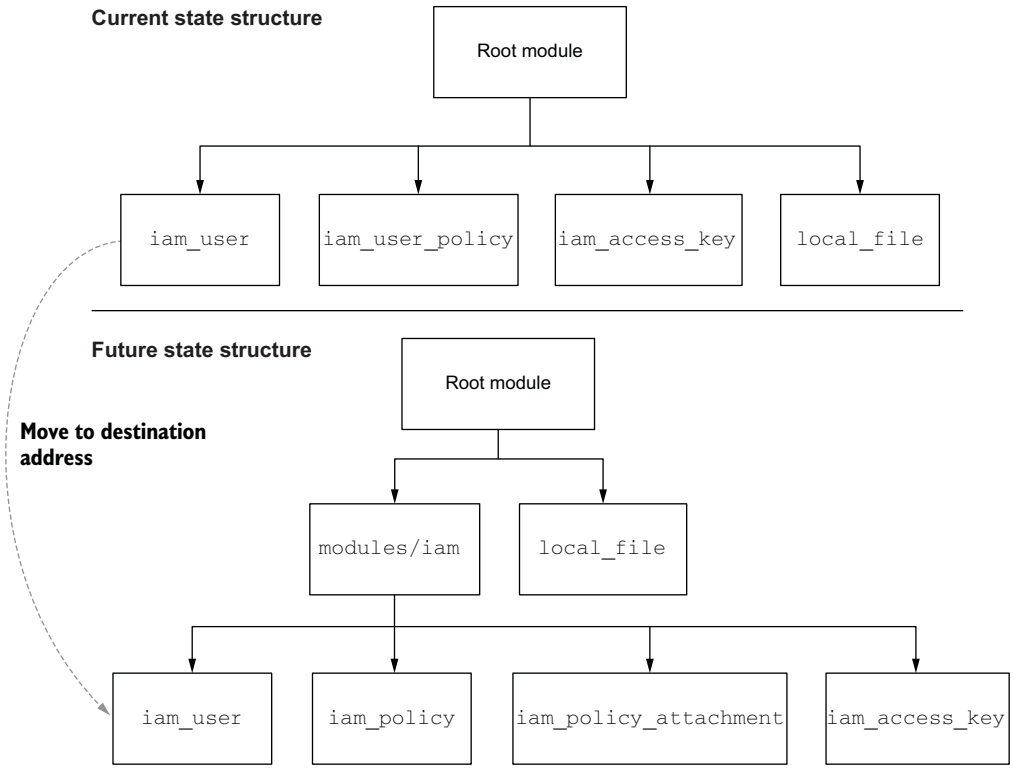


Figure 10.7 Current vs. future structure of the state file. We want to move resources from where they were in the old configuration to where they will be in the new version. This will prevent the resource from being destroyed and re-created during the next `apply`.

Of the three methods, the first is the most flexible, but it is also the most dangerous because of the potential for human error. The second and third methods are easier and safer. In the following two sections, we see these methods in practice.

WARNING Manually editing the state file is not recommended except in niche situations, such as correcting provider errors.

10.3.2 Moving resources

We have to move the existing IAM users' state from their current resource address to their final resource address so they won't be deleted and re-created during the next `apply`. To accomplish this, we will use `terraform state mv` to move the resource state around. The command to move a resource (or module) into the desired destination address is

```
terraform state mv [options] SOURCE DESTINATION
```

`SOURCE` and `DESTINATION` both refer to resource addresses. The source address is where the resource is currently located, and the destination address is where it will go.

But how do we know the current resource addresses? The easiest way to find it is with `terraform state list`:

```
$ terraform state list
aws_iam_access_key.app1
aws_iam_access_key.app2
aws_iam_user.app1
aws_iam_user.app2
aws_iam_user_policy.app1
aws_iam_user_policy.app2
local_file.credentials
```

> **NOTE** If you haven't already done so, use `terraform init` to download providers and install modules.

All we need to do is move the IAM users for app1 and app2 into the `iam` module. The source address for app1 is `aws_iam_user.app1`, and the destination address for app1 is `module.iam[\"app1\"]`. Therefore, to move the resource state, we just need to run the following command:

```
$ terraform state mv aws_iam_user.app1 module.iam[\"app1\"].aws_iam_user.user
Move "aws_iam_user.app1" to "module.iam[\"app1\"].aws_iam_user.user
Successfully moved 1 object(s).
```

Similarly, for app2:

```
$ terraform state mv aws_iam_user.app2 module.iam[\"app2\"].aws_iam_user.user
Move "aws_iam_user.app2" to "module.iam[\"app2\"].aws_iam_user.user
Successfully moved 1 object(s).
```

By listing the resources in the state file again, you can verify that the resources have indeed been moved successfully:

```
$ terraform state list
aws_iam_access_key.app1
aws_iam_access_key.app2
aws_iam_user_policy.app1
aws_iam_user_policy.app2
local_file.credentials
module.iam["app1"].aws_iam_user.user
module.iam["app2"].aws_iam_user.user
```

> **NOTE** You can move a resource or module to any address, even one that does not exist within your current configuration. This can cause unexpected behavior, which is why you have to be careful that you get the right address.

10.3.3 Redeploying

Our mission was to migrate existing IAM users to their future position in Terraform state so they won't be deleted when the configuration code is updated, based on our refactoring. We did make a stipulation that we don't want IAM users to be deleted and re-created (because reasons), but we didn't make this condition for IAM access keys or policies, because having these be rotated is a desirable side effect.

A quick `terraform plan` verifies that we have indeed accomplished our mission: now only seven resources are slated to be created and five destroyed, as opposed to the nine and seven from earlier. This means the two IAM users will not be destroyed and re-created, as they are already in their correct position:

```
$ terraform plan
...
  # module.iam["app2"].aws_iam_user_policy_attachment.attachment[0] will be
created
  + resource "aws_iam_user_policy_attachment" "attachment" {
      + id         = (known after apply)
      + policy_arn = (known after apply)
      + user       = "app2-svc-account"
    }

Plan: 7 to add, 0 to change, 5 to destroy.
```

We can now apply the changes with confidence, knowing that our state migration has been accomplished:

```
$ terraform apply -auto-approve
...
module.iam["app2"].aws_iam_user_policy_attachment.attachment[0]: Creation
complete after 2s [id=app2-svc-account-20200929075715719500000002]
local_file.credentials: Creating...
local_file.credentials: Creation complete after 0s
[id=270e9e9b124fdf55e223ac263571e8795c5b6f19]

Apply complete! Resources: 7 added, 0 changed, 5 destroyed.
```

10.3.4 Importing resources

The other way Terraform state can be migrated is by deleting and reimporting resources. Resources can be deleted with `terraform state rm` and imported with `terraform import`. Deleting resources is fairly self-explanatory (they are removed from the state file), but importing resources requires further explanation. Resource imports are how unmanaged resources are converted into managed resources. For example, if you created resources out of band, such as through the CLI or using another IaC tool like CloudFormation, you could import them into Terraform as managed resources. `terraform import` is to unmanaged resources what `terraform refresh` is to managed resources. We will use `terraform import` to reimport a deleted resource into the correct resource address (not a traditional use case, I'll grant, but a useful teaching exercise nonetheless).

> **NOTE** Check with the relevant Terraform provider documentation to ensure that imports are allowed for a given resource.

Let's first remove the IAM user from Terraform state so we can reimport it. The syntax of the remove command is as follows:

```
terraform state rm [options] ADDRESS
```

This command allows you to remove specific resources/modules from Terraform state. I usually use it to fix corrupted states, such as when buggy resources prevent you from applying or destroying the rest of your configuration code.

> **TIP** Corrupted state is usually the result of buggy provider source code, and you should file a support ticket on the corresponding GitHub repository if this ever happens to you.

Before we remove the resource from state, we need the ID so we can reimport it later:

```
$ terraform state show module.iam[\"app1\"].aws_iam_user.user
# module.iam["app1"].aws_iam_user.user:
resource "aws_iam_user" "user" {
    arn           = "arn:aws:iam::215974853022:user/app1-svc-account"
    force_destroy = true
    id            = "app1-svc-account"
    name          = "app1-svc-account"
    path          = "/"
    tags          = {}
    unique_id     = "AIDATESI2XGPBXYYGHJOO"
}
```

The ID value for this resource is the IAM user's name: in this case, app1-svc-account. A resource's ID is set at the provider level and is not always what you think it should be, but it is guaranteed to be unique. You can see what it is using `terraform show` or figure it out by reading provider documentation.

