Devops Shack

HashiCorp Vault

Comprehensive guide

By DevOps Shack

🔹 1. Introduction to HashiCorp Vault

✅ What is Vault?

HashiCorp Vault is a powerful, flexible, identity-aware secrets management and data protection system. It enables secure storage and access to sensitive information such as:

- **API keys**
- **Passwords**
- **Tokens**
- **Certificates**
- **Encryption keys**

Vault acts as a **central secrets management hub**, offering a consistent API for securely accessing, storing, and distributing secrets — regardless of whether they are static or dynamic. Vault is identity-aware, logs every action, and can provide fine-grained access control down to the specific secret or path level.

✅ Why Vault Exists

In modern cloud-native environments and DevOps pipelines, secrets like database passwords, API tokens, and SSH keys are often:

- Hardcoded in configuration files or scripts
- Shared across environments or teams
- Stored in plain text
- Difficult to rotate without downtime

These practices introduce significant **security risks**, such as data leaks, unauthorized access, and breaches. Vault addresses these challenges by offering:

🔐 Centralization

Instead of secrets scattered in configs, Vault centralizes them in an encrypted, access-controlled vault.

🛡️ Fine-Grained Access Control

Vault policies define exactly **who** can access **what**, and **how**.

🔁 Secret Lifecycle Management

Secrets can be automatically **rotated**, **revoked**, and **leased** with defined TTL (time-to-live) to minimize exposure.

🔧 Real-World Example

A company uses multiple microservices that all connect to a PostgreSQL database. Traditionally, every service might use the **same hardcoded password**, posing a risk.

With Vault:

- Each microservice gets **dynamic database credentials**
- These credentials have a **short TTL**
- If compromised, they **expire quickly**
- Access is **audited** and **policy-controlled**

✅ Result: No static passwords, automatic revocation, centralized control, and complete audit logs.

🔹 2. Why Use a Secrets Manager?

🔑 Password Manager vs. Secrets Manager

Password Manager	Secrets Manager
Meant for human use	Meant for machine-to-machine
Manual copy-paste usage	Programmatic access via API
Browser extensions	CLI, SDK, or HTTP API
No versioning or TTL	Supports TTL, revocation

Secrets managers like Vault are specifically designed to **automate secrets management** in dynamic, cloud-native, and microservice-based environments.

✅ Core Benefits of a Secrets Manager

1. **Centralized Management**
    - All secrets stored securely in one place.
    - Easy management of access and auditability.
2. **Encryption at Rest and Transit**
    - All secrets are encrypted using strong algorithms (AES-256).
    - Vault ensures secure handling even in memory.

3. **Fine-Grained Access Control**
    - Policies define access per role, path, or method.
    - Example: A service can read only its DB password, not others.
4. **Dynamic Secrets**
    - Secrets are created on-demand.
    - Example: Vault generates a temporary AWS IAM key that expires in 1 hour.
5. **Lease and Revocation**
    - All secrets have TTL.
    - Vault can revoke any secret instantly if compromise is suspected.

🔧 Real-World Scenario

Imagine a DevOps team manually rotates database passwords every 30 days. This leads to:

- Downtime during password updates
- Forgotten rotations
- Static secrets in playbooks or CI/CD pipelines

With Vault:

- Every build job requests a temporary credential from Vault
- Vault generates and revokes passwords automatically
- No need to manage static passwords anymore

🔹 3. Vault Architecture

HashiCorp Vault follows a robust and secure client-server architecture. It is designed with high scalability, pluggability, and security in mind.

🏗️ Core Components of Vault Architecture

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1. Storage Backend

Vault needs persistent storage to save encrypted secrets and metadata. This is called the **storage backend**.

Popular options:

- **Integrated Storage (Raft)** – Recommended for production use since Vault 1.4+
- **Consul** – Reliable and widely used for service discovery + HA coordination
- **DynamoDB** – Useful in AWS-based deployments
- **Google Cloud Storage** / **Azure Blob** – Useful in respective clouds
- **Filesystem** – Only for dev/test use

🔒 Vault encrypts all data before it writes to storage. The storage backend never sees plaintext secrets.

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2. Seal/Unseal Mechanism

Vault encrypts all data with a master key. This master key is encrypted with a **root key**, which is split into multiple **unseal keys** using Shamir's Secret Sharing.

- Default is **5 key shares, 3 required to unseal**
- You must provide unseal keys every time Vault starts (unless auto-unseal is enabled)

Auto-Unseal (Cloud KMS support):

- AWS KMS
- GCP KMS
- Azure Key Vault

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3. Vault API Server

The **Vault server** exposes a RESTful HTTP API on port 8200. All client interactions — whether CLI, GUI, or SDK — are done over this API.

- All requests are authenticated
- All access is logged (if auditing is enabled)
- All responses are encrypted

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4. Audit Devices

Audit logs are essential for production security. Vault provides pluggable audit backends:

- File
- Syslog
- Socket
- Kafka (via plugins)

vault audit enable file file_path=/var/log/vault_audit.log

Each API request is logged, including:

- Who made it
- What was requested
- When it was done
- What was returned

🔐 Logs are critical for forensics and access compliance.

