

Terraforming Cloud Platforms Student Manual



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1. Terraform refresher

Introduction to Terraform



Terraform is an open-source Infrastructure as Code (IaC) tool developed by HashiCorp, designed to enable users to define, provision, and manage infrastructure using declarative configuration files. By treating infrastructure as code, Terraform allows for version-controlled, automated, and repeatable deployments across various environments. It supports multiple cloud providers, including Azure, AWS, and Google Cloud, as

well as on-premises and hybrid infrastructure solutions. This flexibility makes Terraform an essential tool for organizations aiming to maintain consistency and scalability in their infrastructure management.

Key Features of Terraform

One of Terraform's core strengths is its Infrastructure as Code (IaC) approach, allowing infrastructure configurations to be written in code. This capability facilitates version control, peer reviews, and automated deployments, ensuring consistency across development, testing, and production environments. The declarative approach used by Terraform enables users to define the desired end state of infrastructure, while Terraform determines the necessary steps to achieve that state. Unlike imperative approaches that require step-by-step instructions, Terraform's declarative model simplifies infrastructure management by handling dependencies and order of execution automatically.

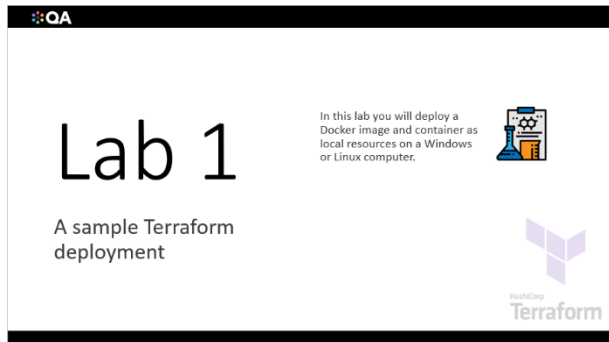
Another significant advantage is Terraform's multi-cloud support, which allows users to manage infrastructure across different cloud providers using a single configuration language. This feature eliminates the need for cloud-specific tooling, making it easier to implement hybrid or multi-cloud strategies. Terraform also ensures idempotency, meaning that running the same configuration multiple times results in the same infrastructure state without unintended changes. This behaviour is critical for maintaining consistency in large-scale environments and avoiding configuration drift.

Terraform Workflow

Terraform operates through a structured workflow consisting of four main stages: init, plan, apply, and destroy. The terraform init command initializes the working directory, downloading required providers and modules to set up the environment. The terraform plan command generates an execution plan, showing what changes will be made to align the current infrastructure state with the desired configuration. This step allows users to review and validate modifications before applying them. The terraform apply

command executes the planned changes, creating, updating, or deleting resources as defined in the configuration files. Finally, terraform destroy removes infrastructure resources when they are no longer needed, ensuring efficient resource cleanup and cost management.

Lab 1 Sample Deployment



This lab is intended as a refresher to Terraform and guides you through using it to interact with locally installed Docker. It (re)introduces providers, used to indicate the infrastructure that will be managed, and also the structure and composition of terraform files. You will review an example terraform file before initializing the client, planning, and then applying the deployment. You will then modify the deployment before eventually destroying it.

2. JSON Syntax Primer

Introduction to JSON in Terraform

JSON (JavaScript Object Notation) is a lightweight, text-based format used for data exchange between systems. It is widely adopted due to its simplicity and ease of parsing, making it a preferred format for automation and machine-readability. In Terraform, JSON serves as an alternative to HashiCorp Configuration Language (HCL), offering a more rigid structure that aligns well with programmatic automation, templating, and integrations with other tools. While HCL is more human-friendly due to its flexibility and readability, JSON is often used when Terraform configurations need to be dynamically generated or processed by external systems.

JSON Structure in Terraform

A JSON document is composed of key-value pairs, where keys must always be strings enclosed in double quotes, while values can be of different data types such as strings, numbers, booleans, arrays, objects, or null. Objects in JSON are enclosed within curly braces {} and hold multiple key-value pairs, while arrays are enclosed in square brackets [] and store an ordered collection of values. The hierarchical nature of JSON allows complex structures to be defined through nested objects and arrays. This characteristic is particularly useful in Terraform, as it enables detailed infrastructure configurations in a structured manner.

For example, defining an Azure Virtual Network in Terraform using JSON follows this format:

```
{
  "resource": {
    "azurerm_virtual_network": {
      "example": {
        "name": "example-vnet",
        "address_space": ["10.0.0.0/16"],
        "location": "East US",
        "resource_group_name": "example-resources"
      }
    }
  }
}
```

This structure clearly represents the hierarchical relationship between the resource type (`azurerm_virtual_network`), the unique identifier (`example`), and its associated configuration properties such as `name`, `address_space`, `location`, and `resource_group_name`.

Basic Syntax Rules

To ensure a valid JSON configuration, several syntax rules must be followed. First, all keys must be enclosed in double quotes. Second, values can be of different types, including strings, numbers, booleans, arrays, and objects, allowing flexibility in defining configurations. Third, commas are required to separate key-value pairs within objects and elements within arrays. Missing or misplaced commas often result in JSON parsing errors, making strict adherence to these rules essential.

Representation of Terraform Blocks in JSON

Terraform configurations rely on blocks to define infrastructure components such as resources, modules, and variables. While HCL represents blocks using a structured indentation format, JSON represents them as nested objects, maintaining the hierarchical relationship through proper nesting. For example, a module block in Terraform JSON is represented as an object within the "module" key, containing further nested properties that define its parameters.

Identifiers in JSON-based Terraform Configurations

Identifiers in Terraform JSON files serve as unique names assigned to resources, modules, and variables. These identifiers must be unique within their respective scope to prevent conflicts. For instance, in the previous example, "example" is an identifier for

the virtual network resource, distinguishing it from other virtual networks that may exist within the configuration.

Handling Comments in JSON

Unlike HCL, JSON does not natively support comments. This limitation requires developers to find alternative ways to document their configurations, such as using self-explanatory key names, maintaining separate documentation, or embedding metadata within objects. In situations where explanatory context is necessary, structured metadata fields within JSON objects can be used to store descriptive information.

Variables and their types in Terraform JSON

Terraform supports multiple variable types that allow dynamic customization of configurations. These include strings for text-based values, numbers for numeric entries, booleans for true/false logic, lists (arrays) for ordered collections of elements, and maps (objects) for key-value pairs. Variables in Terraform JSON are typically defined under the "variable" key, with each variable name as a sub-key. For example, defining an Azure Resource Group name as a variable in JSON follows this format:

```
{
  "variable": {
    "resource_group_name": {
      "default": "example-resources"
    }
  }
}
```

This structure allows the variable "resource_group_name" to be referenced dynamically within the configuration.

Arguments and Their Role in JSON-based Terraform Configurations

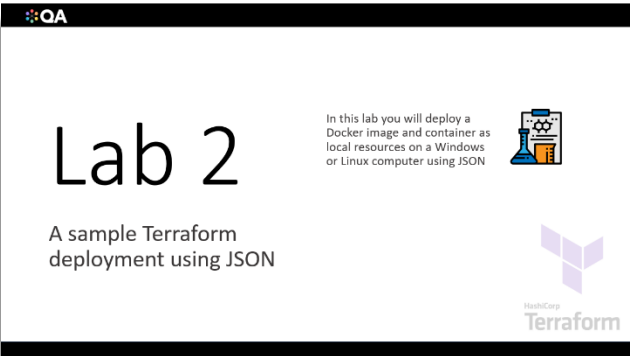
Arguments in Terraform JSON are key-value pairs used to configure the properties of resources. These arguments define essential attributes such as the name, address space, location, and resource group for a given resource. The following example illustrates how arguments are used within a Terraform JSON configuration for an Azure Virtual Network:

```
{
  "resource": {
    "azurerm_virtual_network": {
      "example": {
        "name": "example-vnet",
```

```
"address_space": ["10.0.0.0/16"],  
"location": "East US",  
"resource_group_name": "example-resources"  
}  
}  
}  
}
```

Each argument, such as "name" and "address_space", specifies configuration details required for proper deployment.