Let's delete the app1 IAM user from state with the `terraform state rm` command and pass in the resource ID from `terraform state show`:

```
$ terraform state rm module.iam[\"app1\"].aws_iam_user.user
Removed module.iam["app1"].aws_iam_user.user
Successfully removed 1 resource instance(s).
```

Now Terraform is not managing the IAM resource and doesn't even know it exists. If we were to run another `apply`, Terraform would attempt to create an IAM user with the same name, which would cause a name conflict error—you cannot have two IAM users with the same name in AWS. We need to import the resource into the desired location and bring it back under the yoke of Terraform. We can do that with `terraform import`. Here is the command syntax:

```
terraform import [options] ADDRESS ID
```

`ADDRESS` is the destination resource address where you want your resource to be imported (configuration must be present for this to work), and `ID` is the unique resource ID (app1-svc-account). Import the resource now with `terraform import`:

```
$ terraform import module.iam[\"app1\"].aws_iam_user.user app1-svc-account
module.iam["app1"].aws_iam_user.user: Importing from ID "app1-svc-account"...
module.iam["app1"].aws_iam_user.user: Import prepared!
  Prepared aws_iam_user for import
module.iam["app1"].aws_iam_user.user: Refreshing state... [id=app1-svc-account]
```

```
Import successful!

The resources that were imported are shown above. These resources are now in
your Terraform state and will henceforth be managed by Terraform.
```

An interesting thing to note is that the state we import doesn't match our configuration. In fact, if you call `terraform plan`, it will suggest performing an update in place:

```
$ terraform plan
...
An execution plan has been generated and is shown below.
Resource actions are indicated with the following symbols:
  ~ update in-place

Terraform will perform the following actions:

  # module.iam["app1"].aws_iam_user.user will be updated in-place
  ~ resource "aws_iam_user" "user" {
        arn           = "arn:aws:iam::215974853022:user/app1-svc-account"
      + force_destroy = true
        id            = "app1-svc-account"
        name          = "app1-svc-account"
        path          = "/"
        tags          = {}
        unique_id     = "AIDATESI2XGPBXYYGHJOO"
    }

Plan: 0 to add, 1 to change, 0 to destroy.
```

If you inspect the state file, you'll notice that the `force_destroy` attribute is set to `null` instead of `true` (which is what it should be):

```
...
    {
      "module": "module.iam[\"app1\"]",
      "mode": "managed",
      "type": "aws_iam_user",
      "name": "user",
      "provider": "provider[\"registry.terraform.io/hashicorp/aws\"]",
      "instances": [
        {
          "schema_version": 0,
          "attributes": {
            "arn": "arn:aws:iam::215974853022:user/app1-svc-account",
            "force_destroy": null,
            "id": "app1-svc-account",
            "name": "app1-svc-account",
            "path": "/",
            "permissions_boundary": null,
            "tags": {},
            "unique_id": "AIDATESI2XGPBXYYGHJOO"
          },
```

```
          "private": "eyJzY2hlbWFfdmVyc2lvbiI6IjAifQ=="
        }
      ]
    }, ...
```

Why did this happen? Well, importing resources is the same as performing `terraform refresh` on a remote resource. It reads the current state of the resource and stores it in Terraform state. The problem is that `force_destroy` isn't an AWS attribute and can't be read by making an API call. It comes from Terraform configuration, and since we haven't reconciled the state yet, it hasn't had a chance to update.

It's important to have `force_destroy` set to `true` because occasionally a race condition exists between when a policy is destroyed and when the IAM user is destroyed, causing an error. `force_destroy` deletes an IAM resource even if there are still attached policies. The easiest and best way to fix this is with `terraform apply`, although you could also update the state manually:

```
$ terraform apply -auto-approve
...
local_file.credentials: Refreshing state...
     [id=4c65f8946d3bb69c819a7245fe700838e5e357fb]
module.iam["app1"].aws_iam_user.user: Modifying... [id=app1-svc-account]
module.iam["app1"].aws_iam_user.user: Modifications complete after 0s
[id=app1-svc-account]

Apply complete! Resources: 0 added, 1 changed, 0 destroyed.
```

Now that we're back in a good state, we can clean up as usual with `terraform destroy`:

```
$ terraform destroy -auto-approve
...
module.iam["app2"].aws_iam_policy.policy[0]: Destruction complete after 1s
module.iam["app2"].aws_iam_user.user: Destruction complete after 4s
module.iam["app1"].aws_iam_user.user: Destruction complete after 4s

Destroy complete! Resources: 9 destroyed.
```

This concludes the IAM scenario. In the next section, we move on and discuss how to test infrastructure as code.

10.4 Testing infrastructure as code

Testing infrastructure as code is a bit different than testing application code. Generally, when testing application code, you have at least three levels of testing:

- *Unit tests*—Do individual parts function in isolation?
- *Integration tests*—Do combined parts function as a component?
- *System tests*—Does the system as a whole operate as intended?

With Terraform, we don't usually perform unit tests, as there isn't really a need to do so. Terraform configuration is mostly made up of resources and data sources, both of

which are unit-tested at the provider level. The closest we have to this level of testing is static analysis, which basically makes sure configuration code is valid and has no obvious errors. Static analysis is done with either a linter, such as `terraform-lint` (https://github.com/terraform-linters/tflint), or a validation tool, such as `terraform validate`. Despite being a shallow form of testing, static analysis is useful because it's so quick.

> **NOTE** Some people claim that `terraform plan` is equivalent to a dry run, but I disagree. `terraform plan` is not a dry run because it refreshes data sources, and data sources can execute arbitrary (potentially malicious) code.

Integration tests make sense as long as you are clear about what a *component* is. If a unit in Terraform is a single resource or data source, it follows that a component is an individual module. Modules should therefore be relatively small and encapsulated to make them easier to test.

System tests (or functional tests) can be thought of as deploying an entire project, typically consisting of multiple modules and submodules. If your infrastructure deploys an application, you might also layer regression and performance testing as part of this step. We don't cover system testing in this section because it's subjective and unique to the infrastructure you are deploying.

We are going to write a basic integration test for a module that deploys an S3 static website. This integration test could also be generalized to work for any kind of Terraform module.

10.4.1 Writing a basic Terraform test

HashiCorp has recently developed a Go library called terraform-exec (https://github.com/hashicorp/terraform-exec) that allows for executing Terraform CLI commands programmatically. This library makes it easy to write automated tests for initializing, applying, and destroying Terraform configuration code (see figure 10.8). We'll use this library to perform integration testing on the S3 static website module.

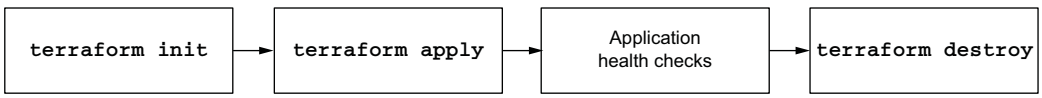


Figure 10.8 Testing a Terraform module requires calling Terraform CLI commands programmatically.

Why not Terratest?

Terratest, by Gruntworks (https://terratest.gruntwork.io), is one of the most popular Terraform testing frameworks. It's been around for a number of years and has a lot of community support. Like terraform-exec, it's implemented as a Go library with

(continued)

helper functions for invoking Terraform CLI commands, but it has gradually morphed into a more general-purpose testing framework. Many people use it for testing not only Terraform modules but also Docker, Kubernetes, and Packer.

I'm not writing this section on Terratest because there's already a lot of material on how to use it and because terraform-exec does some things better. For example, as a tool developed by HashiCorp, terraform-exec has feature parity with Terraform, whereas Terratest does not. You can run all Terraform CLI commands with terraform-exec using any combination of flags, while Terratest only allows a small subset of the most common commands. Additionally, terraform-exec has a sister library, terraform-json, that lets you parse Terraform state as regular golang structures. This makes it easy to read anything you want from the state file. Overall, they are similar tools and can be used interchangeably, but I feel terraform-exec is the more polished of the two.

Listing 10.10 shows the code for a basic Terraform test. It downloads the latest version of Terraform, initializes Terraform in a ./testfixtures directory, performs `terraform apply`, checks the health of the application, and finally cleans up with `terraform destroy`. Create a new directory in your `GOPATH`, and insert the code into a terraform-_module_test.go file.

Listing 10.10 terraform_module_test.go

```
package test

import (
    "bytes"
    "context"
    "fmt"
    "io/ioutil"
    "net/http"
    "os"
    "testing"

    "github.com/hashicorp/terraform-exec/tfexec"
    "github.com/hashicorp/terraform-exec/tfinstall"
    "github.com/rs/xid"
)

func TestTerraformModule(t *testing.T) {
    tmpDir, err := ioutil.TempDir("", "tfinstall")
    if err != nil {
        t.Error(err)
    }
    defer os.RemoveAll(tmpDir)

    latestVersion := tfinstall.LatestVersion(tmpDir, false)
    execPath, err := tfinstall.Find(latestVersion)
```

Downloads the latest version of the Terraform binary

```
    if err != nil {
        t.Error(err)
    }

    workingDir := "./testfixtures"
    tf, err := tfexec.NewTerraform(workingDir, execPath)
    if err != nil {
        t.Error(err)
    }

    ctx := context.Background()
    err = tf.Init(ctx, tfexec.Upgrade(true), tfexec.LockTimeout("60s"))
    if err != nil {
        t.Error(err)
    }

    defer tf.Destroy(ctx)
    bucketName := fmt.Sprintf("bucket_name=%s", xid.New().String())
    err = tf.Apply(ctx, tfexec.Var(bucketName))
    if err != nil {
        t.Error(err)
    }

    state, err := tf.Show(context.Background())
    if err != nil {
        t.Error(err)
    }

    endpoint := state.Values.Outputs["endpoint"].Value.(string)
    url := fmt.Sprintf("http://%s", endpoint)
    resp, err := http.Get(url)
    if err != nil {
        t.Error(err)
    }

    buf := new(bytes.Buffer)
    buf.ReadFrom(resp.Body)
    t.Logf("\n%s", buf.String())

    if resp.StatusCode != http.StatusOK {
        t.Errorf("status code did not return 200")
    }
}
```

Reads the configuration from ./testfixtures

Initializes Terraform

Ensures that terraform destroy runs even if an error occurs

Calls terraform apply with a variable

Reads the output value

Fails the test if the status code is not 200

TIP In CI/CD, integration testing should always occur after static analysis (e.g., `terraform validate`) because integration testing takes a long time.