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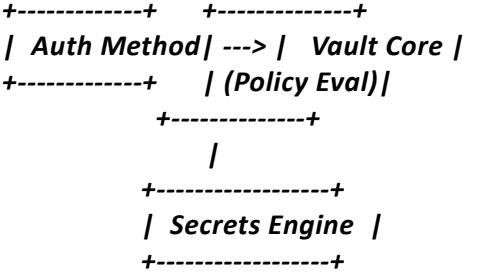
5. Auth Methods & Secrets Engines

Vault supports a **plugin system** for both:

- **Authentication backends**: How clients authenticate (LDAP, AppRole, Kubernetes, etc.)
- **Secrets engines**: What kind of secrets are being managed (KV, database, AWS, etc.)

🖼️ **Logical Flow (Simplified Diagram)**



1. A client sends a token or credential to **auth method**
2. Vault evaluates the **policy**
3. If permitted, Vault returns secrets from the **secrets engine**

🌐 **High-Level Lifecycle of a Vault Request**

1. **Authenticate** – via AppRole, AWS IAM, etc.
2. **Policy Evaluation** – "Is this action allowed?"
3. **Execution** – Read/write to secrets engine
4. **Lease Assignment** – If the secret has a TTL
5. **Audit Logging** – Log the request and response

🧠 **Key Takeaways**

- Vault separates responsibilities using modular plugins.
- All secrets are encrypted before hitting disk.
- Vault has **no concept of users**, only **identities and tokens**.
- The architecture is built for high security and observability.

🔹 4. Vault Core Concepts

HashiCorp Vault is built around a few core concepts that form the foundation of its security model and functionality. Understanding these concepts is key to using Vault effectively in real-world, production-grade environments.

✅ 1. Seal & Unseal

What does "sealed" mean in Vault?

When Vault is sealed:

- The master encryption key is not present in memory.
- No operations can be performed (read/write/list/etc.)
- The server is effectively in lockdown.

How unsealing works:

- The master key is encrypted with a "root key."
- That root key is split into **key shares** using Shamir's Secret Sharing.
- A **minimum threshold** of key shares is required to unseal the Vault.

vault operator unseal <key1>

vault operator unseal <key2>

vault operator unseal <key3> # Now Vault is unsealed

Auto-Unseal (cloud-based): Vault can unseal itself automatically using a cloud KMS:

- AWS KMS
- Azure Key Vault
- GCP Cloud KMS

```
seal "awskms" {
  region     = "us-west-2"
  kms_key_id = "abcd-1234-5678"
}
```

✅ 2. Tokens

Vault does **not** use usernames and passwords directly (except with the userpass method). Instead, it uses **tokens** for access.

Types of Tokens:

- **Root Token**:

- Created during initialization.
- Has full access (should be used rarely).
- Cannot be revoked unless Vault is reinitialized.

- **Child Tokens**:
  - Scoped with specific policies.
  - Can have TTL, renewable, and can be revoked.

Token Capabilities:

- **Policies** define what each token can do.
- Tokens are **revocable** at any time.
- Tokens can be **orphaned** (not tied to parent token).

```
vault token create -policy="dev-team" -ttl=2h
```

```
vault token revoke <token_id>
```

✅ 3. Policies

Policies are written in **HCL (HashiCorp Configuration Language)** or **JSON**. They define what actions are allowed on which paths.

Example:

```
path "kv/data/dev/*" {
  capabilities = ["create", "update", "read", "delete", "list"]
}
```

- **Capabilities**:
  - read, create, update, delete, list, sudo

Policies are attached to:

- Tokens
- AppRoles
- Authenticated identities

📌 Best Practice: **Principle of Least Privilege** — Grant only what's needed.

✅ 4. Auth Methods

Vault supports many **authentication backends**, each tailored for a specific use case.

Auth Method	Use Case
userpass	Simple user login (dev/test only)
approle	Machines and CI/CD pipelines
github	GitHub team access
ldap	Enterprise directory authentication
kubernetes	Pods authenticating using service account
aws	EC2 IAM role authentication
jwt	Generic OIDC/JWT auth flows

🔧 **Example: Enabling AppRole Auth Method**

```
vault auth enable approle
```

```
vault write auth/approle/role/webapp \
  token_policies="webapp" \
  secret_id_ttl=60m \
  token_ttl=30m \
  token_max_ttl=120m
```

Then retrieve the role_id and secret_id:

```
vault read auth/approle/role/webapp/role-id
```

```
vault write -f auth/approle/role/webapp/secret-id
```

These values are used by clients (e.g., CI jobs, apps) to get a token.

📚 **Summary**

- Vault is sealed by default and must be unsealed before use.
- Everything revolves around tokens — there are no "users."
- Policies define what each token can do.
- Auth methods map real-world identities to policies and tokens.

