"This book is an essential guide for every architect and developer deploying secure, business-critical solutions on Azure."

—*from the foreword by* **Scott Guthrie,**
Executive Vice President, Cloud + AI Group, Microsoft

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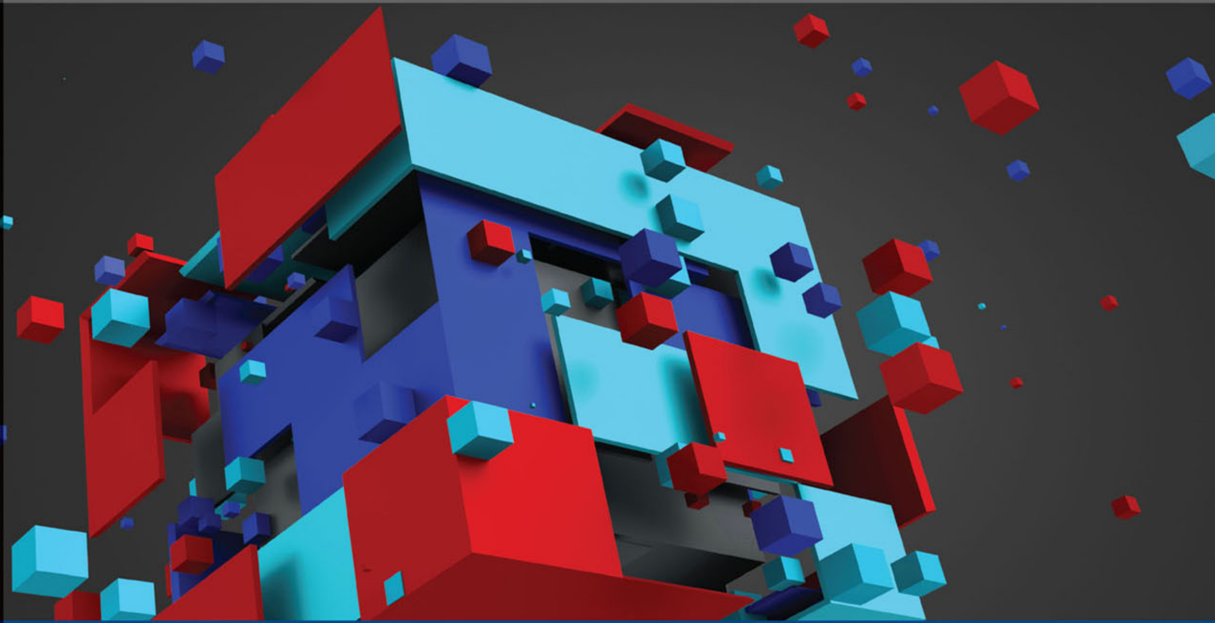
Designing and Developing Secure Azure Solutions

Best practices



Michael Howard • Simone Curzi • Heinrich Gantenbein

FREE SAMPLE CHAPTER

Microsoft

Designing and Developing Secure Azure Solutions

Michael Howard
Heinrich Gantenbein
Simone Curzi

Designing and Developing Secure Azure Solutions

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For my family, who had patience with me as I wrote another book.

—MICHAEL

With love to my wife Denyse, thanking her for the support she provides.

—HEINRICH

With gratitude and love to my family, Silvia, Alice, and Viola, who endure and support me tirelessly.

—SIMONE

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Austin, Texas

Heinrich Gantenbein
St. Paul, Minnesota

Simone Curzi
Perugia, Italy

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Foreword

In the last decade we have witnessed a dramatic shift in the way organizations have harnessed technology to completely reinvent and transform how they do business. Recent global challenges and unpredictable far-reaching events have only accelerated that change, and organizations have had to pivot and adapt to meet their customer and employee needs and ensure business resilience.

This digital transformation has been made possible in part by technology advancements and hyperscale cloud providers like Microsoft Azure that provide organizations with the agility to realize new efficiencies and capabilities. However, as we continue through this era of unprecedented transformation, including migration to the cloud, we are also experiencing new threats and requirements to ensure security and privacy.