10.4.2 Test fixtures

Before we can run the test, we need something to test against. Create a ./testfixtures directory to hold the test fixtures. In this directory, create a new main.tf file with the following contents. This code deploys a simple S3 static website and outputs the URL as `endpoint`.

Listing 10.11 main.tf

```
provider "aws" {
    region = "us-west-2"
}

variable "bucket_name" {
    type = string
}

resource "aws_s3_bucket" "website" {
  bucket = var.bucket_name
  acl = "public-read"
  policy = <<-EOF
    {
      "Version": "2008-10-17",
      "Statement": [
        {
          "Sid": "PublicReadForGetBucketObjects",
          "Effect": "Allow",
          "Principal": {
            "AWS": "*"
          },
          "Action": "s3:GetObject",
          "Resource": "arn:aws:s3:::${var.bucket_name}/*"
        }
      ]
    }
  EOF

  website {
    index_document = "index.html"
  }
}

resource "aws_s3_bucket_object" "object" {
  bucket = aws_s3_bucket.website.bucket
  key    = "index.html"
  source = "index.html"
  etag = filemd5("${path.module}/index.html")
  content_type = "text/html"
}

output "endpoint" {
  value = aws_s3_bucket.website.website_endpoint
}
```

The website home page is read from a local index.html file.

The test uses endpoint to check the application's health.

We also need an index.html in the ./testfixtures directory. This will be the website home page. Copy the following code into index.html.

Listing 10.12 index.html

```
<html>
<head>
    <title>Ye Olde Chocolate Shoppe</title>
</head>
```

```
<body>
  <h1>Chocolates for Any Occasion!</h1>
  <p>Come see why our chocolates are the best.</p>
</body>
</html>
```

Your working directory now contains the following files:

```
.
├── terraform_module_test.go
└── testfixtures
    ├── index.html
    └── main.tf

1 directory, 3 file
```

10.4.3 Running the test

First, import dependencies with `go mod init`:

```
$ go mod init
go: creating new go.mod: module github.com/scottwinkler/tia-chapter10
```

Then set the environment variables for your AWS access and secret access keys (you could also set these as normal Terraform variables in main.tf):

```
$ export AWS_ACCESS_KEY_ID=<your AWS access key>
$ export AWS_SECRET_ACCESS_KEY=<your AWS secret access key>
```

> **NOTE** You could also generate access keys using the IAM module from the previous section, as long as you gave it an appropriate deployment policy.

We can now run the test with `go test -v`. This command may take a few minutes to run because it has to download providers, create infrastructure, run tests, and destroy infrastructure:

```
$ go test -v
=== RUN   TestTerraformModule
    terraform_module_test.go:63:
        <html>
        <head>
            <title>Ye Olde Chocolate Shoppe</title>
        </head>
        <body>
          <h1> Chocolates for Any Occasion!</h1>
          <p> Come see why our chocolates are the best.</p>
        </body>
        </html>
--- PASS: TestTerraformModule (70.14s)
PASS
ok      github.com/scottwinkler/tia-chapter10    70.278s
```

10.5 Fireside chat

Code should not only be functional, it should also be readable and maintainable. This is especially true for self-service infrastructure such as centralized repositories used by

public cloud and governance teams. That being said, there is no question that refactoring Terraform configuration is difficult. You have to be able to migrate state, anticipate runtime errors, and not lose any stateful information in the process.

Because of how hard refactoring can be, it's often a good idea to test your code at the module level. You can do this with either Terratest or the terraform-exec library. I recommend terraform-exec because it was developed by HashiCorp and is the more polished of the two. Ideally, you should perform integration testing on all modules within your organization.

Summary

- `terraform taint` manually marks resources for destruction and re-creation. It can be used to rotate AWS access keys or other time-sensitive resources.
- A flat module can be converted into nested modules with the help of module expansions. Module expansions permit the use of `for_each` and `count` on modules, as with resources.
- The `terraform state mv` command moves resources and modules around, while `terraform state rm` removes them.
- Unmanaged resources can be converted to managed resources by importing them with `terraform import`. This is like performing `terraform refresh` on existing resources.
- Integration tests for Terraform modules can be written using a testing framework such as Terratest or terraform-exec. A typical testing pattern is to initialize Terraform, run an `apply`, validate outputs, and destroy infrastructure.

11 Extending Terraform by writing a custom provider

This chapter covers

- Developing a Terraform provider from scratch
- Implementing CRUD operations for managed resources
- Writing acceptance tests for the provider schema and resource files
- Deploying a serverless API to listen to requests from the provider
- Building and installing third-party providers

Extending Terraform by writing your own provider is one of the most satisfying things you can do with the technology. It demonstrates high-level proficiency and grants you the power to bend Terraform to your will. Nevertheless, even the simplest provider requires a considerable investment of time and effort. When might it be worth writing your own Terraform provider?

Two excellent reasons to write a provider are

- To wrap a remote API so you can manage your infrastructure as code
- To expose utility functions to Terraform

Almost all Terraform providers wrap remote APIs because this is what they were designed to do. Recall from chapter 2 that Terraform Core is essentially a glorified state-management engine. Without Terraform providers, Terraform would not know how to provision cloud-based infrastructure. By creating a custom provider, you enable Terraform to manage more and new kinds of resources.

Exposing utility functions to Terraform is another reason to create a custom provider, although considerably less common. Utility functions include anything not supported by one of the built-in functions, such as zipping files (Archive provider), reading/writing files (Local provider), or creating random passwords (Random provider). Because creating your own provider has a lot of associated overhead, many people choose to implement utility functions with a `local-exec` provisioner or the Shell provider rather than writing a one-off provider.

In this chapter, we develop a Petstore provider by wrapping a remote Petstore API. Pets are data objects representing animal friends, with attributes such as name, species, and age. Our Petstore provider allows us to manage pets as code by exposing a `petstore_pet` resource that can create, read, update, and delete pets. Figure 11.1 depicts a pet resource deployed by the Petstore provider, as seen through the UI.

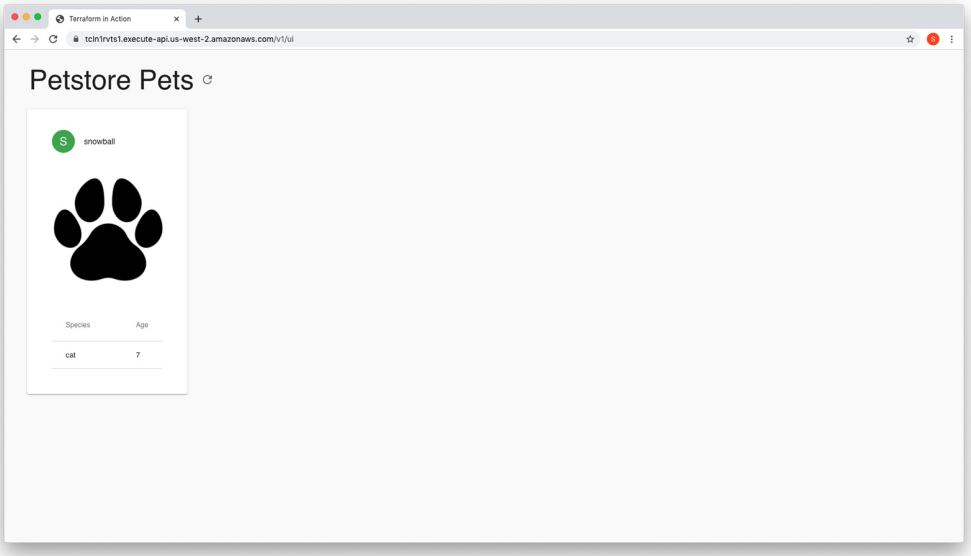


Figure 11.1 A pet resource provisioned with the Petstore provider, as seen through the UI

11.1 Blueprints for a Terraform provider

Although we've been using providers since chapter 1, we haven't explained in much detail how they work. In this section, we go through the different parts of a provider and the surrounding ecosystem. By the end of this section, you will have a big-picture understanding of what we'll implement in the next few sections.

11.1.1 Terraform provider basics

The primary purpose of any Terraform provider is to expose resources to Terraform and initialize shared configuration objects. Resources, as you already know, come in two flavors: managed and unmanaged. Managed resources are regular resources that implement create, read, update, delete (CRUD) methods for lifecycle management. Unmanaged resources, also known as data sources or read-only resources, are less complex and implement only the `Read` part of CRUD.

Shared configuration objects are exactly as the name suggests: configuration objects that are shared between resource entities, usually for optimization or authentication purposes. These can be things like client and database connections, mutexes (concurrency locks), and temporary access keys. Terraform always initializes these shared configuration objects before performing any CRUD actions.

NOTE If a provider fails or hangs during initialization, it is almost always due to a shared configuration object having invalid or expired credentials.

There are two prerequisites for creating your own provider that wraps a remote API:

- *Existing remote API*—Since Terraform makes calls against a remote API, there must be an existing remote API to make calls to. This can be your own API or someone else's.
- *Golang client SDK for the API*—Providers are written in golang, so you should have a golang client SDK for your API in place before proceeding. This will save you from having to make ugly, raw HTTP requests against the API.