🔹 5. Vault Deployment Options

HashiCorp Vault is versatile when it comes to how it can be deployed. Whether you're experimenting on your laptop or rolling it out across a multi-region enterprise-grade architecture, Vault provides tailored modes to support different environments.

🧪 1. Dev Mode (Development Server)

This is the simplest mode and is great for:

- Learning
- Local testing
- Demos

```
vault server -dev
```

Features:

- Runs entirely in memory (no persistent storage)
- Automatically unsealed on start
- Generates a root token automatically
- Uses default kv secrets engine

⚠️ **Not for production** — secrets disappear on restart, and security is minimal.

🏢 2. Production Mode

In production, you want full encryption, persistence, and high availability.

🔐 **Key components for production:**

- **Persistent storage backend**
- **TLS encryption**
- **Unseal configuration (manual or auto-unseal)**
- **Audit logging**
- **Secure ACL policies**

```
storage "raft" {
  path = "/opt/vault/data"
}

listener "tcp" {
  address     = "0.0.0.0:8200"
```

```
 tls_cert_file = "/etc/vault/tls/cert.pem"
 tls_key_file  = "/etc/vault/tls/key.pem"
}

seal "awskms" {
 region     = "us-west-2"
 kms_key_id = "abcd-1234"
}
```

✅ **Considerations:**

- Use **firewall rules** to restrict API access
- Enable **audit devices**
- Rotate keys and tokens regularly

☁️ **3. High Availability (HA)**

Vault can be run in a **HA configuration** to ensure uptime, availability, and failover.

🔁 **Supported Storage Backends for HA:**

- **Consul** (external coordination)
- **Integrated Raft storage** (recommended since Vault 1.4+)

🔄 **How HA works:**

- One node is **active**
- Others are **standby**
- Standbys automatically become active if the leader fails

```
storage "raft" {
 path    = "/opt/vault/data"
 node_id = "vault-node-1"
}

ha_enabled = true
```

🧱 **4. Deployment Topologies**

🧪 **Dev Lab (non-HA):**

[Vault (dev mode)]

🏢 **Basic Prod (1 node, TLS, Raft storage):**

```
[ Vault (active) ] --> [ TLS ] --> [ Users / Apps ]
        |
    [ Raft Storage ]
```

☁️ Full HA with Auto-Unseal:

```
[ Vault Node 1 (active) ]
[ Vault Node 2 (standby) ]
[ Vault Node 3 (standby) ]
      |       |       |
   [ Raft Integrated Storage ]
      |
   [ AWS KMS for Auto-Unseal ]
```

🧠 Key Best Practices

- Always enable TLS with **valid certs**
- Prefer **Raft over Consul** unless you're already using Consul
- Enable **audit logging**
- Use **load balancers** in front of Vault cluster
- Use **cloud KMS** for unseal automation

🔹 6. Authentication Methods

Authentication in Vault determines **who** or **what** is accessing Vault and **what they are allowed to do** (via policies). Vault provides multiple pluggable auth methods to support a wide range of identity systems — from static credentials to cloud-based identity verification.

🧩 Vault Authentication Overview

- Vault **does not have users** in the traditional sense.
- Vault issues **tokens** upon successful authentication.
- Each auth method maps an external identity to Vault's internal identity system (token + policy).
- You can enable multiple auth methods at once.

🔐 Common Auth Methods

Auth Method	Best Use Case
token	Basic auth for automation/scripts
userpass	Manual testing, small teams
ldap	Enterprises with centralized directory access
github	Developers in GitHub orgs
approle	CI/CD pipelines, automation
aws	IAM-role-based auth for EC2, Lambda
kubernetes	Pod-to-Vault authentication
jwt/oidc	App or user access via identity provider

✅ AppRole Authentication (Best for CI/CD)

AppRole is a **programmatic login** method ideal for:

- Jenkins
- GitLab CI
- Automation scripts

It uses:

- role_id (public)
- secret_id (private)

🔧 **Enable and Configure AppRole:**

```
vault auth enable approle

vault write auth/approle/role/webapp \
  token_policies="webapp" \
  secret_id_ttl=60m \
  token_ttl=30m \
  token_max_ttl=60m
```

Retrieve credentials:

```
vault read auth/approle/role/webapp/role-id

vault write -f auth/approle/role/webapp/secret-id
```

Login using AppRole:

```
vault write auth/approle/login \

  role_id="..." \

  secret_id="..."
```

☸️ **Kubernetes Authentication**

Kubernetes Auth method allows Vault to authenticate Pods using their **ServiceAccount JWT tokens**.

🔧 **Use Cases:**

- Inject secrets into running containers
- Fetch DB credentials from inside pods

🔧 **Setup Steps:**

1. Enable Kubernetes auth:

```
vault auth enable kubernetes
```

2. Configure Kubernetes connection:

```
vault write auth/kubernetes/config \

  token_reviewer_jwt="<JWT>" \

  kubernetes_host="https://<K8S-API-ENDPOINT>" \

  kubernetes_ca_cert=@/var/run/secrets/kubernetes.io/serviceaccount/ca.crt
```

3. Create Vault role:

```
vault write auth/kubernetes/role/webapp \
  bound_service_account_names="vault-auth" \
  bound_service_account_namespaces="default" \
  policies="webapp" \
  ttl="24h"
```

🛡️ AWS IAM Authentication

This method uses the **identity of an EC2 instance or Lambda function** to authenticate to Vault.