When people think of security, they often think of endpoint protection, firewalls, and anti-malware tools, which are critically important, but architects and developers can't ignore application security during design and development. This book — *Designing and Developing Secure Azure Solutions* — is a necessary resource to understanding the essential elements of end-to-end secure software design and development on Azure. It addresses two areas I care about deeply – the security of Azure and software development.

The Microsoft Cloud has many reliability and security benefits compared to on-premises solutions, but architects and developers cannot ignore fundamental security practices when they deploy on Azure. Cloud-based solutions have a shared responsibility model, and some of the security onus is on the tenant as well as the cloud provider. *Designing and Developing Secure Azure Solutions* provides a holistic and approachable resource for anyone building secure workloads running on Azure. Readers working on Azure solutions will gain a contemporary understanding of secure development, design, and implementation.

The authors Michael, Heinrich, and Simone have decades of application security experience between them. They have worked with governments and companies — large and small — enabling each to design, develop, deploy, and manage secured solutions on Azure. I know the authors to be dedicated to helping anyone designing and developing on Azure achieve the reliability, scalability, and security demanded by their organizations and end users.

This book is an essential guide for every architect and developer deploying secure, business-critical solutions on Azure.

Scott Guthrie
Executive Vice President
Cloud + AI Group, Microsoft

Introduction

In mid-2021, during a recording of the *Azure Security Podcast*, Azure security expert and author Yuri Diogenes asked Michael if he planned to write an update to his book, *The Security Development Lifecycle*. Without hesitation, Michael responded, "No!"

But that wasn't the end of the matter.

The question Yuri asked planted a seed. Over the next few weeks, the three of us—Michael, Heinrich, and Simone—assembled a plan to write this book. Between us, we have worked with hundreds of customers to help them deploy business-critical solutions on Azure with confidence. This book is the culmination of that real-world experience.

The reason we wrote this book was not only to help you understand how to design and develop secure solutions running on Azure but to offer you pragmatic advice. The Venn diagram shown in Figure I-1 reflects how we see this book.

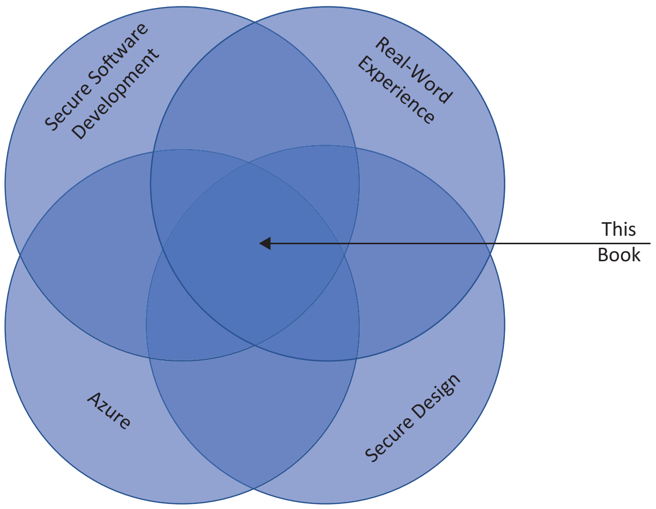

FIGURE I-1 The Intersection of this book's areas of coverage.

We do not cover some areas within Azure; otherwise, this book would be quite a tome. Most notably, we do not cover topics such as the following:

- **Privileged access workstations (PAWs)** A PAW is a workstation designed for administrative tasks only. It does not have access to email, general web browsing, and other productivity tasks. PAWs are used by elevated accounts to perform actions in high-risk environments, such as production, account administration, and more. You can learn more about PAWs here: *https://azsec.tech/irb*.

- **Conditional access and multifactor authentication (MFA)** These are often handled by an identity team, and the infrastructure should already be in place. With that said, conditional access and MFA are critical to securing an Azure-based solution. Learn more here: *https://azsec.tech/59d*.
- **Privacy** This is a book on security. Although security and privacy do overlap, security is mainly about fortifying a system and its data against unauthorized use, while privacy is about handling personal data. You can have security without privacy, but you cannot have privacy without security.

We've kept things relatively brief by including lots of links to outside information rather than covering some topics in depth in this book.

Organization of this book

This book is not designed to be read from cover to cover. You can do that, of course, but we have tried to make the chapters as independent as possible so they can be read individually. With that said, there are cross-references between chapters, and you might sometimes need to read a section of a different chapter to get the big picture.