TIP Always have separate repositories for the client SDK and the provider! Providers are sufficiently complicated, and there's no need to make it harder on yourself by combining SDK code with provider code.

Using a Terraform provider with a golang client SDK to talk to a remote API is shown in figure 11.2.

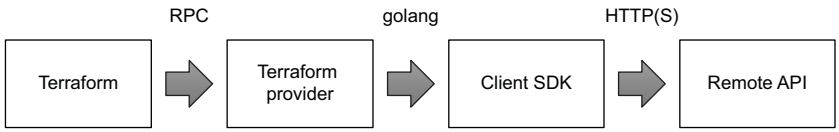


Figure 11.2 Terraform Core communicates with providers over RPC, which then uses a client SDK written in golang to make HTTP requests against a remote API.

Why Golang?

Golang is an excellent choice for open source projects because it's fast, statically compiled, cross-platform compliant, and easy to learn. It's no wonder that HashiCorp chose golang for so many of its major open source projects including Terraform, Consul, Nomad, Vault, and Packer.

(continued)

Providers are plugins that communicate with Terraform over remote procedure calls (RPCs). Despite HashiCorp's propensity for golang and the fact that Terraform Core was written in Go, as long as providers implement the expected interface, they can be written in any language. Practically speaking, however, this is rarely done. Providers are (almost) always written in Go because all the tooling and libraries for developing them is written in Go. Most notably, the important Terraform plugin SDK (https://github.com/hashicorp/terraform-plugin-sdk) library (formerly the `helper` package under Terraform Core) is written in Go.

11.1.2 Petstore provider architecture

In this chapter, we develop a custom Terraform Petstore provider from scratch. This provider is relatively simple, with minimal schema configuration, and it exports only a single resource, but it allows all the best practices and can be used as a template for developing new providers.

There are five files:

- main.go—The entry point for the provider, which is mostly uninteresting boilerplate
- petstore/provider.go—Contains the provider definition, resource mapping, and initialization of shared configuration objects
- petstore/provider_test.go—A file for basic acceptance tests of the provider
- petstore/resource_ps_pet.go—The pet resource that defines CRUD operations for managing a pet resource
- petstore/resource_ps_pet_test.go—More basic acceptance tests, this time for the pet resource

The complete file structure is as follows:

```
$ tree
.
├── main.go
└── petstore
    ├── provider.go
    ├── provider_test.go
    ├── resource_ps_pet.go
    └── resource_ps_pet_test.go
```

NOTE Normally, provider authors create matching read-only resources (aka data sources) to complement managed resources. We will not do that here to save space, but you can find an example in appendix E.

As discussed previously, we need a remote API to make calls against a golang client SDK to wrap the API. The API will be handled by a serverless Petstore app deployed on AWS, adapted from one we deployed in chapter 4. We'll use an SDK that I prepared in advance (https://github.com/terraform-in-action/go-petstore) because creating an SDK is largely tedious and uninteresting work, no matter what people say.

Creating a client SDK for an API

A software development kit (SDK) is a collection of libraries, tools, documentation, and example code used by developers to create applications for specific platforms. An SDK for an API (aka client SDK or client library) is a set of reusable functions used to interface with the API in a particular programming language. It authenticates to the server, makes HTTP requests, processes responses, and handles any errors. You can choose to lovingly create such a library from scratch or generate one from a specification file, but the goal of any good SDK should be to make it easy for users to invoke the API.

An SDK should always be written against an API specification file. There are many kinds of API specifications, but the most common one for RESTful APIs is the OpenAPI specification (formerly known as Swagger; http://mng.bz/A1Az). The OpenAPI specification is an API description format that allows you to describe the inputs and outputs of REST APIs in YAML or JSON. Good practice is to write the API specification first and then write the SDK and/or API to meet that specification.

One interesting possibility that results from writing your API to a specification is generating server stubs (API implementation files) and client libraries on the fly. Both save developer time and make it easy to support additional programming languages. Nevertheless, generated code is not always a perfect fit, and you may be better off writing custom code. For example, if you intend for your API only to be called by a Terraform provider, I suggest writing the golang client library from scratch. It may be boring and tedious work, but at least you can tailor the library for exactly how the provider will use it.

11.2 Writing the Petstore provider

In this section, we write all the functional code that goes in the Petstore provider. We'll start by setting up the Go project's entry point before configuring the provider schema and finally defining our pet resource. By the end of this section, we will have a complete provider—minus acceptance tests, which come in the next section.

11.2.1 Setting up the Go project

I will assume you have some familiarity with Go—but if you don't, that's ok. Golang is easy to understand, especially if you have previous experience with a scripting language like JavaScript or a C-based language like Java. The first thing you need to do when getting started with Go is create a new project under your `GOPATH`. The `GOPATH` environment variable specifics the location of your Go workspace, which is where all Go code is typically kept. If no `GOPATH` is set, it is assumed to be $HOME/go on Unix systems and %USERPROFILE%\go on Windows. Under `GOPATH` are two subdirectories: src and bin. Create a new Go project by making an empty directory under src with a corresponding package directory for the Petstore provider. For example,

```
$ mkdir $GOPATH/src/github.com/terraform-in-action/terraform-provider-petstore
```

NOTE The package directory is based on a GitHub username. You may want to replace it with your own username.

Next, create a main.go file in this directory containing the following code.

Listing 11.1 main.go

```
package main

import (
    "github.com/hashicorp/terraform-plugin-sdk/v2/plugin"
    "github.com/terraform-in-action/terraform-provider-petstore/petstore"
)

func main() {
    plugin.Serve(&plugin.ServeOpts{
        ProviderFunc: petstore.Provider})
}
```

Declares that the file is part of the main package

Import local and external packages

Serve Petstore provider

The main.go file is the primary entry point for the plugin when Terraform invokes it. The first line, `package main`, declares that this file is part of the `main` package, which is the root Go package for any given project. There are two declared imports: one from the `terraform-plugin-sdk` and one locally referenced import.

After that comes the `main` function, `func main() {...}`, which is the first thing called when executing the binary. All this does is serve up the Petstore provider, which is a plugin implementing the `terraform.ResourceProvider` interface, as defined by the Terraform plugin SDK.

11.2.2 Configuring the provider schema

The provider schema defines the attributes for the provider configuration, exports resources, and initializes any shared configuration objects. All this takes place during the `terraform init` step when the provider is first installed.

We start by defining a `Provider()` function, which will return a `terraform.ResourceProvider` interface. The `ResourceProvider` interface has several mandatory fields; I always like to start with `Schema`. Not to be confused with the overall provider schema, `Schema` is a parameter that outlines the allowed provider configuration attributes in Terraform. Ultimately, this will let us declare our provider in HCL:

```
provider "petstore" {
    address = var.address
}
```

I begin with `Schema` because the design of the provider configuration often influences the design of any resources or data sources implemented by the provider. Usually, what is passed into the provider configuration is for setting up shared configuration objects. Things like access keys, addresses, and other shared secrets are appropriate, whereas resource-specific data is not. Our provider configuration is easy enough, as there's only a single attribute called `address` (of type `string`), which configures the endpoint of the Petstore server. Note that the Petstore API is unauthenticated; hence there is no need for shared secrets.

WARNING You should always implement authentication for any production API and never bake secrets into the provider source code.

One more thing to mention about `address` is that we may wish to optionally set it with an environment variable rather than a Terraform variable so the provider can be run in automation. We can do this with the help of a prebuilt function from the plugin SDK called `schema.EnvDefaultFunc`. This function makes it possible to set a default environment variable if the attribute is not directly set in the provider configuration.

TIP It is a good idea to make critical configuration attributes, such as access keys and addresses, optionally configurable as environment variables for ease of use in automation.

Go ahead and create a petstore directory, and in it, create a provider.go file with the following code.

Listing 11.2 provider.go

```
package petstore

import (
    "net/url"

    "github.com/hashicorp/terraform-plugin-sdk/v2/helper/schema"
    sdk "github.com/terraform-in-action/go-petstore"
)

func Provider() *schema.Provider {
    return &schema.Provider{
        Schema: map[string]*schema.Schema{
            "address": &schema.Schema{
                Type:        schema.TypeString,
                Optional:    true,
                DefaultFunc: schema.EnvDefaultFunc("PETSTORE_ADDRESS", nil),
            },
        },
    }
}
```

Allows attribute to be optionally set from an environment variable

NOTE The petstore directory can also be referred to as a golang package.

Any provider's schema can be printed with the `terraform providers schema` command. An example of printing the Petstore provider's schema is shown here:

```
$ terraform providers schema -json | jq .
{
  "format_version": "0.1",
  "provider_schemas": {
    "registry.terraform.io/terraform-in-action/petstore": {
      "provider": {
        "version": 0,
        "block": {
```

```
            "attributes": {
              "address": {
                "type": "string",
                "description_kind": "plain",
                "optional": true
              }
            },
            "description_kind": "plain"
          }
        },
        "resource_schemas": {
          "petstore_pet": {
            "version": 0,
            "block": {
              "attributes": {
                "age": {
                  "type": "number",
                  "description_kind": "plain",
                  "required": true
                },
                "id": {
                  "type": "string",
                  "description_kind": "plain",
                  "optional": true,
                  "computed": true
                },
                "name": {
                  "type": "string",
                  "description_kind": "plain",
                  "optional": true
                },
                "species": {
                  "type": "string",
                  "description_kind": "plain",
                  "required": true
                }
              },
              "description_kind": "plain"
            }
          }
        }
      }
    }
  }
}
```

Now that we have the basic provider schema, we must register all resources that the provider exports to Terraform in a map structure. The map keys will be the names of the resources in Terraform, and the map value will be a pointer to `schema.Resource` objects. This map will have only a single resource, `petstore_pet`, which manages the lifecycle of a pet entity. We have not created it yet, but let's preemptively add a function called `resourcePSPet()` that we define in the next section. Edit provider.go to add this resource map.