🔧 Steps:

1. Enable AWS auth:

```
vault auth enable aws
```

2. Create a Vault role bound to an IAM role:

```
vault write auth/aws/role/dev-role \
  auth_type=iam \
  bound_iam_principal_arn="arn:aws:iam::123456789:role/vault-role" \
  policies="dev-policy"
```

3. On EC2 instance:

```
vault write auth/aws/login \
  role="dev-role" \
  iam_http_request_method="POST" \
  iam_request_url="$URL" \
  iam_request_body="$BODY" \
  iam_request_headers="$HEADERS"
```

GitHub Authentication

Allows users in a GitHub organization to authenticate.

```
vault auth enable github
```

```
vault write auth/github/config organization="devopsteam"
```

```
vault write auth/github/map/teams/devops value="dev-policy"
```

Users log in with:

```
vault login -method=github token=<your_github_token>
```

LDAP Authentication

For organizations with Active Directory or OpenLDAP.

```
vault auth enable ldap
```

```
vault write auth/ldap/config \
  url="ldap://ldap.example.com" \
  userdn="ou=users,dc=example,dc=com" \
  groupdn="ou=groups,dc=example,dc=com" \
  binddn="cn=admin,dc=example,dc=com" \
  bindpass='admin_password' \
  userattr="uid" \
  groupfilter="(objectClass=groupOfNames)"
```

Map LDAP groups to policies:

```
vault write auth/ldap/groups/dev-team policies="dev-policy"
```

Best Practices

- Use **AppRole** for automation.
- Use **Kubernetes Auth** for internal workloads.
- Use **OIDC or GitHub** for developer-facing auth.
- Always limit token TTL and renewals.
- Regularly rotate secret_id if using AppRole.

🔹 7. Access Control (Policies)

HashiCorp Vault enforces security through **policies**. Policies define what a user, application, or identity can and cannot do inside Vault.

Vault's policies are written using **HCL (HashiCorp Configuration Language)** or JSON, and they are applied to identities via **tokens, roles, or auth methods**.

🔐 Why Policies Matter

- Vault doesn't rely on usernames or roles natively.
- Access is entirely governed by **capabilities on paths**.
- You assign **read/write/delete/etc.** privileges to specific paths in Vault.

🧩 Anatomy of a Vault Policy

A Vault policy is a mapping of **path** to **capabilities**:

```
path "kv/data/dev/*" {
  capabilities = ["create", "update", "read"]
}
```

Capabilities include:

- create – Write new secrets
- read – Read existing secrets
- update – Overwrite secrets
- delete – Delete secrets
- list – List secrets in a path
- sudo – Bypass normal policy restrictions

💉 Example: Read-Only Policy for Dev Secrets

```
path "kv/data/dev/*" {
  capabilities = ["read", "list"]
}
```

This allows read-only access to **any key** under the path kv/data/dev/.

🧪 Example: Admin Policy for All Paths

```
path "*" {
  capabilities = ["create", "read", "update", "delete", "list", "sudo"]
}
```

Use with **caution** — this grants **full access** to everything.

📌 Attaching Policies to Tokens or Roles

When a token is created (manually or via login), it can have one or more policies attached:

```
vault token create -policy="dev-policy" -ttl=1h
```

If you're using AppRole or Kubernetes auth, assign the policy to the **role**, not the token directly:

```
vault write auth/approle/role/myapp \
    token_policies="dev-policy"
```

📁 Real-World Scenario

Let’s say you want to configure access like this:

Role	Path Prefix	Capabilities
Developer	kv/data/dev/*	read, list, update
CI/CD Pipeline	database/creds/ci	read
Admin	*	All

You would create 3 policies:

- dev-policy.hcl
- cicd-policy.hcl
- admin-policy.hcl

Then apply them to roles, auth backends, or tokens.

🔍 Listing and Inspecting Policies

List all policies:

vault policy list

View a specific policy:

vault policy read dev-policy

Delete a policy:

vault policy delete dev-policy

🛡️ Vault Default Policies

- root: Full access — only the root token should use this.
- default: Automatically assigned if no policy is provided.

Best practice: **Never use root token in daily operations.** Use specific policies for each use case.

💡 Pro Tips

- Structure secrets using logical paths (kv/data/dev, kv/data/prod)
- Grant minimal capabilities — **principle of least privilege**
- Use HCL format for better readability
- Store policies in version-controlled Git repos
- Create readonly, admin, ci, developer templates

🔹 8. Secrets Engines

🔑 What is a Secrets Engine?