Lab 2 Using JSON formatted Terraform files




Lab 2

A sample Terraform deployment using JSON

In this lab you will deploy a Docker image and container as local resources on a Windows or Linux computer using JSON





This lab will compare a Terraform HCL (HashiCorp Configuration Language) configuration with a JSON formatted terraform file

3. Cloud Authentication Strategies

Overview

When using Terraform and automation tools in cloud environments, securely managing authentication credentials is critical. Cloud providers offer different authentication mechanisms and understanding when to use Service Principals (SPs) / Service Accounts versus Managed Identity offerings (or their equivalents) is essential.

Cloud authentication strategies must balance security, ease of management, and automation capabilities. Service Principals and Service Accounts are widely used for CI/CD pipelines and external clients, while Managed Identities, Instance Profiles, and Workload Identity Federation eliminate the need for credential management but are limited to internal workloads.

This module explores authentication best practices across Azure, AWS, and Google Cloud, comparing Service Principals vs. Managed Identities, discussing cloud-specific implementations, and providing recommendations for secure Terraform authentication.

Why Secure Authentication Matters in Terraform?

Terraform requires authentication credentials to provision cloud infrastructure. Hardcoding credentials in configuration files or environment variables introduces security risks, making systems vulnerable to credential leaks or unauthorized access. Using cloud-native authentication mechanisms ensures that credentials remain secure, minimizing manual management while enforcing access control policies.

Cloud providers offer native services for securely storing and retrieving authentication credentials, reducing exposure risks. These services allow Terraform to authenticate dynamically, eliminating static credential storage. Organizations must implement role-based access controls, least privilege principles, and audit logging to enforce security and compliance.

Understanding Cloud Authentication Models

Each major cloud provider offers two primary authentication models:

Service Principals / Service Accounts

Service Principals (Azure), IAM Users/Roles (AWS), and Service Accounts (Google Cloud) are used to authenticate applications, CI/CD pipelines, and external automation. These identities are non-human accounts that allow Terraform and other automation tools to authenticate securely.

To use a Service Principal or Service Account, a set of credentials is generated, usually consisting of an ID and secret key. These credentials must be stored securely, ideally in a secret management solution. The main advantage of this model is its flexibility, as Service Principals and Service Accounts can be used in any environment, including multi-cloud and hybrid setups.

However, one major drawback is credential management. Since these credentials do not automatically rotate, they must be manually rotated or stored in a system that supports automatic key rotation, such as Azure Key Vault, AWS Secrets Manager, or Google Cloud Secret Manager.

Managed Identities / Instance Profiles / Workload Identity Federation

Managed Identities (Azure), Instance Profiles (AWS), and Workload Identity Federation (Google Cloud) offer seamless authentication for workloads running inside the cloud provider's infrastructure. These services eliminate the need for storing or rotating credentials manually, as authentication happens transparently through IAM policies.

Managed Identities work by associating an identity with a cloud resource (such as a Virtual Machine or Function App). This identity is then granted the necessary permissions to authenticate with cloud services. Similarly, AWS Instance Profiles allow

EC2 instances and Lambda functions to assume roles with defined permissions, while Google's Workload Identity Federation enables Kubernetes workloads to authenticate without using long-lived credentials.

While these solutions significantly improve security by eliminating static credentials, they are limited in scope. They cannot be used for CI/CD pipelines, external clients, or cross-cloud automation. These solutions are ideal for internal cloud workloads but do not replace the need for Service Principals or Service Accounts in broader authentication use cases.

Cloud-Specific Implementations

Azure: Service Principals vs. Managed Identities

Azure provides two primary authentication mechanisms:

- **Service Principals (SPs):** Used for CI/CD pipelines, automation, and cross-cloud authentication. Requires explicit credential management.
- **Managed Identities:** Designed for internal workloads within Azure, eliminating the need for credential storage.

A Service Principal in Azure acts as an identity that Terraform, or other tools can use to authenticate with Azure resources. These are typically stored in Azure Key Vault for security. In contrast, Managed Identities are automatically handled by Azure Active Directory and can be assigned to Virtual Machines, App Services, and Kubernetes workloads without requiring explicit credentials.

AWS: IAM Users/Roles vs. Instance Profiles/Federated Identities

AWS offers authentication options tailored to specific use cases:

- **IAM Users & IAM Roles:** Equivalent to Service Principals, best suited for CI/CD pipelines and external automation.
- **Instance Profiles & IAM Roles for AWS Services:** Used for internal workloads, such as EC2 instances and Lambda functions.

For external automation, IAM Users or Roles can be configured with access keys that are stored securely in AWS Secrets Manager. For internal workloads, AWS recommends using Instance Profiles, where credentials are provided dynamically through AWS STS (Security Token Service), ensuring security, and reducing operational overhead.

Google Cloud: Service Accounts vs. Workload Identity Federation

Google Cloud provides:

- **Service Accounts:** Similar to Service Principals, used for CI/CD and external automation.
- **Workload Identity Federation:** Designed for internal Google Cloud workloads, removing the need for JSON keys.

Google Cloud Service Accounts work well for Terraform and automation but require proper key management practices to prevent exposure. Workload Identity Federation allows Kubernetes workloads to authenticate using external identity providers without requiring a stored key.

Secure Terraform Authentication Across Cloud Providers

Organizations should follow **best practices** to ensure Terraform authentication is secure:

1. **Store credentials securely** in a managed secret management solution (e.g., AWS Secrets Manager, Azure Key Vault, or Google Cloud Secret Manager).
2. **Use short-lived credentials** where possible (AWS STS, Google Workload Identity Federation) to reduce the attack surface.
3. **Enforce RBAC policies** to ensure Terraform only has access to necessary resources.
4. **Monitor and audit authentication events** to detect anomalies.

Terraform Authentication Configuration Examples

Each cloud provider supports retrieving authentication credentials dynamically

AWS Example using Secrets Manager

```
provider "aws" {
  access_key =
data.aws_secretsmanager_secret_version.access_key.secret_string
  secret_key =
data.aws_secretsmanager_secret_version.secret_key.secret_string
  region    = "us-east-1"
}
```

Azure Example using Key Vault

```
provider "azurerm" {
  client_id    = data.azurerm_key_vault_secret.client_id.value
  client_secret = data.azurerm_key_vault_secret.client_secret.value
  tenant_id    = data.azurerm_key_vault_secret.tenant_id.value
}
```

```
subscription_id = "your-subscription-id"
features {}
}
```

Google Cloud Example using Secret Manager

```
provider "google" {
  credentials = file(var.gcp_credentials)
  project    = "your-project-id"
  region     = "us-central1"
}
```

Recommendation

Organizations should use Service Principals, IAM Users, or Service Accounts for CI/CD and automation pipelines, ensuring that credentials are securely stored. Managed Identities, Instance Profiles, and Workload Identity Federation should be used for internal workloads to avoid credential management. Combining these authentication methods allows for a secure and scalable approach to Terraform and cloud automation.

Choosing the Right Credentials Storage

When managing Service Principal (SP) credentials for Terraform in a multi-developer environment, it is crucial to strike a balance between security, accessibility, and persistence. The table below outlines different ways to store credentials, each with distinct security implications. Below this, we explore these methods in more detail and discuss their applicability to secure SP usage across multiple developers.