Listing 11.3 provider.go

```
package petstore

import (
    "net/url"

    "github.com/hashicorp/terraform-plugin-sdk/v2/helper/schema"
    sdk "github.com/terraform-in-action/go-petstore"
)

func Provider() *schema.Provider {
    return &schema.Provider{
        Schema: map[string]*schema.Schema{
            "address": &schema.Schema{
                Type:        schema.TypeString,
                Optional:    true,
                DefaultFunc: schema.EnvDefaultFunc("PETSTORE_ADDRESS", nil),
            },
        },

        ResourcesMap: map[string]*schema.Resource{
            "petstore_pet": resourcePSPet(),
        },
    }
}
```

Finally, we need to initialize shared configuration objects. For our purposes, this is the client that the SDK uses to make API requests against the Petstore server. The logic for doing this is encapsulated in the `ConfigureFunc` field of the provider schema. The output of this function is a shared configuration object that will be made available to all resources. The complete code for provider.go is shown next.

Listing 11.4 provider.go

```
package petstore

import (
    "net/url"

    "github.com/hashicorp/terraform-plugin-sdk/v2/helper/schema"
    sdk "github.com/terraform-in-action/go-petstore"
)

func Provider() *schema.Provider {
    return &schema.Provider{
        Schema: map[string]*schema.Schema{
            "address": &schema.Schema{
                Type:        schema.TypeString,
                Optional:    true,
                DefaultFunc: schema.EnvDefaultFunc("PETSTORE_ADDRESS", nil),
            },
        },
```

```
        ResourcesMap: map[string]*schema.Resource{
            "petstore_pet": resourcePSPet(),
        },

        ConfigureFunc: providerConfigure,
    }
}

func providerConfigure(d *schema.ResourceData) (interface{}, error) {
    hostname, _ := d.Get("address").(string)
    address, _ := url.Parse(hostname)
    cfg := &sdk.Config{
        Address: address.String(),
    }
    return sdk.NewClient(cfg)
}
```

11.3 Creating a pet resource

The function `resourcePSPet()` returns a `schema.Resource` interface. Our pet resource is an implementation of this interface. As you might have guessed, four of the fields on this interface have to do with function hooks invoked during CRUD lifecycle management:

- `Create`—A pointer to a function that's invoked when a create lifecycle event is triggered. Create lifecycle events are triggered when new resources are created, such as during an initial `apply` and during force-new updates.
- `Read`—A pointer to a function that's invoked when a read lifecycle event is triggered. Read events are triggered during the generation of an execution plan to determine whether configuration drift has occurred. Additionally, the `Read()` function is typically called as a side effect of `Create()` and `Update()`.
- `Update`—A pointer to a function that's invoked when an update lifecycle event is triggered. It handles in-place (aka non-destructive) updates. This field may be omitted if all attributes in the resource schema are marked as `ForceNew`.
- `Delete`—A pointer to a function that's invoked when a delete lifecycle event is triggered. Delete lifecycle events are triggered during `terraform destroy`; when a resource is removed from configuration (or marked as tainted), followed by a `terraform apply`; and when an attribute marked as `ForceNew` has been changed.

It's important to know when each of the four CRUD functions will be invoked so you can predict and handle any errors. During an initial `apply` with no previous state, Terraform calls `Create()`, which has the side effect of calling `Read()`. During `terraform plan`, `Read()` is called by itself. During an in-place update, `Read()` is called first, like during the plan, and then `Update()` is called, which has the side effect of calling `Read()` again. Force-new updates call `Read()`, then `Delete()`, then `Create()`, and finally `Read()` again. Destroy operations always call `Read()` and then `Delete()`. Figure 11.3 is a reference diagram.

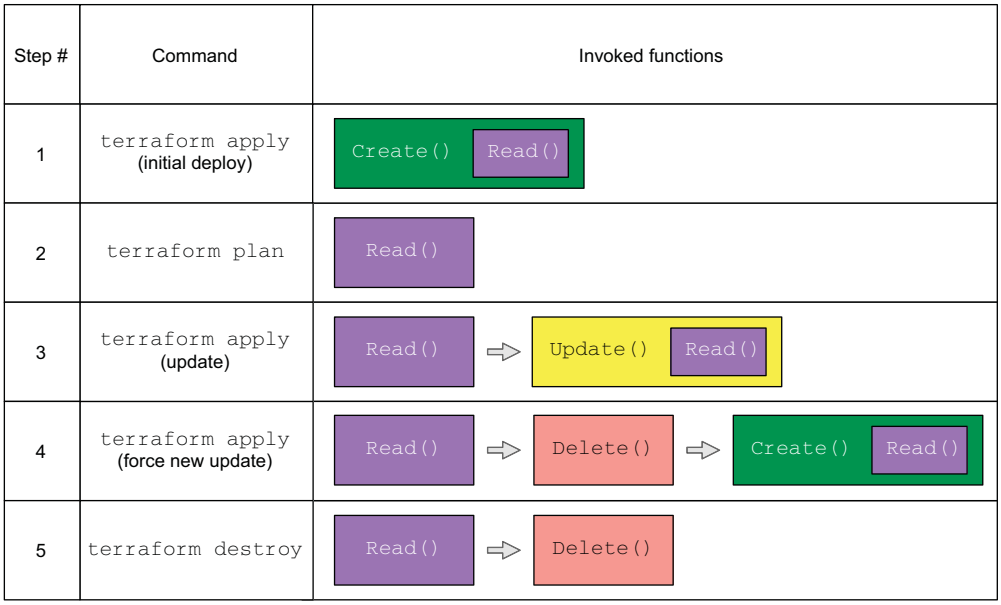


Figure 11.3 Different methods are invoked based on the command as well as the current state and configuration. Some methods (`Create()` and `Update()`) have the side effect of calling other methods (`Read()`).

Besides CRUD methods, the resource schema has another required field called `Schema`. Like the provider schema, this is a map of attributes that a resource defines. The type of each attribute must be specified, as well as whether the attribute is required, optional, or `ForceNew`. Our pet resource has three attributes : `name`, `species`, and `age`. `name` is an optional attribute because not all pets have names. `species` will be marked as required and `ForceNew` (because making a change to a pet's species is kind of a big deal). `age` is an integer type that's required but not marked as `ForceNew`, because it's highly likely the pet will have a birthday in the future, meaning we have to update its age.

Let's now define the function for the pet resource in a separate file called resource_ps_pet.go.

Listing 11.5 resource_ps_pet.go

```
package petstore

import (
    "github.com/hashicorp/terraform-plugin-sdk/v2/helper/schema"
    sdk "github.com/terraform-in-action/go-petstore"
)

func resourcePSPet() *schema.Resource {
    return &schema.Resource{
```

```
        Create: resourcePSPetCreate,
        Read:   resourcePSPetRead,
        Update: resourcePSPetUpdate,
        Delete: resourcePSPetDelete,
        Importer: &schema.ResourceImporter{
            State: schema.ImportStatePassthrough,
        },

        Schema: map[string]*schema.Schema{
            "name": {
                Type:     schema.TypeString,
                Optional: true,
                Default:  "",
            },
            "species": {
                Type:     schema.TypeString,
                ForceNew: true,
                Required: true,
            },
            "age": {
                Type:     schema.TypeInt,
                Required: true,
            },
        },
    }
}
```

Not all pets have a name, so this is optional.

All pets are part of a species.

Pets have an age attribute that can be updated in-place.

Next, we will define the `Create()`, `Read()`, `Update`, and `Delete()` methods.

11.3.1 Defining Create()

`Create()` is a function responsible for provisioning a new resource based on user-supplied input and setting the resource's unique ID. The ID is important because without it, the resource won't be marked as created by Terraform, and it also will not be persisted to Terraform state. The implementation of `Create()` usually means performing a `POST` request against the remote API, waiting for a response, handling any retry logic, and invoking a `Read()` operation afterward.

> **TIP** Although you could write the logic for performing a raw HTTP `POST` request inline in the `Create()` function, I do not recommend doing so. That's what the client SDK is for.

Because we already have a Petstore client SDK (which encapsulates much of the tedious logic of interacting with the API), the `Create()` method becomes incredibly simple.

Listing 11.6 resource_ps_pet.go

```
package petstore

import (
    "github.com/hashicorp/terraform-plugin-sdk/v2/helper/schema"
    sdk "github.com/terraform-in-action/go-petstore"
)
```

```
func resourcePSPet() *schema.Resource {
    return &schema.Resource{
        Create: resourcePSPetCreate,
        Read:   resourcePSPetRead,
        Update: resourcePSPetUpdate,
        Delete: resourcePSPetDelete,
        Importer: &schema.ResourceImporter{
            State: schema.ImportStatePassthrough,
        },

        Schema: map[string]*schema.Schema{
            "name": {
                Type:     schema.TypeString,
                Optional: true,
                Default:  "",
            },
            "species": {
                Type:     schema.TypeString,
                ForceNew: true,
                Required: true,
            },
            "age": {
                Type:     schema.TypeInt,
                Required: true,
            },
        },
    }
}

func resourcePSPetCreate(d *schema.ResourceData, meta interface{}) error {
    conn := meta.(*sdk.Client)
    options := sdk.PetCreateOptions{
        Name:    d.Get("name").(string),
        Species: d.Get("species").(string),
        Age:     d.Get("age").(int),
    }

    pet, err := conn.Pets.Create(options)
    if err != nil {
        return err
    }

    d.SetId(pet.ID)
    return resourcePSPetRead(d, meta)
}
```

Meta comes from the output of the provider configuration.