Secrets Engines are **pluggable components** in Vault that handle secrets. They are responsible for **storing**, **generating**, **encrypting**, or **managing access** to secrets like:

- Static key-value secrets
- Dynamic database credentials
- AWS IAM tokens
- Encryption-as-a-service (EaaS)

Each secrets engine is **mounted** at a path (like kv/, database/, or transit/) and can have its own configuration, versioning, and access controls.

🧩 Types of Secrets Engines

Engine	Use Case
kv	Static secrets (API keys, passwords)
transit	Encryption as a service (EaaS)
database	Dynamic, lease-based DB credentials
aws	On-demand IAM credentials
azure	Azure service principal generation
gcp	GCP service accounts
cubbyhole	Private, token-bound temporary secrets
identity	OIDC and identity mapping
pkI	Generate and manage TLS certificates

✅ 1. KV (Key-Value) Secrets Engine

Used for **static secrets** like tokens, passwords, or config settings.

Enable KV:

vault secrets enable -path=kv kv

Store a secret:

vault kv put kv/myapp username=admin password=secret123

Retrieve it:

vault kv get kv/myapp

Delete it:

vault kv delete kv/myapp

✅ 2. Transit Engine (Encryption-as-a-Service)

Transit does not store data. It simply **encrypts/decrypts** data using Vault-managed keys.

Great for:

- Tokenizing PII data
- Application-layer encryption
- PCI/GDPR-compliant workflows

Enable transit:

vault secrets enable transit

Create encryption key:

vault write -f transit/keys/customer-data

Encrypt data:

vault write transit/encrypt/customer-data plaintext=$(base64 <<< "sensitive-info")

Decrypt data:

vault write transit/decrypt/customer-data ciphertext="vault:v1:..."

✅ 3. Database Secrets Engine

Generates **dynamic, time-bound DB credentials** on-the-fly.

Supported DBs:

- PostgreSQL
- MySQL/MariaDB
- MSSQL
- Oracle (via plugins)

Enable and configure:

```
vault secrets enable database


vault write database/config/my-postgresql \
  plugin_name=postgresql-database-plugin \
  allowed_roles="readonly" \
  connection_url="postgres://vaultuser:password@db.example.com:5432/mydb"
```

Create a role:

```
vault write database/roles/readonly \
  db_name=my-postgresql \
  creation_statements="CREATE ROLE \"{{name}}\" WITH LOGIN PASSWORD '{{password}}' VALID UNTIL '{{expiration}}';" \
  default_ttl="1h" \
  max_ttl="24h"
```

Fetch dynamic creds:

```
vault read database/creds/readonly
```

✅ 4. AWS Secrets Engine

Dynamically generates **short-lived AWS credentials** with custom IAM permissions.

Enable:

```
vault secrets enable aws
```

Configure root credentials:

```
vault write aws/config/root \
  access_key=AKIA... \
  secret_key=...
```

Create a Vault role:

```
vault write aws/roles/my-role \
  credential_type=iam_user \
  policy_document=-<<EOF
{
  "Version": "2012-10-17",
  "Statement": [{
```

```
    "Effect": "Allow",
    "Action": "ec2:*",
    "Resource": "*"
  }]
}
EOF
```

Get IAM credentials:

```
vault read aws/creds/my-role
```

✅ 5. Cubbyhole Secrets Engine

- Bound to a **single token**
- Secret is deleted when the token expires
- Used for **one-time secret sharing** or **short-lived bootstrap secrets**

```
vault write cubbyhole/mysecret secret_value="hello"
```

```
vault read cubbyhole/mysecret
```

🔐 Managing Secret Engines

- **List all engines**:

```
vault secrets list
```

- **Disable an engine**:

```
vault secrets disable kv
```

- **Enable at custom path**:

```
vault secrets enable -path=secrets kv
```

🛡️ Security Tips

- Mount secrets engines under logical paths: kv/dev/, kv/prod/, etc.
- Apply least privilege: limit who can access each secrets engine
- Use TTLs and leases where applicable
- Combine engines (e.g., Transit + Database) for advanced workflows

🔹 9. KV v1 vs KV v2 (Key-Value Secrets Engine Versions)

The **Key-Value (KV)** secrets engine is the most commonly used secrets engine in Vault. It allows you to store **static secrets** (such as tokens, passwords, config values) as key-value pairs.

Vault provides **two versions** of the KV engine:

- **KV v1** – Simple and flat
- **KV v2** – Adds versioning and metadata

📦 KV v1: Flat Key-Value Store

Features:

- Supports basic get, put, delete operations
- No support for versioning
- Quick and simple to use

Usage:

```
vault secrets enable -path=kv kv   # default is v1
```

```
vault kv put kv/myapp username="admin" password="pass123"
```

```
vault kv get kv/myapp
```

```
vault kv delete kv/myapp
```

🧠 KV v1 is straightforward but not suited for sensitive workflows that require auditability, version rollback, or change tracking.