Storage Methods for Service Principal (SP) Credentials

Storage Method	Persists ?	Scope	Requires Admin?
Temporary Environment Variables	No	Current session only	No
User Level Environment Variables	Yes	Only current user	No
Machine Level Environment Variables	Yes	System-wide	Yes
PowerShell/Bash Script ()	No	Run manually	No
.env File	No	Run manually	No
Azure Key Vault	Yes	Centralized, cloud-managed	No

AWS Secrets Manager	Yes	Centralized, cloud-managed	No
GCP Secret Manager	Yes	Centralized, cloud-managed	No

Session-Only Environment Variables (Temporary Variables)

Method: Exporting credentials dynamically into environment variables via shell commands (e.g., `export VAR_NAME="value"` in Bash, `env:VAR_NAME = "value"` in PowerShell) or using cloud SDK authentication commands.

Example:

- **Bash:** `export ARM_CLIENT_ID=<client_id>`
- **PowerShell:** `$env:ARM_CLIENT_ID = "<client_id>"`
- **Azure CLI:** `az login --service-principal -u <client_id> -p <client_secret> --tenant <tenant_id>`
- **AWS CLI:** `aws configure set aws_access_key_id <access_key>`
- **GCP CLI:** `gcloud auth application-default login`

Security Considerations: This is a safe approach for short-term use because credentials disappear when the session ends. However, it does not scale well for multiple developers, as each developer must manually re-enter the credentials in each session

Best for: One-time, ad-hoc Terraform authentication where security is a priority over convenience.

User-Level Persistent Variables

Method: Storing credentials persistently for an individual user using environment variables.

Example:

- **Bash:** `echo 'export ARM_CLIENT_ID="<client_id>"' >> ~/.bashrc`
- **PowerShell:** `[System.Environment]::SetEnvironmentVariable("ARM_CLIENT_ID", "<client_id>", "User")`

Security Considerations: This method provides better usability but has some security risks. While credentials are stored in the Windows environment, they may be accessible to scripts or malware running under the same user account. If a developer's machine is compromised, credentials could be exposed.

Best for: Individual developers who need persistent credentials without affecting other users.

Machine-Level Persistent Variables

Method: Storing credentials system-wide for all users.

Example:

- **Bash:** `echo 'export ARM_CLIENT_ID="<client_id>" | sudo tee -a /etc/environment`
- **PowerShell (Admin):**
`[System.Environment]::SetEnvironmentVariable("ARM_CLIENT_ID", "<client_id>", "Machine")`

Security Considerations: High-risk method unless tightly controlled. If a machine is compromised, all users can access the credentials, making this an attractive target for attackers. This should only be used in hardened, dedicated build servers where access is restricted.

Best for: CI/CD pipelines or Terraform automation servers. Not recommended for individual developer machines.

Cloud-Specific Authentication Methods (Recommended for Teams)

Method: Using cloud-native secret storage solutions to securely store and retrieve credentials dynamically.

Example:

- **Azure Key Vault:** `az keyvault secret show --name "SP-SECRET" --vault-name "MyKeyVault"`
- **AWS Secrets Manager:** `aws secretsmanager get-secret-value --secret-id MySecret`
- **GCP Secret Manager:** `gcloud secrets versions access latest --secret=MY_SECRET`

Security Considerations: Credentials are stored securely in a managed vault, but using this method requires additional permissions and infrastructure setup to ensure proper access control and governance.

Best for: Teams needing a secure and scalable solution for multi-developer environments.

PowerShell/Bash Script Authentication

Method: Using a script to dynamically set environment variables for authentication.

Example:

- **PowerShell:** set-env.ps1

```
$env:ARM_CLIENT_ID = "<client_id>"  
$env:ARM_CLIENT_SECRET = "<client_secret>"
```

- **Bash:** set-env.sh

```
export ARM_CLIENT_ID="<client_id>"  
export ARM_CLIENT_SECRET="<client_secret>"
```

Security Considerations: Since credentials are not stored permanently, this method is more secure than persistent environment variables. However, developers must ensure that the script itself is not compromised and should avoid committing it to version control (e.g., use .gitignore).

Best for: Teams that need a repeatable but temporary way to authenticate Terraform.

.env File (Manually Loaded)

Method: Storing credentials in a plaintext .env file that can be sourced when needed.

Example:

- .env file:

```
ARM_CLIENT_ID=<client_id>  
ARM_CLIENT_SECRET=<client_secret>
```

- **Bash:** **source .env**
- **PowerShell:** **Get-Content .env | ForEach-Object { \$name, \$value = \$_.split("="); Set-Item -Path env:\$name -Value \$value }**

Security Considerations: If an .env file is leaked, an attacker can obtain full access to the Service Principal. This method should only be used in controlled environments where access to the file is strictly restricted. An alternative is to store .env files in a secure secrets management tool (e.g., Azure Key Vault, AWS Secrets Manager).

Best for: CI/CD pipelines where strict file security is enforced. Never use in shared development environments.

Choosing the Best Approach for Multi-Developer Access

For Individual Developers:

- Use **User-Level Persistent Variables** for convenience.
- Use a **PowerShell/Bash Script** for better security.

For Teams in a Shared Environment:

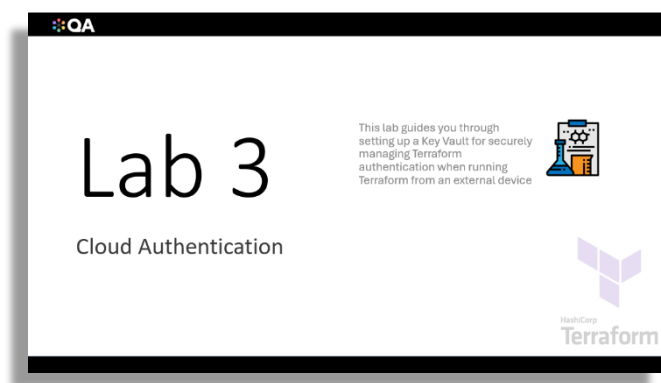
- Use **Cloud-Native Secret Management (Azure Key Vault, AWS Secrets Manager, GCP Secret Manager)** to centrally store and retrieve credentials.
- Avoid **Machine-Level Persistent Variables**, unless in a dedicated CI/CD machine.

For CI/CD Pipelines:

- Use **Machine-Level Persistent Variables** or dynamically inject secrets from a secure store.
- Avoid .env files unless strict access controls are enforced.

By leveraging cloud-native authentication and dynamic credential retrieval, teams can enhance security while maintaining ease of access in Terraform workflows.

Lab 3 Cloud Authentication



This lab guides you through setting up a Cloud specific Key Vault for securely managing Terraform authentication when running Terraform from an external device

4. Modules, Templates and Code Re-use

Introduction to Terraform Modules

Modules in Terraform are self-contained packages of Terraform configurations that help organize and manage infrastructure by grouping related resources together. A module can consist of multiple Terraform configuration files, including resources, input variables, output values, and even nested sub-modules. By using modules, infrastructure teams can standardize deployments, improve reusability, and simplify complex configurations. Instead of defining similar infrastructure components repeatedly across different projects, modules allow teams to write configuration once and reuse it efficiently.

Benefits of Using Modules

Terraform modules offer several key advantages. One of the primary benefits is reusability, as modules can be utilized across multiple projects, reducing the need to rewrite code for similar infrastructure components. This not only saves time but also enhances maintainability. Consistency is another major advantage, as standardizing module configurations minimizes the risk of configuration drift, ensuring that infrastructure remains uniform across different environments. Additionally, modules contribute to simplification by breaking down complex configurations into smaller, manageable components, making it easier to understand, test, and troubleshoot infrastructure code.

Structure of a Terraform Module

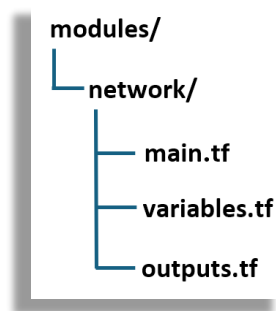
A basic Terraform module typically consists of three primary files:

`main.tf` – Defines the resources and configurations within the module.