The resource ID is set using a unique parameter from the response object.

Best practice is to call Read() after Create().

11.3.2 Defining Read()

`Read()` is a non-destructive operation that retrieves the actual state of a resource from a remote API. It's called whenever a refresh occurs and as a side effect of both `Update()` and `Create()`. Generally, `Read()` uses a unique resource ID to perform a lookup against the API, although it could also use a combination of other attributes to uniquely identify a resource. Regardless of how the lookup is done, the response from the API is considered authoritative. If the actual state doesn't match the desired state,

as described in the current configuration/state file, an update will be triggered during the subsequent `apply`.

> **WARNING** `Read()` should always return the same resource from the API. If it does not, you will end up with orphaned resources. *Orphaned resources* are resources that were originally created by Terraform but that have been lost track of and are now unmanaged.

Add the code from the following listing to the bottom of the resource_ps_pet.go file to implement `Read()`. This code uses the Petstore SDK to look up the pet resource based on ID, throw an error if one has occurred, and set the attributes based on the response from the API.

Listing 11.7 resource_ps_pet.go

```
...
func resourcePSPetCreate(d *schema.ResourceData, meta interface{}) error {
    conn := meta.(*sdk.Client)
    options := sdk.PetCreateOptions{
        Name:    d.Get("name").(string),
        Species: d.Get("species").(string),
        Age:     d.Get("age").(int),
    }

    pet, err := conn.Pets.Create(options)
    if err != nil {
        return err
    }

    d.SetId(pet.ID)
    return resourcePSPetRead(d, meta)
}

func resourcePSPetRead(d *schema.ResourceData, meta interface{}) error {
    conn := meta.(*sdk.Client)
    pet, err := conn.Pets.Read(d.Id())
    if err != nil {
        return err
    }
    d.Set("name", pet.Name)
    d.Set("species", pet.Species)
    d.Set("age", pet.Age)
    return nil
}
```

Setting resource attributes based on the remote or actual state

11.3.3 Defining Update()

Although Terraform is often touted as an immutable infrastructure as code technology (and I describe it as such in chapter 1), strictly speaking, it isn't one. Almost all resources that Terraform manages are mutable to some degree. As a reminder, *immutable infrastructure* is the concept of never performing updates in place. If an update occurs, it takes place by tearing down the old infrastructure (such as a server)

and replacing it with new infrastructure preconfigured to the desired state. By contrast, with *mutable infrastructure*, existing resources are allowed to persist through in-place updates or patches instead of resources being deleted and re-created. Only if every attribute on a resource is marked `ForceNew` (and almost no resource is this way) could the resource be described as immutable.

The purpose of `Update()` is to perform non-destructive, in-place updates on existing infrastructure. It's a tricky method to implement, and it may be tempting to skip the need for it by marking all attributes as `ForceNew`, but I wouldn't recommend doing this. Force-new updates are inconvenient from a user perspective because changes take longer to propagate. This is an example where a good user experience matters more than ease of development or strict adherence to infrastructure immutability.

The sole responsibility of `Update()` is to do whatever it takes to transform the actual state of a resource into the desired state. Typically, this means performing a `PATCH` request followed by a `GET`; but since we have a client SDK, we'll use that instead of making raw HTTP requests. Add the following code to the bottom of resource_ps_pet.go to define and implement `Update()`.

Listing 11.8 resource_ps_pet.go

```
...

func resourcePSPetRead(d *schema.ResourceData, meta interface{}) error {
    conn := meta.(*sdk.Client)
    pet, err := conn.Pets.Read(d.Id())
    if err != nil {
        return err
    }
    d.Set("name", pet.Name)
    d.Set("species", pet.Species)
    d.Set("age", pet.Age)
    return nil
}

func resourcePSPetUpdate(d *schema.ResourceData, meta interface{}) error {
    conn := meta.(*sdk.Client)
    options := sdk.PetUpdateOptions{}
    if d.HasChange("name") {
        options.Name = d.Get("name").(string)
    }
    if d.HasChange("age") {
        options.Age = d.Get("age").(int)
    }
    conn.Pets.Update(d.Id(), options)
    return resourcePSPetRead(d, meta)
}
```

Checks each non-ForceNew attribute to see if it has changed

Perform in-place update.

Like Create(), Update() needs to call Read() as a side effect.

11.3.4 Defining Delete()

The last lifecycle method to implement is `Delete()`. This method is responsible for making an API request to delete an existing resource and set its resource ID to `nil`

(which marks the resource as destroyed and removes it from the state file). I always find `Delete()` the easiest method to implement, but it's still important not to make any mistakes. If `Delete()` fails to delete (such as if the API experienced an internal error due to poor implementation), you will be left with orphaned resources.

> **NOTE** You can call `Read()` after `Delete()` if you wish to ensure that a resource has actually been destroyed, but usually this is not done. `Delete()` is presumed to succeed if the response from the server says it has succeeded. Server errors should be handled by the server or SDK.

The code for `Delete()` is shown in the following listing.

Listing 11.9 resource_ps_pet.go

```
...
func resourcePSPetUpdate(d *schema.ResourceData, meta interface{}) error {
    conn := meta.(*sdk.Client)
    options := sdk.PetUpdateOptions{}
    if d.HasChange("name") {
        options.Name = d.Get("name").(string)
    }
    if d.HasChange("age") {
        options.Age = d.Get("age").(int)
    }
    conn.Pets.Update(d.Id(), options)
    return resourcePSPetRead(d, meta)
}

func resourcePSPetDelete(d *schema.ResourceData, meta interface{}) error {
    conn := meta.(*sdk.Client)
    err := conn.Pets.Delete(d.Id())
    if err != nil {
        return err
    }
    return nil
}
```

For your reference, the complete code for resource_ps_pet.go is presented next.

Listing 11.10 resource_ps_pet.go

```
package petstore

import (
    "github.com/hashicorp/terraform-plugin-sdk/v2/helper/schema"
    sdk "github.com/terraform-in-action/go-petstore"
)

func resourcePSPet() *schema.Resource {
    return &schema.Resource{
        Create: resourcePSPetCreate,
        Read:   resourcePSPetRead,
        Update: resourcePSPetUpdate,
```

```
        Delete: resourcePSPetDelete,
        Importer: &schema.ResourceImporter{
            State: schema.ImportStatePassthrough,
        },

        Schema: map[string]*schema.Schema{
            "name": {
                Type:     schema.TypeString,
                Optional: true,
                Default:  "",
            },
            "species": {
                Type:     schema.TypeString,
                ForceNew: true,
                Required: true,
            },
            "age": {
                Type:     schema.TypeInt,
                Required: true,
            },
        },
    }
}

func resourcePSPetCreate(d *schema.ResourceData, meta interface{}) error {
    conn := meta.(*sdk.Client)
    options := sdk.PetCreateOptions{
        Name:    d.Get("name").(string),
        Species: d.Get("species").(string),
        Age:     d.Get("age").(int),
    }

    pet, err := conn.Pets.Create(options)
    if err != nil {
        return err
    }

    d.SetId(pet.ID)
    return resourcePSPetRead(d, meta)
}

func resourcePSPetRead(d *schema.ResourceData, meta interface{}) error {
    conn := meta.(*sdk.Client)
    pet, err := conn.Pets.Read(d.Id())
    if err != nil {
        return err
    }
    d.Set("name", pet.Name)
    d.Set("species", pet.Species)
    d.Set("age", pet.Age)
    return nil
}

func resourcePSPetUpdate(d *schema.ResourceData, meta interface{}) error {
    conn := meta.(*sdk.Client)
    options := sdk.PetUpdateOptions{}
```

```
    if d.HasChange("name") {
        options.Name = d.Get("name").(string)
    }
    if d.HasChange("age") {
        options.Age = d.Get("age").(int)
    }
    conn.Pets.Update(d.Id(), options)
    return resourcePSPetRead(d, meta)
}

func resourcePSPetDelete(d *schema.ResourceData, meta interface{}) error {
    conn := meta.(*sdk.Client)
    err := conn.Pets.Delete(d.Id())
    if err != nil {
        return err
    }
    return nil
}
```

11.4 Writing acceptance tests

A provider isn't complete until it's been thoroughly tested. Tests are important because they give you the confidence to know that your code is working and (relatively) bug-free. Writing good tests can be tough, but it's worth the effort. In this section, we write two test files: one for the provider schema and one for the pet resource.

> **NOTE** Expect to include tests for any contribution you make to an open source provider.

11.4.1 Testing the provider schema

The primary purpose of testing the provider schema is to ensure that the provider

- Can be successfully initialized
- Has a valid internal schema
- Has all environment variables required for testing

> **NOTE** Sometimes people also test the individual attributes of the provider, along with various ways to configure the provider.