📦 KV v2: Versioned Key-Value Store

Introduced in Vault 0.10.0

Features:

- Built-in **version history**
- Soft delete with **delete & undelete**
- Optional **destroy** (permanently remove)
- Metadata management
- Protection against overwriting unintended versions

Enable KV v2:

vault secrets enable -path=secret kv-v2

Write secret (auto creates version 1):

vault kv put secret/myapp username="admin" password="vault123"

Get latest version:

vault kv get secret/myapp

Get specific version:

vault kv get -version=2 secret/myapp

🗑️ Deletion Semantics (KV v2)

Soft Delete:

vault kv delete secret/myapp

Marks the secret as deleted, but it can still be **recovered**.

Undelete:

vault kv undelete -versions=2 secret/myapp

Destroy (permanently):

vault kv destroy -versions=2 secret/myapp

🔍 Metadata Commands

- List metadata for a key:

vault kv metadata get secret/myapp

- Delete metadata (and all versions):

vault kv metadata delete secret/myapp

⚙️ Comparison: KV v1 vs KV v2

Feature	KV v1	KV v2
Basic CRUD	✅ Yes	✅ Yes
Versioning	❌ No	✅ Yes
Soft Delete	❌ No	✅ Yes
Undelete support	❌ No	✅ Yes

Feature	KV v1	KV v2
Destroy a version	❌ No	✅ Yes
Metadata operations	❌ No	✅ Yes

🛡️ Best Practices

- Use **KV v2** if:
  - You need rollback or version tracking
  - Your secrets are sensitive
  - You want fine-grained deletion control
- Use **KV v1** if:
  - Simplicity and speed matter more
  - You manage secrets via automation and versioning isn't needed

---

🧪 Real-World Use Case

A development team wants to store deployment credentials:

- In dev: they use KV v1 because rollback isn't needed.
- In prod: they use KV v2 so that accidental overwrites can be undone.

This strategy balances simplicity with safety.

🔹 10. Secure Introduction of Clients

Before any application or service can access secrets from Vault, it must **authenticate securely**. This process of securely providing a client with access credentials — without manual intervention — is known as **secure introduction** or **bootstrap authentication**.

🎯 Problem with Static Tokens

You might be tempted to hardcode a token in your app or store it in a config file. But:

- If the token leaks, anyone can access Vault
- You lose visibility into *who* is using Vault
- Revoking a token requires app redeploys

🔐 Hardcoding Vault tokens is a huge **security anti-pattern**.

✅ Secure Introduction Methods

HashiCorp Vault provides two **secure**, dynamic methods for introducing new clients:

---

1. AppRole with Vault Agent (Pull model)

AppRole is ideal for non-human entities (like services or CI/CD jobs). Vault Agent is a lightweight client that runs beside your app.

🧰 How it works:

- You assign an **AppRole** with limited permissions.
- Vault Agent fetches the secret_id and uses it with role_id to login.
- The token is **cached and automatically renewed**.

🔧 Sample Setup:

```
auto_auth {
 method "approle" {
  mount_path = "auth/approle"
  config = {
   role_id_file_path = "./role_id"
   secret_id_file_path = "./secret_id"
  }
 }

 sink "file" {
  config = {
   path = "/home/myapp/.vault-token"
```

```
  }
 }
}
```

Then run Vault Agent:

```
vault agent -config=agent-config.hcl
```

---

2. Kubernetes Auth Method (Push model)

For apps running inside Kubernetes, Vault can trust a Pod's **ServiceAccount JWT** and issue it a Vault token.

🧰 **How it works:**

- Pod starts with a ServiceAccount attached
- It calls Vault /auth/kubernetes/login
- Vault verifies the JWT and issues a scoped token
- The Pod uses this token to read secrets

🔧 **Setup:**

1. Enable Kubernetes auth:

```
vault auth enable kubernetes
```

2. Configure Vault to talk to Kubernetes API:

```
vault write auth/kubernetes/config \
 kubernetes_host="https://<k8s-api>" \
 kubernetes_ca_cert=@ca.crt \
 token_reviewer_jwt=@token.jwt
```

3. Create a role:

```
vault write auth/kubernetes/role/my-app \
 bound_service_account_names="vault-app" \
 bound_service_account_namespaces="default" \
 policies="myapp" \
 ttl="24h"
```

4. Pod logs in:

```
vault write auth/kubernetes/login \
 role="my-app" \
 jwt=$(cat /var/run/secrets/kubernetes.io/serviceaccount/token)
```

🧪 Additional Options

Method	Best For
Vault Agent + AppRole	VMs, CI/CD, bare-metal apps
Kubernetes Auth	Apps running in K8s
AWS IAM Auth	EC2 / Lambda authentication
OIDC	User-interactive auth

🛡️ Security Best Practices

- **Use TTLs** for tokens and credentials
- **Use Vault Agent** to auto-renew tokens
- Never **hardcode Vault tokens** in apps
- Leverage **policies** to restrict what a client can access
- Use **dynamic secrets** to minimize risk even if a token is leaked

---

📦 Real-World Use Case

A CI/CD pipeline uses AppRole to fetch short-lived credentials for deploying apps. The token lasts only 30 minutes and is rotated for each build.