`variables.tf` – Declares input variables that allow customization of the module.

`outputs.tf` – Defines output values, which can be referenced by other modules or configurations.

A typical directory structure for a module looks like this:



This structure ensures clear separation of concerns, making it easy to reuse, update, and manage the module.

Creating a Simple Terraform Module

To illustrate how modules work, consider a module that provisions an Azure Virtual Network.

Defining the Module

In the **main.tf** file, the virtual network is created using input variables for flexibility:

```
resource "azurerm_virtual_network" "vnet" {
```

```
name = var.vnet_name
address_space = var.address_space
location = var.location
resource_group_name = var.resource_group_name
}
```

The **variables.tf** file defines the necessary input parameters:

```
variable "vnet_name" {}
variable "address_space" {}
variable "location" {}
variable "resource_group_name" {}
```

The **outputs.tf** file provides an output value, making the virtual network ID accessible to other configurations:

```
output "vnet_id" {
  value = azurerm_virtual_network.vnet.id
}
```

Using the Module in a Root Configuration

Modules are referenced in a root Terraform configuration using the module block. The example below shows how the previously created module can be used in main.tf:

```
module "network" {
  source      = "../modules/network"
  vnet_name   = "example-vnet"
  address_space = ["10.0.0.0/16"]
  location    = "East US"
  resource_group_name = "example-resources"
}
```

Input and Output Variables in Modules

Terraform modules support input variables, which allow customization based on different environments or requirements. These variables enable users to pass values dynamically instead of hardcoding them within the module. Output variables are used to expose key information, such as resource IDs, so that other modules or configurations can reference them. Properly structuring input and output variables enhances module flexibility and interoperability.

Versioning and Module Sources

Terraform supports different methods for sourcing modules, enabling flexibility in how they are referenced and maintained:

Local Modules – Referenced using relative paths (e.g., ./modules/network), typically used within a single project.

Remote Modules – Hosted in Terraform Registry, GitHub, or private repositories, allowing for better version control and sharing across teams.

Best Practices – Using version constraints (version = ">= 1.0.0") helps manage updates and ensures module stability without unexpected changes.

Introduction to Templates in Terraform

Terraform also supports templates, which allow for the dynamic generation of content such as configuration files, resource names, and startup scripts. By using templates, users can reduce redundancy and enhance the adaptability of Terraform configurations. Templates work well for generating instance initialization scripts, custom resource names, or structured configuration files.

Working with the templatefile Function

The templatefile function in Terraform reads a template file and replaces placeholders with variable values. This is particularly useful when configuring virtual machines, as it allows user-defined startup scripts to be passed dynamically.

For example, consider the following template file init.tmpl that sets a hostname and displays a welcome message:

```
#!/bin/bash
hostnamectl set-hostname ${hostname}
echo "Welcome to ${environment} environment" > /etc/motd
```

The corresponding Terraform configuration would use the templatefile function to substitute variables:

```
resource "azurerm_virtual_machine" "example" {
  name           = "example-vm"
  location       = var.location
  resource_group_name = var.resource_group_name
  vm_size        = "Standard_DS1_v2"

  os_profile {
    computer_name = "example"
    admin_username = "azureuser"
```

```

    custom_data = templatefile("init.tmpl", {
      hostname = "example-vm"
      environment = "production"
    })
  }
}

```

This setup ensures that when the VM is created, it receives a unique hostname and a customized welcome message.

Template Variables and Interpolation

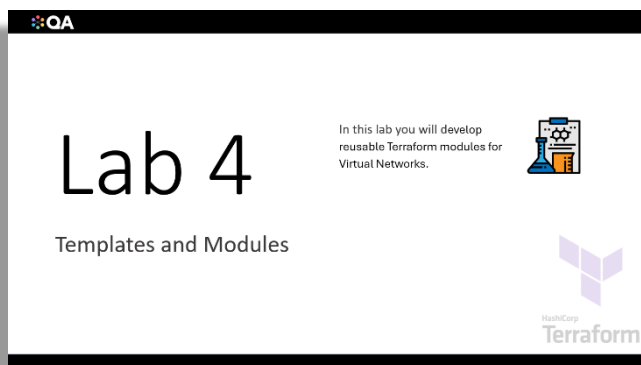
Terraform templates use interpolation to insert variable values dynamically. Placeholders are defined using the `${}` syntax, allowing the inclusion of both simple and complex data types, such as strings, lists, and maps. This method enhances modularity and prevents hardcoded values from being embedded directly in Terraform configurations.

Best Practices for Using Modules and Templates

To maximize the effectiveness of Terraform modules and templates, consider the following best practices:

- Use consistent naming conventions for variables to maintain clarity across different modules.
- Keep templates and modules modular and organized, separating resources logically to improve maintainability.
- Document complex templates and modules to facilitate better collaboration within teams.
- Store modules and templates in version-controlled repositories, such as GitHub or a private registry, ensuring proper tracking and collaboration.

Lab 4 Modules and Templates



The slide features a black header with the 'QA' logo. The main content area has a white background with the text 'Lab 4' in a large, bold font, followed by 'Templates and Modules' in a smaller font. A small icon of a beaker and test tube is positioned to the right of the text. At the bottom right, the 'HashiCorp Terraform' logo is displayed.

In this lab you will develop reusable Terraform modules for Virtual Networks. You will parameterize the module using variables and reuse the module with different parameters.

5. Implementing Checks and Validations in Terraform

Introduction

Ensuring infrastructure as code (IaC) deployments adhere to organizational policies and best practices is crucial in cloud environments. Terraform provides mechanisms to enforce validation rules at different stages of the deployment process, preventing misconfigurations and ensuring compliance. This chapter explores input validation, precondition and postcondition checks, post-deployment validation, and external policy enforcement using HashiCorp Sentinel.

Input Validation in Terraform

Input validation ensures that variable values meet specific criteria before Terraform executes a plan or applies changes. It prevents invalid configurations from being deployed, reducing the risk of failure and misconfiguration.

Example: Validating Naming Conventions

Terraform allows validation rules to be applied to input variables using the validation block:

```
variable "resource_group_name" {
  description = "Name of the resource group."
  type       = string
  validation {
    condition = can(regex("^RG-[1-6]$", var.resource_group_name))
    error_message = "Resource group name must be RG- followed by a number from 1 to 6."
  }
}
```

This ensures that the resource group name follows the required naming convention (RG-1 to RG-6).

Example: Enforcing Region Selection

```
variable "location" {
  description = "Cloud region for resource deployment."
  type       = string
  validation {
    condition = contains(["us-east-1", "us-west-2", "eu-west-1"], var.location)
  }
}
```

```

        error_message = "Location must be one of the predefined regions."
    }
}

```

This condition restricts users to specific cloud regions, ensuring compliance with organizational policies.

Preconditions and Postconditions in Terraform

Terraform allows additional validation through precondition and postcondition blocks, enabling checks at runtime to enforce constraints before and after resource creation.

Example: Ensuring a Storage Account Follows Naming Standards

```

resource "azurerm_storage_account" "example" {
  name                = var.storage_account_name
  resource_group_name = var.resource_group_name
  location            = var.location
  account_tier        = "Standard"
  account_replication_type = "LRS"

  lifecycle {
    precondition {
      condition = startswith(var.storage_account_name, "stg")
      error_message = "Storage account name must start with 'stg'."
    }
    postcondition {
      condition = length(self.name) <= 24
      error_message = "Storage account name must be 24 characters or fewer."
    }
  }
}

```

This configuration enforces naming policies and prevents Terraform from creating resources that violate those rules.