Create a provider_test.go file containing the following code.

Listing 11.11 provider_test.go

```
package petstore

import (
    "context"
    "testing"

    "github.com/hashicorp/terraform-plugin-sdk/v2/diag"
    "github.com/hashicorp/terraform-plugin-sdk/v2/helper/schema"
    "github.com/hashicorp/terraform-plugin-sdk/v2/terraform"
)
```

```
var testAccProviders map[string]*schema.Provider
var testAccProvider *schema.Provider

func init() {                                    <-- Initializes global variables
    testAccProvider = Provider()
    testAccProviders = map[string]*schema.Provider{
        "petstore": testAccProvider,
    }
}

func TestProvider(t *testing.T) {                <-- Tests that the provider schema is valid
    if err := Provider().InternalValidate(); err != nil {
        t.Fatalf("err: %s", err)
    }
}

func TestProvider_impl(t *testing.T) {           <-- Tests that the provider can be initialized
    var _ *schema.Provider = Provider()
}

func testAccPreCheck(t *testing.T) {             <-- Tests that the PETSTORE_ADDRESS environment variable is set
    if os.Getenv("PETSTORE_ADDRESS") == "" {
        t.Fatal("PETSTORE_ADDRESS must be set for acceptance tests")
    }

    if diags := Provider().Configure(context.Background(),
&terraform.ResourceConfig{}); diags.HasError() {
        for _, d := range diags {
            if d.Severity == diag.Error {
                t.Fatalf("err: %s", d.Summary)
            }
        }
    }
}
```

11.4.2 Testing the pet resource

Writing a test for a Terraform resource is more difficult than writing tests for the provider schema because it requires utilizing a custom testing framework developed by HashiCorp. Don't worry: you don't have to know much about this testing framework to get through this scenario. However, the framework is worth looking into because it allows you to do cool stuff like run test sequences against resources with various configurations and run pre-processor and post-processor functions. It was tailor-made for testing Terraform resources and is certainly easier than rolling your own framework.

Although you can do a lot with resource testing, at a bare minimum you need the following:

- A basic create/destroy test with validation that attributes get set in the state file
- A function that verifies test resources have been destroyed
- A function that tests the HCL configuration with all input attributes set

The test code for the pet resource is shown in the next listing. Copy it into a resource_ps_pet_test.go file under the petstore directory.

Listing 11.12 resource_ps_pet_test.go

```
package petstore

import (
    "fmt"
    "testing"

    "github.com/hashicorp/terraform-plugin-sdk/v2/helper/resource"
    "github.com/hashicorp/terraform-plugin-sdk/v2/terraform"
    sdk "github.com/terraform-in-action/go-petstore"
)

func TestAccPSPet_basic(t *testing.T) {
    resourceName := "petstore_pet.pet"

    resource.Test(t, resource.TestCase{
        PreCheck:     func() { testAccPreCheck(t) },
        Providers:    testAccProviders,
        CheckDestroy: testAccCheckPSPetDestroy,
        Steps: []resource.TestStep{
            {
                Config: testAccPSPetConfig_basic(),
                Check: resource.ComposeTestCheckFunc(
                    resource.TestCheckResourceAttr(resourceName, "name",
                    "Princess"),
                    resource.TestCheckResourceAttr(resourceName, "species",
                    "cat"),
                    resource.TestCheckResourceAttr(resourceName, "age", "3"),
                ),
            },
        },
    })
}

func testAccCheckPSPetDestroy(s *terraform.State) error {
    conn := testAccProvider.Meta().(*sdk.Client)
    for _, rs := range s.RootModule().Resources {
        if rs.Type != "petstore_pet" {
            continue
        }
        if rs.Primary.ID == "" {
            return fmt.Errorf("No instance ID is set")
        }
        _, err := conn.Pets.Read(rs.Primary.ID)
        if err != sdk.ErrResourceNotFound {
            return fmt.Errorf("Pet %s still exists", rs.Primary.ID)
        }
    }
    return nil
}

func testAccPSPetConfig_basic() string {
    return fmt.Sprintf(`
    resource "petstore_pet" "pet" {
        name    = "Princess"
        species = "cat"
```

Basic acceptance test for a Terraform resource

PreCheck ensures that PETSTORE_ADDRESS has been set.

Uses the global provider initialized with init()

Ensures that the resource gets destroyed

Simple test that creates a resource using a sample configuration and checks that the set attributes are as expected

Destroy function implementation

Function that returns a string containing resource configuration

```
        age      = 3
      }
`)
}
```

11.5 Build, test, deploy

The code for the provider is now complete, but we still have a few tasks to do. First, we need an actual Petstore API to test against, then we need to test and build the provider binary, and finally we need to run end-to-end tests with real configuration code.

11.5.1 Deploying the Petstore API

For your convenience, I have packaged the API into a module that can easily be deployed with a few lines of Terraform code. This module deploys a serverless backend with an API gateway, a lambda function, and a Relational Database Service (RDS) database. It parallels the architecture of the serverless app deployed in chapter 5, except it's on AWS rather than Azure. Basically, I took the web app deployed in chapter 4 and modified it to run on serverless technologies.

Following is the code for the Petstore module. Create a new, separate Terraform workspace with this file.

Listing 11.13 petstore.tf

```
terraform {
  required_version = ">= 0.15"
  required_providers {
    aws = {
      source = "hashicorp/aws"
      version = "~> 3.28"
    }
    random = {
      source = "hashicorp/random"
      version = "~> 3.0"
    }
  }
}

provider "aws" {
  region  = "us-west-2"
}

module "petstore" {
  source = "terraform-in-action/petstore/aws"
}

output "address" {
  value = module.petstore.address
}
```

Deploy as usual by performing `terraform init` followed by terraform `apply`:

```
$ terraform init
...
```

```
Terraform has been successfully initialized!

$ terraform apply
...
Plan: 24 to add, 0 to change, 0 to destroy.

Changes to Outputs:
  + address = (known after apply)

Do you want to perform these actions?
  Terraform will perform the actions described above.
  Only 'yes' will be accepted to approve.

  Enter a value:
```

After you confirm the `apply`, deploying the serverless application should take about 5–10 minutes. At the end, you will get the address for your deployed API:

```
Apply complete! Resources: 1 added, 0 changed, 0 destroyed.

Outputs:

address = https://tcln1rvts1.execute-api.us-west-2.amazonaws.com/v1
```

If you navigate to this address in the browser, it will redirect you to a simple web UI. Notice that the UI is empty to start with because there are no pets in the database yet (see figure 11.4).

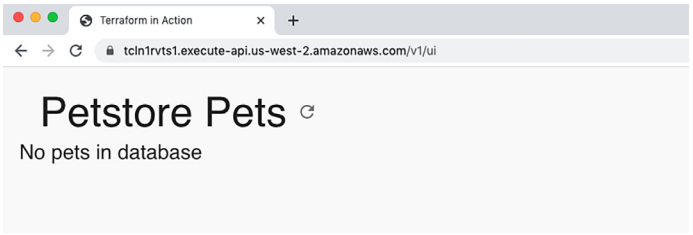


Figure 11.4 Initially there are no pets in the database, so the web UI doesn't show anything.

11.5.2 Testing and building the provider

Create a new Go module with `go mod init`, and then download dependencies with `go mod get`:

```
$ go mod init
go: creating new go.mod: module github.com/terraform-in-action/terraform-
provider-petstore

$ go mod get
go: finding module for package github.com/hashicorp/terraform-plugin-
sdk/v2/plugin
go: finding module for package github.com/hashicorp/terraform-plugin-
sdk/v2/helper/schema
```

```
go: finding module for package github.com/terraform-in-action/go-petstore
go: found github.com/hashicorp/terraform-plugin-sdk/v2/plugin in
github.com/hashicorp/terraform-plugin-sdk/v2 v2.4.0
go: found github.com/terraform-in-action/go-petstore in
github.com/terraform-in-action/go-petstore v0.1.1
```

Now set `TF_ACC` to `1` to enable running acceptance tests:

```
$ export TF_ACC=1
```

> **NOTE** `TF_ACC` is an environment variable required by design to prevent developers from incurring unintended charges when running tests (see http://mng.bz/ZY2P).

If we were to run the acceptance tests now, we would get an error because the `PETSTORE_ADDRESS` environment variable has not been set. This is due to the `PreCheck` function in `TestAccPSPet_basic()`:

```
$ go test -v ./petstore
=== RUN   TestProvider
--- PASS: TestProvider (0.00s)
=== RUN   TestProvider_impl
--- PASS: TestProvider_impl (0.00s)
=== RUN   TestAccPSPet_basic
    provider_test.go:35: PETSTORE_ADDRESS must be set for acceptance tests
--- FAIL: TestAccPSPet_basic (0.00s)
FAIL
FAIL    github.com/terraform-in-action/terraform-provider-petstore/petstore
0.354s
FAIL
```

To proceed, we must set `PETSTORE_ADDRESS` to the address of our deployed Petstore API. We need to do this because otherwise, Terraform will not know where to send requests:

```
$ export PETSTORE_ADDRESS=<your Petstore address>
```

Now the acceptance tests pass:

```
$ go test -v ./petstore
=== RUN   TestProvider
--- PASS: TestProvider (0.00s)
=== RUN   TestProvider_impl
--- PASS: TestProvider_impl (0.00s)
=== RUN   TestAccPSPet_basic
--- PASS: TestAccPSPet_basic (2.89s)
PASS
ok      github.com/terraform-in-action/terraform-provider-petstore/petstore
3.082s
```

Since the tests pass, the provider is ready to be built. You can do that with `go build`:

```
$ go build
```

The binary will appear in your working directory:

```
$ ls -o
total 56976
-rw-r--r--  1 swinkler       216 Jan 20 19:56 go.mod
-rw-r--r--  1 swinkler     45873 Jan 20 19:56 go.sum
-rw-r--r--  1 swinkler       337 Jan 20 21:20 main.go
drwxr-xr-x  6 swinkler       192 Jan 20 21:21 petstore
-rwxr-xr-x  1 swinkler  29108564 Jan 20 22:26 terraform-provider-petstore
```

TIP Most provider authors use a Makefile and CI triggers to automate the steps of building, testing, and distributing the provider. I recommend looking at some simpler providers, like `terraform-provider-null` and `terraform-provider-tfe`, for inspiration.