A Kubernetes-based app uses Vault Agent Injector to fetch TLS certs from Vault and store them in a mounted volume at runtime.

🔹 11. Leasing & Renewals

In Vault, most secrets are not static. They are **leased**, meaning they have a **Time-To-Live (TTL)** and expire automatically after a period.

This concept is central to Vault's design and provides massive advantages over traditional secrets management systems.

📦 What Is a Lease?

A **lease** is a time-bound association between a client and a secret.

- When a secret is issued, it comes with a **lease ID** and a **TTL**.
- Vault tracks the lease internally and can **revoke** it when:
    - It expires
    - You revoke it manually
    - The parent token is revoked

Every lease can be **renewed** or **revoked** before it expires.

✅ How Leasing Works (Behind the Scenes)

Let's say you generate dynamic PostgreSQL credentials:

```
vault read database/creds/readonly
```

Vault will return:

```
{
  "data": {
    "username": "v-root-abc1",
    "password": "random-pass"
  },
  "lease_id": "database/creds/readonly/abcxyz",
  "lease_duration": 3600,
  "renewable": true
}
```

- The lease is good for **1 hour**.
- Vault will **revoke** the credentials when the lease expires.

- You can **renew** the lease if needed.

🛠️ **Useful Lease Commands**

🔍 **Check lease info:**

vault lease lookup database/creds/readonly/abcxyz

🔄 **Renew a lease:**

vault lease renew database/creds/readonly/abcxyz

You can also **specify a new TTL** (within allowed range):

vault lease renew -increment=3600 <lease_id>

❌ **Revoke a lease:**

vault lease revoke database/creds/readonly/abcxyz

🧠 **Leases Are Everywhere**

Leases apply to:

- **Dynamic secrets** (like database, AWS, GCP)
- **Tokens**
- **Temporary access to encryption keys**
- **PKI certificates**

🔐 **Token Renewal & Expiration**

Tokens are also **leased**.

When you log in via AppRole, Kubernetes, etc., your Vault token has a TTL:

vault token lookup

Output:

```
{
  "ttl": 3600,
  "renewable": true,
  "expire_time": "2025-04-11T20:00:00Z"
}
```

Renew the token:

vault token renew

🕒 TTL Hierarchy

Vault calculates the **least** of:

- The **token TTL**
- The **secret TTL**
- The **policy max TTL**
- The **lease's default TTL**

Example: If your policy TTL is 1 hour but the secret engine's TTL is 24h, the secret expires in 1 hour.

You can configure default and max TTLs per backend:

```
vault write database/roles/readonly \
  default_ttl="1h" \
  max_ttl="24h"
```

🧪 Real-World Scenario

You generate short-lived AWS credentials for deployment:

```
vault read aws/creds/dev-role
```

You use the credentials to run a deployment job.

The lease is revoked after 15 minutes, making those credentials useless — even if compromised.

⚙️ Vault Agent Auto-Renew

If you're using **Vault Agent**, it can automatically renew leases and tokens behind the scenes.

```
cache {
  use_auto_auth_token = true
}

auto_auth {
  ...
}
```

```
listener "tcp" {
  ...
}
```

📌 Summary

- **Every secret** in Vault can have a TTL.
- Vault uses **leases** to track secret lifecycles.
- You can renew or revoke leases using simple CLI/API calls.
- Vault Agent makes renewal automatic.

🔹 12. Audit Devices

🔎 Why Auditing Matters

Vault is a **security-critical system**. Every interaction with Vault should be traceable.

Audit devices record all requests and responses to Vault, including:

- Who made the request
- When it was made
- What was requested
- What Vault returned

Audits **do not** log sensitive data (like full secrets), but they log metadata.

✅ Enabling an Audit Device

Enable file-based audit:

```
vault audit enable file file_path=/var/log/vault_audit.log
```

Enable syslog:

```
vault audit enable syslog
```

Disable an audit:

```
vault audit disable file
```

🚨 It's recommended to enable **at least one** audit device in production.

📋 Audit Log Example (Truncated):

{
"time": "2025-04-11T12:00:00.000Z",
"auth": { "client_token": "hmac-sha256", "display_name": "approle" },
"request": { "path": "kv/data/creds", "operation": "read" },
"response": { "status": 200 }
}

🔹 13. Vault Agent

The Vault Agent is a lightweight daemon that:

- Handles **authentication** (auto-auth)
- Automatically **renews tokens and leases**
- Can **render secrets into templates**

✅ **Example Use Case:**

Run Vault Agent alongside your app. It logs in using AppRole, renews tokens in the background, and writes secrets to a file.

🔧 **Vault Agent HCL Config:**

```
auto_auth {
 method "approle" {
  mount_path = "auth/approle"
  config = {
   role_id_file_path = "./role_id"
   secret_id_file_path = "./secret_id"
  }
 }

 sink "file" {
  config = {
   path = "/home/app/.vault-token"
```

```
  }
 }
}
```

Run agent:

```
vault agent -config=agent.hcl
```

🔹 14. Template Rendering

Vault Agent can render secrets into files using **Go templating**.