Post-Deployment Validation

Validation should not stop at Terraform's internal mechanisms. Some misconfigurations may only become evident after deployment. Cloud platforms provide policy enforcement tools that can be used in combination with Terraform.

Example: Using Policy for Post-Deployment Checks

Cloud policy mechanisms can be used to enforce resource compliance after deployment. For example, Azure Policy can check for compliance and, if a resource violates policy, the deployment is rejected or flagged for review.

```
{
  "properties": {
    "displayName": "Enforce Storage Account Naming Policy",
    "policyType": "Custom",
    "mode": "All",
    "parameters": {},
    "policyRule": {
      "if": {
        "allOf": [
          {
            "field": "name",
            "notLike": "stg*"
          },
          {
            "field": "type",
            "equals": "Microsoft.Storage/storageAccounts"
          }
        ]
      },
      "then": {
        "effect": "deny"
      }
    }
  }
}
```

This ensures that all storage accounts conform to naming conventions, even if Terraform validation was bypassed.

Enforcing Policy with HashiCorp Sentinel

HashiCorp Sentinel is a policy-as-code framework that provides fine-grained control over Terraform deployments. It allows organizations to define rules that must be met before Terraform applies any changes.

Example: Sentinel Policy to Restrict VM Naming

```
import "tfplan/v2" as tfplan
```

```

main = rule {
  all tfplan.resources.azurearm_virtual_machine as _, instances {
    all instances as _, r {
      r.name matches "^VM[1-6]$"
    }
  }
}

```

This policy ensures that virtual machines are named according to the VM1 to VM6 format.

Preventing Policy Bypass

One challenge of using validation within Terraform files is that developers can modify the rules. To prevent policy bypass, organizations should enforce governance through:

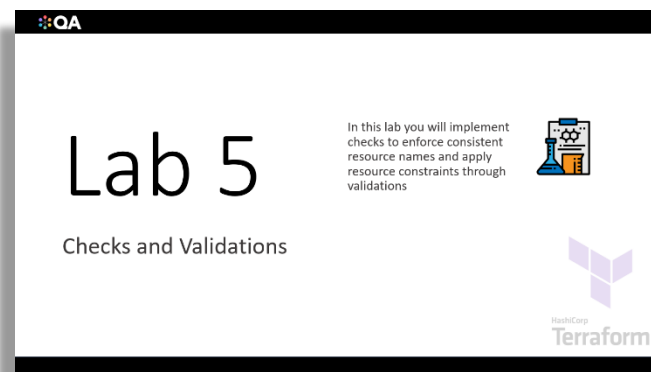
- **Terraform Cloud/Enterprise Sentinel Policies:** Ensuring policies run at the organization level.
- **Azure Policy, AWS Config Rules, or GCP Organization Policies:** Blocking non-compliant resources at the cloud provider level.
- **Code Reviews and Change Management:** Implementing peer reviews before merging infrastructure changes.

Best Practise

Implementing checks and validations in Terraform improves security, consistency, and governance of cloud deployments. By combining Terraform's built-in validation, cloud-native policy enforcement, and external policy frameworks like Sentinel, organizations can ensure that their infrastructure remains compliant and robust.

- Use Terraform variable validation to enforce input constraints.
- Apply precondition and postcondition checks to validate resources dynamically.
- Implement post-deployment checks using cloud-native policies (Azure Policy, AWS Config, GCP Organization Policies).
- If available, use Sentinel for policy-as-code enforcement at the organization level.
- Combine validation strategies to prevent misconfigurations and unauthorized changes.

Lab 5 Checks and Validations



This lab takes you through deploying resources whilst enforcing naming and policy constraints

6. Dynamic Terraform Configurations: Expressions, Loops, and Functions

Introduction

Expressions, conditional logic, loops, dynamic blocks, and built-in functions provide powerful mechanisms for writing efficient and reusable Terraform configurations. By leveraging these capabilities, you can create adaptable infrastructure templates that respond dynamically to different environments, input parameters, and deployment scenarios.

Terraform provides a rich set of features for dynamically configuring infrastructure, enabling modular, reusable, and efficient deployments. Expressions, conditional logic, loops, dynamic blocks, and built-in functions allow Terraform configurations to adapt based on input variables, compute derived values, and simplify complex configurations. This chapter explores these capabilities, illustrating their applications in Terraform-based infrastructure management

Expressions in Terraform

Expressions in Terraform enable configurations to be flexible and data-driven. Instead of hardcoding values, users can compute values dynamically using variables, functions, and resource attributes.

Types of Expressions

- **Literal expressions:** Directly define static values, e.g., "eastus", 10, true.
- **Interpolation expressions:** Use `${}` syntax to reference variables and functions, e.g., `${var.location}`.

- **Computed expressions:** Combine values dynamically, e.g., `${var.instance_type == "prod" ? "Standard_D4_v2" : "Standard_B2s"}`.
- **Complex expressions:** Use built-in functions for data manipulation, such as `join()`, `split()`, and `regex()`.

Conditional Expressions

Conditional expressions allow configurations to be dynamic based on specific conditions. The syntax follows: `condition ? true_value : false_value`

Example: Setting an Instance Type Based on Environment

```
output "instance_type" {
  value = var.env == "prod" ? "Standard_D4_v2" : "Standard_B2s"
}
```

If `var.env` is "prod", Terraform assigns "Standard_D4_v2"; otherwise, it defaults to "Standard_B2s". This technique is useful for adjusting configurations based on environment-specific settings without modifying the code manually.

Example: Toggling Resource Creation

```
resource "azurerm_virtual_machine" "example" {
  count = var.create_vm ? 1 : 0
  name = "example-vm"
}
```

Terraform only creates the VM if `var.create_vm` is true.

Loops in Terraform

Terraform provides two looping mechanisms for dynamically generating multiple resources:

Using `for_each`

The `for_each` loop iterates over maps and sets.

```
variable "vm_names" {
  type = set(string)
  default = ["vm1", "vm2", "vm3"]
}

resource "azurerm_virtual_machine" "example" {
  for_each = var.vm_names
  name     = each.key
}
```

```
}
```

Terraform creates a separate VM for each name in `vm_names`.

Using count

The `count` parameter controls how many instances of a resource are created, indexed numerically.

```
variable "storage_count" {  
  default = 3  
}  
  
resource "azurerm_storage_account" "example" {  
  count = var.storage_count  
  name = "storage${count.index}"  
}
```

Terraform creates three storage accounts (`storage0`, `storage1`, `storage2`).

Dynamic Blocks in Terraform

Dynamic blocks generate nested configurations dynamically based on input data.

Syntax of a Dynamic Block

```
dynamic "block_name" {  
  for_each = variable_or_list  
  content {  
    attribute = block_name.value.key  
  }  
}
```

Example: Assigning Multiple Security Rules Dynamically

```
variable "security_rules" {  
  type = list(object({  
    name     = string  
    priority = number  
    direction = string  
  }))  
  default = [  
    { name = "allow-ssh", priority = 100, direction = "Inbound" },  
    { name = "allow-http", priority = 200, direction = "Inbound" }  
  ]  
}
```

```

resource "azurerm_network_security_group" "example" {
  name = "example-nsg"

  dynamic "security_rule" {
    for_each = var.security_rules
    content {
      name      = security_rule.value.name
      priority  = security_rule.value.priority
      direction = security_rule.value.direction
    }
  }
}

```

This generates security rules dynamically based on input data.