11.5.3 Installing the provider

There are a few different ways to install custom providers, as described on HashiCorp's website (http://mng.bz/RKAK). For development providers, the easiest method is to edit your Terraform CLI configuration file (.terraformrc) to point to a directory containing your developer provider plugins. Let's do that now.

The CLI configuration is a single file named terraform.rc on Windows and .terraformrc on Linux or Mac. It applies per-user settings for CLI behaviors across all Terraform working directories. Add the following code to override where Terraform looks to install the Petstore plugin.

Listing 11.14 .terraformrc

```
provider_installation {
  dev_overrides {
    "terraform-in-action/petstore" =
"PATH/TO/DIRECTORY/WITH/PETSTORE/BINARY"
  }

  direct {}
}
```

Overrides the location of the Petstore plugin

Allows all other providers to be downloaded from the registry as usual

11.5.4 Pets as code

Now we are ready to manage pets as code. Create a new Terraform workspace with a main.tf file.

Listing 11.15 main.tf

```
terraform {
  required_providers {
    petstore = {
      source  = "terraform-in-action/petstore"
      version = "~> 1.0"
    }
  }
}
```

```
provider "petstore" {
  address = "https://tcln1rvts1.execute-api.us-west-2.amazonaws.com/v1"
}

resource "petstore_pet" "pet" {
  name    = "snowball"
  species = "cat"
  age     = 20
}
```

Your provider address goes here.

Initializing Terraform installs the Petstore provider plugin from the directory specified in .terraformrc:

```
$ terraform init

Initializing the backend...

Initializing provider plugins...
- Reusing previous version of terraform-in-action/petstore from the
dependency lock file
- Installing terraform-in-action/petstore v1.0.0...
- Installed terraform-in-action/petstore v1.0.0 (self-signed, key ID
37082CDD8344B056)

Partner and community providers are signed by their developers.
If you'd like to know more about provider signing, you can read about it here:
https://www.terraform.io/docs/plugins/signing.html

Warning: Provider development overrides are in effect

The following provider development overrides are set in the CLI configuration:
 - terraform-in-action/petstore in
/Users/swinkler/go/src/github.com/terraform-in-action/terraform-provider-
petstore

The behavior may therefore not match any released version of the provider
and applying changes may cause the state to become incompatible with
published releases.

Terraform has been successfully initialized!

You may now begin working with Terraform. Try running "terraform plan" to see
any changes that are required for your infrastructure. All Terraform commands
should now work.

If you ever set or change modules or backend configuration for Terraform,
rerun this command to reinitialize your working directory. If you forget,
other commands will detect it and remind you to do so if necessary.
```

Developer override for the provider plugin

Now that Terraform has detected the provider version and installed it successfully, run an `apply` in the workspace:

```
$ terraform apply

Warning: Provider development overrides are in effect
```

```
The following provider development overrides are set in the CLI configuration:
 - terraform-in-action/petstore in
/Users/swinkler/go/src/github.com/terraform-in-action/terraform-provider-
petstore

The behavior may therefore not match any released version of the provider
and applying changes may cause the state to become incompatible with
published
releases.


An execution plan has been generated and is shown below.
Resource actions are indicated with the following symbols:
  + create

Terraform will perform the following actions:

  # petstore_pet.pet will be created
  + resource "petstore_pet" "pet" {
      + age     = 7
      + id      = (known after apply)
      + name    = "snowball"
      + species = "cat"
    }

Plan: 1 to add, 0 to change, 0 to destroy.

Do you want to perform these actions?
  Terraform will perform the actions described above.
  Only 'yes' will be accepted to approve.

  Enter a value:
```

As you can see, Terraform recognizes our provider as valid and plans to create a new pet resource! Confirm the `apply` to proceed:

```
petstore_pet.pet: Creating...
petstore_pet.pet: Still creating... [10s elapsed]
petstore_pet.pet: Creation complete after 11s [id=1308d843-337f-4fc4-8eb6-
3e522553d217]

Apply complete! Resources: 1 added, 0 changed, 0 destroyed.
```

> **NOTE** It can take up to 30 seconds for the initial API request to succeed due to the serverless nature of the API. Once the lambda function has warmed up, the request time will be much faster. If you are still not getting a response after 30 seconds, it could be an error with the API request/response—turning on trace-level logs with `TF_LOG=TRACE` may help identify the problem.

The resource now exists as a record in the Petstore database. You can view it by navigating to the UI again and verifying that a new resource exists (see figure 11.5).

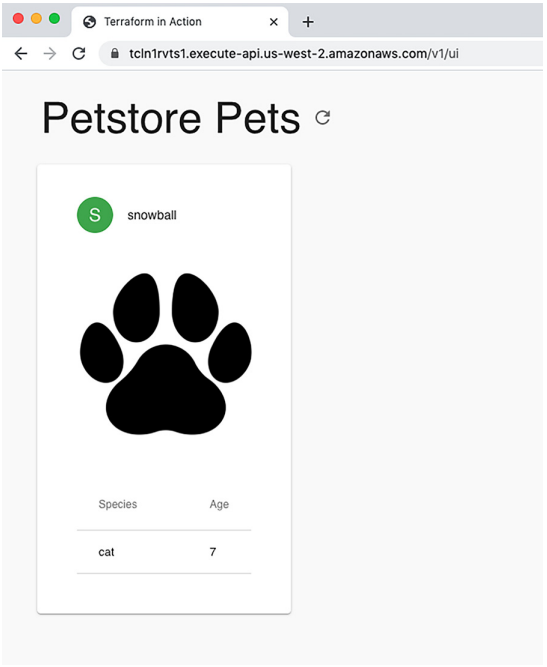


Figure 11.5 The provisioned pet resource, as seen in the UI

NOTE Another way to verify that the resource exists is to query the raw API: for example, using a `GET` against https://tcln1rvts1.execute-api.us-west-2.amazonaws.com/v1/api/pets.

The resource has been recorded in the state file, which we can view with `terraform state show`:

```
$ terraform state show petstore_pet.pet
# petstore_pet.pet:
resource "petstore_pet" "pet" {
    age     = 7
    id      = "1308d843-337f-4fc4-8eb6-3e522553d217"
    name    = "snowball"
    species = "cat"
}
```

If we make changes to the configuration code, such as incrementing `age` from 7 to 8, we get the following message during the next `apply`:

```
$ terraform apply
petstore_pet.pet: Refreshing state... [id=1308d843-337f-4fc4-8eb6-
     3e522553d217]

An execution plan has been generated and is shown below.
Resource actions are indicated with the following symbols:
  ~ update in-place
```

```
Terraform will perform the following actions:

  # petstore_pet.pet will be updated in-place
  ~ resource "petstore_pet" "pet" {
      ~ age     = 7 -> 8
        id      = "1308d843-337f-4fc4-8eb6-3e522553d217"
        name    = "snowball"
        # (1 unchanged attribute hidden)
    }

Plan: 0 to add, 1 to change, 0 to destroy.

Do you want to perform these actions?
  Terraform will perform the actions described above.
  Only 'yes' will be accepted to approve.

  Enter a value:
```

After updating, clean up by deleting the resource from the API with `terraform destroy`:

```
$ terraform destroy -auto-approve
petstore_pet.pet: Destroying... [id=1308d843-337f-4fc4-8eb6-3e522553d217]
petstore_pet.pet: Destruction complete after 0s

Destroy complete! Resources: 1 destroyed.
```

This concludes the scenario. Don't forget to tear down the Petstore API with `terraform destroy`!

11.6 Fireside chat

In this chapter, we developed a custom Terraform Petstore provider (http://mng.bz/2zX0). The Petstore provider invokes a remote API with a client SDK written in golang. Instead of directly calling the API to provision resources, customers can now use Terraform to manage their pets as code.

Custom providers work best with micro APIs and self-service platforms. If you are a service owner, you probably already make your service available to customers through a RESTful API. Unfortunately, most customers do not want to go through the trouble of learning how to authenticate against an API and provision resources. This can lower the adoption rate of even a great self-service platform. By writing a Terraform provider for your API, you make it easy for people to start using your API with little or no knowledge of the API or underlying protocols and procedures.

Before ending the chapter, I want to cover some commonly asked questions about developing Terraform providers:

- *How do I create a data source?* See appendix E on this topic. It was omitted here for length reasons.
- *How do I publish providers?* There are a few steps to publishing a provider. First, you need to register the provider at `registry.terraform.io`. You also need