💉 Example Template:

config.tpl

```
{
 "db_username": "{{ with secret \"kv/data/myapp\" }}{{ .Data.data.username }}{{ end }}",
 "db_password": "{{ with secret \"kv/data/myapp\" }}{{ .Data.data.password }}{{ end }}"
}
```

Agent config:

```
template {
 source = "./config.tpl"
 destination = "/etc/config.json"
}
```

Run Vault Agent. It'll write the populated config file with secrets to disk.

🔹 15. Vault with Kubernetes (Helm)

Vault can be deployed and integrated with Kubernetes using **Helm charts** and the **Vault Injector**.

✅ Deploy Vault via Helm

```
helm repo add hashicorp https://helm.releases.hashicorp.com
helm install vault hashicorp/vault
```

Use the **Vault Injector** to auto-inject secrets into Pods as:

- Environment variables

- Mounted files

🧪 **Sample Pod Annotation:**

```
annotations:
  vault.hashicorp.com/agent-inject: "true"
  vault.hashicorp.com/role: "myapp"
  vault.hashicorp.com/agent-inject-secret-db-creds: "kv/data/db"
  vault.hashicorp.com/agent-inject-template-db-creds: |
    {{- with secret "kv/data/db" -}}
    DB_USERNAME={{ .Data.data.username }}
    DB_PASSWORD={{ .Data.data.password }}
    {{- end }}
```

Secrets are injected at container runtime.

🔹 **16. HA Setup with Integrated Storage**

Vault supports **native Raft storage** for HA — no need for Consul or external DB.

🔧 **Example config for Raft HA:**

```
storage "raft" {
  path    = "/opt/vault/data"
  node_id = "vault-1"
}

listener "tcp" {
  address     = "0.0.0.0:8200"
  tls_disable = 1
}

seal "awskms" {
  region     = "us-west-2"
```

```
  kms_key_id = "abc-123"
}

api_addr = "http://vault-1:8200"
cluster_addr = "http://vault-1:8201"
```

All Vault nodes share a **Raft consensus cluster**. One becomes **active**, the rest are **standby**.

🔁 For high availability, add Vault behind a load balancer.

🔹 17. Enterprise Features

Vault Enterprise includes advanced functionality:

- 🔹 **Namespaces**
  - Like multi-tenancy
  - Separate auth backends, secrets engines, policies
- 🔹 **Replication**
  - **Performance Replication** (multi-region reads)
  - **Disaster Recovery Replication**
- 🔹 **Sentinel**
  - Policy-as-code enforcement
  - Add business rules to Vault operations

🔹 18. Dynamic Secrets: Database

Vault can **generate temporary DB credentials** on-demand.

🔧 **Configure PostgreSQL Plugin**

```
vault write database/config/my-postgresql \
  plugin_name=postgresql-database-plugin \
  allowed_roles="readonly" \
  connection_url="postgres://{{username}}:{{password}}@localhost:5432/mydb"
```

🔧 **Create a role:**

```
vault write database/roles/readonly \
```

```
  db_name=my-postgresql \
  creation_statements="CREATE ROLE \"{{name}}\" WITH LOGIN PASSWORD '{{password}}' VALID UNTIL '{{expiration}}';" \
  default_ttl="1h" \
  max_ttl="24h"
```

🔍 **Fetch credentials:**

```
vault read database/creds/readonly
```

You get:

- A temporary username
- A temporary password
- TTL of 1 hour

🔹 **19. CI/CD Integration**

Vault integrates easily with CI/CD tools like:

- **GitHub Actions**
- **GitLab CI**
- **Jenkins**
- **ArgoCD**

🔧 **Example: GitLab CI**

```
vault:
  script:
    - export VAULT_TOKEN=$(vault login -method=approle ...)
    - export DB_PASSWORD=$(vault kv get -field=password kv/db)
    - ./deploy.sh
```

Use Vault CLI or **Vault Agent Injector** to inject secrets into pipelines.

🔹 **20. Real-World Use Cases**

🔐 **1. Replace secrets in Ansible/Playbooks**

Use lookup('hashi_vault', ...) to pull secrets during provisioning.

🔄 2. Auto-Rotate DB Credentials

Dynamic secrets rotate every hour. Vault revokes old creds automatically.

☁️ 3. Short-Lived Cloud Access

Vault generates AWS/GCP/Azure credentials with TTL = 15 mins. Perfect for CI/CD.

🔗 4. Central Secrets Hub in Multi-Cloud

Vault works across:

- AWS
- GCP
- Azure
- On-prem VMs
- Kubernetes

Centralize all secrets in one place.

✅ Final Words

HashiCorp Vault is not just a secrets manager — it's a **dynamic trust broker**, a **central identity-aware secret lifecycle controller**, and a **security automation powerhouse**.

Whether you're securing a single app or managing a global infrastructure, Vault empowers you with:

- Auditability
- Dynamic access control
- Secrets rotation
- Enterprise-grade architecture