Common Functions in Terraform

Terraform includes various built-in functions to manipulate and transform data. These functions are categorized into:

String Functions

join(separator, list): Concatenates elements with a separator.

```

output "joined_names" {
  value = join("-", ["azure", "resource", "group"])
}

```

Output: "azure-resource-group"

split(separator, string): Splits a string into a list.

```

output "split_names" {
  value = split("-", "azure-resource-group")
}

```

Output: ["azure", "resource", "group"]

Numeric Functions

max() and min(): Return the maximum or minimum value.

```

output "max_value" {
  value = max(10, 20, 15)
}

```

Output: 20

Date/Time Functions

timestamp(): Returns the current UTC time in ISO 8601 format.

```
output "current_timestamp" {  
  value = timestamp()  
}
```

Output: "2025-02-17T12:00:00Z" (example output)

Filesystem Functions

file(filepath): Reads the content of a specified file.

```
output "file_content" {  
  value = file("./config.txt")  
}
```

This function is useful for injecting configuration data into Terraform resources.

Regular Expressions (Regex) in Terraform

Regular expressions (Regex) are powerful string-matching patterns used for searching, extracting, and manipulating text. They allow Terraform users to define complex search criteria to validate input, extract values, or transform text dynamically. Regex is particularly useful in scenarios where resource names follow a structured pattern, and users need to enforce consistency or extract meaningful segments from text-based attributes.

Terraform supports regex functions that help match and process strings based on defined patterns. These functions provide flexibility in handling data, ensuring that configurations adhere to expected formats and reducing manual string manipulation efforts.

These examples demonstrate how regex functions can be applied to extract structured information, validate input, and enforce naming conventions dynamically in Terraform.

Extracting a numerical ID from a resource name

```
output "resource_id" {  
  value = regex("id-(\d+)", "resource-id-12345")  
}
```

Output: "12345"

Validating an email format

```
output "is_valid_email" {
```

```
value = can(regex("^[a-zA-Z0-9._%+-]+@[a-zA-Z0-9.-]+\.[a-zA-Z]{2,}$",
"user@example.com"))
}
```

Output: true

Extracting multiple region names from a string

```
output "regions" {
  value = regexall("(us-east-1|us-west-2|eu-central-1)", "deploy-us-east-1-us-west-2")
}
```

Output: ["us-east-1", "us-west-2"]

Extract the first match of a pattern with regex

```
output "environment" {
  value = regex("(prod|dev|test)", "stg-prod-finance-eastus")
}
```


Output: "prod"

Extracting all matches with regexall

```
output "all_matches" {
  value = regexall("(eastus|westus|centralus)", "prod-finance-eastus-westus")
}
```

Output: ["eastus", "westus"]



Lab 6 Expression and Dynamic Blocks



Lab 6

Expression and Dynamic Blocks

In this lab you will use expressions, dynamic blocks, Terraform functions, and regular expressions to create flexible and reusable infrastructure configurations



HashiCorp
Terraform

In this lab you will use expressions, dynamic blocks, Terraform functions, and regular expressions to create flexible and reusable infrastructure configurations

7. Administering Cloud BLOB Storage

Introduction

Object storage is designed to store large volumes of unstructured data, such as media files, documents, backups, and logs. It provides scalability, durability, and cost-effective storage, making it ideal for applications that require efficient handling of massive datasets. Most major cloud providers offer object storage solutions, including AWS S3, Azure Blob Storage, and Google Cloud Storage (GCS). While their implementations vary slightly, they share common concepts such as storage accounts, containers/buckets, objects (blobs), access tiers, and lifecycle policies.

Overview of Object Storage in AWS, Azure, and Google Cloud

Each cloud provider has its own implementation of object storage, but they follow a similar structure:

Concept	AWS S3	Azure Blob Storage	Google Cloud Storage (GCS)
Storage Account	S3 Bucket	Storage Account	GCS Bucket
Container	N/A (S3 uses flat storage)	Storage Container	N/A (GCS uses flat storage)
Object Types	Objects (Standard, Intelligent-Tiering, Glacier)	Blobs (Block, Append, Page)	Objects (Standard, Nearline, Coldline, Archive)
Access Tiers	Standard, IA, Glacier	Hot, Cool, Archive	Standard, Nearline, Coldline, Archive
Replication	Cross-Region, Same-Region	LRS, GRS, RA-GRS	Multi-Region, Dual-Region, Regional

Despite these differences, Terraform provides a consistent way to define and manage object storage across these providers.

Key Features of Cloud Object Storage

All cloud object storage services support:

- Scalability & Durability – Designed to handle petabytes of data with automatic redundancy.
- Access Tiers – Optimize storage costs based on how frequently data is accessed.
 - Frequent Access: AWS S3 Standard, Azure Hot, GCP Standard
 - Infrequent Access: AWS S3 IA, Azure Cool, GCP Nearline
 - Archival Storage: AWS Glacier, Azure Archive, GCP Archive
- Replication – Ensures high availability by copying data across regions.

- AWS: Cross-Region Replication (CRR) and Same-Region Replication (SRR)
- Azure: LRS (Local), GRS (Geo-Redundant), RA-GRS (Read-Access GRS)
- GCP: Multi-Region, Dual-Region, Regional storage classes

Provisioning Object Storage with Terraform

Terraform enables cloud-agnostic infrastructure provisioning. Below are equivalent Terraform configurations for AWS S3, Azure Blob Storage, and GCP Cloud Storage.

AWS S3 Example

```
resource "aws_s3_bucket" "example" {  
  bucket = "example-bucket"  
  acl    = "private"  
}  
  
resource "aws_s3_bucket_versioning" "example" {  
  bucket = aws_s3_bucket.example.id  
  versioning_configuration {  
    status = "Enabled"  
  }  
}
```

This configuration provisions an S3 bucket with versioning enabled to track object changes over time.

Azure Blob Storage Example

```
resource "azurerm_storage_account" "example" {  
  name = "examplestorageacct"  
  resource_group_name = "example-resources"  
  location = "East US"  
  account_tier = "Standard"  
  account_replication_type = "LRS"  
}  
  
resource "azurerm_storage_container" "example" {  
  name = "example-container"  
  storage_account_name = azurerm_storage_account.example.name  
  container_access_type = "private"  
}
```

Here, we define an Azure Storage Account and a private Blob Storage container.

Google Cloud Storage Example

```
resource "google_storage_bucket" "example" {  
  name = "example-bucket"  
  location = "US"  
  storage_class = "STANDARD"  
  versioning {  
    enabled = true  
  }  
}
```

This defines a Google Cloud Storage bucket with versioning enabled.

Managing Object Storage Configurations Across Clouds

All providers offer additional configuration options, including versioning, access policies, and lifecycle management.

Versioning

Versioning helps track changes and prevent accidental deletions.

- **AWS S3:** Enabled using `aws_s3_bucket_versioning`
- **Azure Blob Storage:** Managed through `azurerm_storage_management_policy`
- **Google Cloud Storage:** Controlled via `versioning { enabled = true }` in the bucket configuration

Access Policies and Security

Securing object storage is critical. SAS tokens (Azure), IAM policies (AWS), and Signed URLs (GCP) are commonly used for controlled access.

Example: AWS S3 Bucket Policy for Restricted Access

```
resource "aws_s3_bucket_policy" "example" {  
  bucket = aws_s3_bucket.example.id  
  policy = <<EOF  
{  
  "Version": "2012-10-17",  
  "Statement": [  
    {  
      "Effect": "Allow",  
      "Principal": "*",  
      "Action": "s3:GetObject",
```

```

        "Resource": "arn:aws:s3:::example-bucket/*"
    }
]
}
EOF
}

```

This policy allows public read access to objects in an S3 bucket.

Lifecycle Management

Object storage lifecycle policies help optimize costs by automatically transitioning objects between storage classes or deleting them after a set period.

AWS S3 Lifecycle Rule: Move Objects to Glacier After 30 Days

```

resource "aws_s3_bucket_lifecycle_configuration" "example" {
    bucket = aws_s3_bucket.example.id

    rule {
        id   = "move-to-glacier"
        status = "Enabled"

        transition {
            days      = 30
            storage_class = "GLACIER"
        }
    }
}

```

Azure Blob Storage Lifecycle Policy: Delete Blobs After 30 Days

```

resource "azurerm_storage_management_policy" "example" {
    storage_account_id = azurerm_storage_account.example.id

    rule {
        name = "expire-old-blobs"
        enabled = true

        filters {
            blob_types = ["blockBlob"]
        }

        actions {
            base_blob {

```

```

        delete_after_days_since_modification_greater_than = 30
    }
}
}
}

```

GCP Cloud Storage Lifecycle Rule: Delete Objects After 30 Days

```

resource "google_storage_bucket" "example" {
  name     = "example-bucket"
  location = "US"
  storage_class = "STANDARD"

  lifecycle_rule {
    action {
      type = "Delete"
    }
    condition {
      age = 30
    }
  }
}

```

Lab 7 Managing Object Storage

QA

The lab will guides you through provisioning and managing cloud object storage.

Lab 7

Managing Object
storage

In this lab you will create,
manage and control access to
object storage resources



8. Administering Cloud RDBMS

Introduction

Relational databases (RDBMS) store structured data using tables with relationships defined between them. They support SQL-based queries for efficient data retrieval, manipulation, and transaction handling. Cloud providers offer fully managed RDBMS services, which automate database provisioning, backups, scaling, and security,

reducing administrative overhead. The most widely used cloud-based relational database services include AWS RDS, Azure SQL Database, and Google Cloud SQL, each providing built-in high availability, scalability, and advanced security features.

Overview of RDBMS Offerings in AWS, Azure, and Google Cloud

Each cloud provider offers managed relational database services with similar capabilities:

Feature	AWS RDS	Azure SQL Database	Google Cloud SQL
Database Engine Support	MySQL, PostgreSQL, SQL Server, MariaDB, Oracle	SQL Server (only)	MySQL, PostgreSQL, SQL Server
High Availability	Multi-AZ Deployments	Geo-Replication, Zone Redundancy	High-Availability Configuration
Scalability	Read Replicas, Auto Scaling	Elastic Pools, Serverless	Read Replicas, Auto Scaling
Security Features	IAM Authentication, Encryption, Security Groups	Threat Detection, Encryption, Firewall Rules	IAM Authentication, Encryption, Private IP

Despite variations, Terraform provides a consistent way to deploy and manage relational databases across these platforms.

Key Features of Cloud RDBMS Solutions

Managed relational databases in AWS, Azure, and GCP provide:

- High Availability & Redundancy – Ensuring minimal downtime through multi-zone replication.
- Scalability – Options for vertical scaling (upgrading instance sizes) and horizontal scaling (read replicas, sharding).
- Security & Compliance – Features like encryption at rest & in transit, IAM-based authentication, and firewall rules to restrict access.
- Automated Backups – Scheduled and on-demand backups for disaster recovery.

Provisioning Relational Databases with Terraform

Terraform allows cloud-agnostic provisioning of relational databases. Below are equivalent configurations for AWS RDS, Azure SQL Database, and GCP Cloud SQL.

AWS RDS Example

```
resource "aws_db_instance" "example" {
  identifier = "example-db"
  engine    = "mysql"
  instance_class = "db.t3.micro"
```

```

    allocated_storage = 20
    username = "admin"
    password = "P@ssword1234!"
    publicly_accessible = false
    skip_final_snapshot = true
}

```

This provisions an Amazon RDS MySQL database with private access.

Azure SQL Database Example

```

resource "azurerm_sql_server" "example" {
  name = "example-sqlserver"
  resource_group_name = var.resource_group_name
  location = var.location
  version = "12.0"
  administrator_login = "sqladmin"
  administrator_login_password = "P@ssword1234!"
}

```

```

resource "azurerm_sql_database" "example" {
  name = "example-db"
  resource_group_name = var.resource_group_name
  location = var.location
  server_name = azurerm_sql_server.example.name
  sku_name = "Basic"
}

```

This deploys an Azure SQL Database under an SQL Server instance.

Google Cloud SQL Example

```

resource "google_sql_database_instance" "example" {
  name = "example-db"
  database_version = "MYSQL_8_0"
  region = "us-central1"
  settings {
    tier = "db-f1-micro"
  }
}

resource "google_sql_database" "example" {
  name = "example-db"
  instance = google_sql_database_instance.example.name
}

```

```
}
```

This Terraform configuration sets up a Cloud SQL MySQL database in Google Cloud.

Database Configuration and Management

All cloud providers offer configurations to enhance database security, access control, and performance optimization.

Firewall Rules and Network Security

Restricting database access is essential for security. AWS, Azure, and GCP allow firewall-based access control.

AWS RDS Security Group Rule (Restrict to Specific IPs)

```
resource "aws_security_group_rule" "allow_db_access" {  
  type = "ingress"  
  from_port = 3306  
  to_port = 3306  
  protocol = "tcp"  
  cidr_blocks = ["192.168.1.0/24"]  
}
```

Azure SQL Firewall Rule (Allowing Specific IP Ranges)

```
resource "azurerm_sql_firewall_rule" "example" {  
  name = "AllowMyIP"  
  resource_group_name = var.resource_group_name  
  server_name = azurerm_sql_server.example.name  
  start_ip_address = "0.0.0.0"  
  end_ip_address = "255.255.255.255"  
}
```

GCP Cloud SQL Authorized Networks (Restricting Access to an IP Range)

```
resource "google_sql_user" "example" {  
  name = "admin"  
  instance = google_sql_database_instance.example.name  
  password = "P@ssword1234!"  
}
```

```
resource "google_sql_database_instance" "example" {  
  settings {  
    ip_configuration {  
      authorized_networks {  
        value = "192.168.1.0/24"  
      }  
    }  
  }  
}
```

```
}  
}  
}
```

These configurations ensure that only authorized networks can access the database.

Monitoring & Auditing

Database auditing helps track user activity and detect security threats.

AWS RDS Enhanced Monitoring

```
resource "aws_db_instance" "example" {  
  monitoring_interval = 60  
}
```

Azure SQL Database Auditing Policy

```
resource "azurerm_sql_database_extended_auditing_policy" "example" {  
  database_id = azurerm_sql_database.example.id  
  storage_endpoint =  
    azurerm_storage_account.example.primary_blob_endpoint  
  retention_in_days = 30  
}
```

GCP Cloud SQL Logging & Monitoring

```
resource "google_logging_project_sink" "example" {  
  name = "example-sql-logs"  
  destination =  
    "storage.googleapis.com/${google_storage_bucket.example.name}"  
}
```

These configurations help track database performance, detect anomalies, and meet compliance requirements.

Lab 8 Deploying and Managing RDBMS

QA

The lab will guide you through deploying and managing a cloud hosted RDBMS solution and perform a database migration.

Lab 8

Deploy and Manage
RDBMS

In this lab you will build a VM-hosted RDBMS solution and perform a database migration



9. Bonus Module - Kubernetes Management with Terraform

Introduction

Kubernetes is an open-source platform for orchestrating and managing containerized applications. It simplifies deployment, scaling, and operations by distributing workloads across multiple nodes, ensuring high availability and fault tolerance. Kubernetes is widely adopted across cloud providers, including Azure Kubernetes Service (AKS), Amazon Elastic Kubernetes Service (EKS), and Google Kubernetes Engine (GKE), each offering managed solutions with built-in integrations and security features.



Key Components of Kubernetes

Kubernetes is built on several core components that work together to manage containerized applications:

Clusters – Groups of nodes managed together as a single unit.

Nodes – Physical or virtual machines that run Kubernetes workloads.

Deployments & Services – Kubernetes objects used to manage application scaling and networking.

Pods – The smallest deployable unit in Kubernetes, consisting of one or more containers.

Most cloud providers offer managed Kubernetes services to reduce operational complexity and automate infrastructure management.

Overview of Managed Kubernetes Services (AKS, EKS, GKE)

Each cloud provider offers a managed Kubernetes service, providing similar functionality with slight variations:

Factor	AKS	EKS	GKE
Control Plane Cost	Free	Paid (\$0.10/hr)	Free for Standard mode
Node Autoscaling	VM Scale Sets	Cluster Autoscaler	Built-in with Autopilot
Load Balancing	Azure Load Balancer	AWS Load Balancer Controller	GCP Network Load Balancer
Storage Options	Azure Disks, Azure Files	EBS, EFS, S3	Persistent Disk, Filestore
IAM & Authentication	Azure AD, RBAC	IAM Roles for Service Accounts	Workload Identity
Monitoring & Logging	Azure Monitor	AWS CloudWatch & Prometheus	Google Cloud Observability (Cloud Monitoring & Logging)

Despite these differences, Kubernetes clusters in AKS, EKS, and GKE can be provisioned using Terraform for a consistent infrastructure-as-code approach.

Provisioning Kubernetes Clusters with Terraform

Terraform enables multi-cloud Kubernetes deployments by providing consistent, repeatable infrastructure configurations.

Deploying an Azure Kubernetes Service (AKS) Cluster

```
resource "azurerm_kubernetes_cluster" "example" {
  name          = "example-aks"
  location      = var.location
  resource_group_name = var.resource_group_name
  dns_prefix    = "exampleaks"

  default_node_pool {
    name     = "default"
    node_count = 2
    vm_size  = "Standard_DS2_v2"
  }
}
```

```

    identity {
      type = "SystemAssigned"
    }
  }
}

```

This configuration creates a 2-node AKS cluster with a system-assigned identity.

Deploying an AWS Elastic Kubernetes Service (EKS) Cluster

```

resource "aws_eks_cluster" "example" {
  name     = "example-eks"
  role_arn = aws_iam_role.eks.arn

  vpc_config {
    subnet_ids = aws_subnet.eks[*].id
  }
}

resource "aws_eks_node_group" "example" {
  cluster_name = aws_eks_cluster.example.name
  node_role_arn = aws_iam_role.eks_nodes.arn
  subnet_ids   = aws_subnet.eks[*].id
  scaling_config {
    desired_size = 2
    min_size     = 1
    max_size     = 3
  }
}

```

This configuration provisions an EKS cluster with a node group supporting autoscaling.

Deploying a Google Kubernetes Engine (GKE) Cluster

```

resource "google_container_cluster" "example" {
  name     = "example-gke"
  location = "us-central1"
  initial_node_count = 2

  node_config {
    machine_type = "e2-medium"
  }
}

```

This configuration creates a 2-node GKE cluster in the us-central1 region.

Managing Kubernetes Resources with Terraform

Once a cluster is deployed, Terraform's Kubernetes provider can be used to manage workloads within the cluster.

Example: Deploying a Nginx Application in Kubernetes

The following example defines a Nginx deployment and exposes it via a service.

Provider Configuration (For AKS)

```
provider "kubernetes" {  
  host = azurerm_kubernetes_cluster.example.kube_config[0].host  
  client_certificate =  
base64decode(azurerm_kubernetes_cluster.example.kube_config[0].client_  
certificate)  
  client_key =  
base64decode(azurerm_kubernetes_cluster.example.kube_config[0].client_  
key)  
  cluster_ca_certificate =  
base64decode(azurerm_kubernetes_cluster.example.kube_config[0].cluste  
r_ca_certificate)  
}
```

Kubernetes Deployment

```
resource "kubernetes_deployment" "nginx" {  
  metadata {  
    name = "nginx-deployment"  
  }  
  
  spec {  
    replicas = 2  
    selector {  
      match_labels = {  
        app = "nginx"  
      }  
    }  
    template {  
      metadata {  
        labels = {  
          app = "nginx"  
        }  
      }  
    }  
  }  
}
```

```

spec {
  container {
    name = "nginx"
    image = "nginx:1.14.2"
    ports {
      container_port = 80
    }
  }
}
}
}
}
}
}
}

```

Kubernetes Service to Expose the Deployment

```

resource "kubernetes_service" "nginx" {
  metadata {
    name = "nginx-service"
  }

  spec {
    selector = {
      app = "nginx"
    }

    port {
      port      = 80
      target_port = 80
    }

    type = "LoadBalancer"
  }
}

```

This configuration:

- Deploys two Nginx pods within the cluster.
- Creates a Kubernetes service to expose the application externally.

Multi-Cloud Kubernetes Deployment Considerations

Deploying Kubernetes clusters across AWS, Azure, and GCP requires consideration of platform-specific differences:

Factor	AKS	EKS	GKE
Control Plane Cost	Free	Paid (\$0.10/hr)	Free for Standard mode
Node Autoscaling	VM Scale Sets	Cluster Autoscaler	Built-in with Autopilot
Load Balancing	Azure Load Balancer	AWS Load Balancer Controller	GCP Network Load Balancer
Storage Options	Azure Disks, Azure Files	EBS, EFS, S3	Persistent Disk, Filestore
IAM & Authentication	Azure AD, RBAC	IAM Roles for Service Accounts	Workload Identity

Terraform and Kubernetes State Management

As you know, Terraform manages infrastructure declaratively using a **state file** to track resources it creates. However, Kubernetes operates dynamically, adjusting workloads and resources based on system conditions. This **difference in state management** can cause conflicts when Terraform attempts to enforce a desired state.

Common Issues with Terraform Managing Kubernetes Resources:

- **Autoscaling Conflicts:** If Kubernetes scales pods dynamically (e.g., Horizontal Pod Autoscaler), Terraform's state may become outdated. Running terraform apply can unintentionally revert Kubernetes' scaling decisions.
- **Drift Between Terraform and Kubernetes:** Kubernetes can recreate or reschedule pods for various reasons (node failures, resource optimizations). Terraform does not track these changes unless explicitly refreshed.
- **Limited Control over Kubernetes-Specific Features:** Terraform manages resources at the infrastructure level, while Kubernetes handles workloads at the application level. This separation can make managing Kubernetes-native features more cumbersome with Terraform alone.

To avoid these issues, it is often beneficial to use **Helm** to manage Kubernetes workloads while Terraform provisions the infrastructure.

Introducing Helm charts



Helm is a powerful package manager for Kubernetes that simplifies the deployment, configuration, and management of applications within a Kubernetes cluster. Much like how apt or yum manage packages on Linux systems, Helm manages Kubernetes applications through reusable templates known as **Helm charts**. These charts bundle Kubernetes manifests (like deployments, services, and config maps) with default configuration values, allowing users to deploy complex applications with just a few commands or configuration adjustments.

When managing Kubernetes with Terraform, Helm plays a crucial role in reducing complexity. While Terraform excels at infrastructure provisioning—such as setting up clusters, networking, and cloud resources—managing dynamic, application-level resources like deployments, services, and autoscalers can become cumbersome. Defining these resources directly with Terraform requires extensive boilerplate code, and handling updates, rollbacks, or versioning manually increases operational overhead.

Integrating Helm with Terraform bridges this gap. Terraform's **Helm provider** allows you to deploy and manage Helm charts declaratively, just like other infrastructure components. Instead of writing verbose Kubernetes resource definitions, you simply reference a Helm chart and specify key configuration values. This approach reduces code duplication, simplifies resource management, and leverages the Kubernetes community's best practices baked into popular charts. Additionally, Helm's versioning and rollback features provide greater flexibility in managing application lifecycle changes, making deployments more resilient and adaptable in dynamic environments.

By combining Terraform's infrastructure-as-code capabilities with Helm's application management strengths, teams can achieve a more streamlined, efficient, and scalable approach to Kubernetes operations.