The book also covers multiple ways to achieve a task, such as the following:

- Using the Azure Portal (although it's not common to use the Azure Portal in production systems because deploying in the real world usually uses a pipeline to push resources)
- Using the Azure command-line Interface (CLI)
- Using PowerShell code
- Using more complete code examples in different languages such as C#, Python, JavaScript, and more

Tip We have uploaded code samples and snippets to our GitHub repository at *https://github.com/AzureDevSecurityBook/*, so please make a point of visiting regularly.

Who should read this book

Just who is this book for? It's for anyone deploying solutions on Azure—whether they're architects, developers, or testers—who might not know a great deal about security but who want to make sure their design and code are as secure as possible. We cover a lot of ground in the book, but we also cover many complex topics in depth.

One final point: if you use the NIST Cybersecurity Framework (NIST CSF), then you're familiar with its core components: identify, protect, detect, respond, and recover. The material in this book focuses primarily on the protect component and some aspects of the detect component. Rolling out industry-grade solutions on Azure requires your organization to cover the other four components of the NIST CSF. You can read more about the NIST CSF in Chapter 8, "Compliance and risk programs," and on the NIST website, at *https://azsec.tech/81t*.

Thanks for reading!

Conventions and features in this book

This book presents information using conventions designed to make the information readable and easy to follow:

- Boxed elements with labels such as "Note" provide additional information
- Text that you type (apart from code blocks) appears in bold
- A plus sign (+) between two key names means that you must press those keys at the same time. For example, "Press Alt+Tab" means that you hold down the Alt key while you press the Tab key
- A vertical bar between two or more menu items (e.g. File | Close), means that you should select the first menu or menu item, then the next, and so on

System requirements

Examples and scenarios in the book require access to a Microsoft Azure subscription and a computer that can connect to Azure. You can learn more about a trial subscription at this site:

azure.microsoft.com/en-us/free

GitHub Repo

The book's GitHub repository includes sample code and code snippets, and the authors will update this over time. The repo is *github.com/AzureDevSecurityBook/*.

The download content will also be available on the book's product page: *MicrosoftPressStore.com/SecureAzureSolutions/downloads*

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CHAPTER 3

Security patterns

After completing this chapter, you will be able to:

- Adopt the proposed patterns to improve how you securely design your solutions.
- Identify even more Azure security patterns, further improving your understanding of Azure.

What is a pattern?

Design patterns are not new to information technology, but they still play a fundamental role. Design patterns were conceived by a British-American architect of Austrian origins named Christopher Alexander. In 1977, Alexander wrote a book about recurring solutions to common problems related to building physical structures. However, this book became influential beyond its original field. Indeed, Alexander's work inspired four computer scientists and researchers—Erich Gamma, Richard Helm, Ralph Johnson, and John Vlissides—to apply the same concepts to software design. The result was a book titled *Design Patterns: Elements of Reusable Object-Oriented Software*, which is still widely used today.

In his book, Christopher Alexander defines patterns as follows:

> "Each pattern describes a problem which occurs over and over again in our environment, and then describes the core of the solution to that problem, in such a way that you can use this solution a million times over, without ever doing it the same way twice."

The point here is that patterns represent a structured approach to address common problems. They are a way to collect and share know-how that has consistently provided value to many disciplines, including software design. Given that this book relates to the development of secure solutions on Azure, we focus here on design patterns in that context.

Our take on Azure security patterns

Azure uses design patterns extensively. You can find them almost everywhere such as when dealing with data protection at rest, implementing user authentication, and too many other scenarios to include here. Instead of reinventing the wheel, Azure adopts the same patterns and sometimes even the same services to provide critical capabilities and address common problems.

It is essential to know Azure's security patterns because they represent the best way to address common security problems. They may even enable you to design secure solutions without adopting more sophisticated approaches, like threat modeling, discussed in Chapter 4, "Threat modeling." This chapter introduces some of these patterns and includes the following information about each one:

- The name of the pattern
- The intent of and motivation behind the pattern
- A description of the pattern
- Examples of the pattern's implementation in Azure
- Related security principles (discussed in Chapter 2, "Secure design")
- Related patterns

Furthermore, the patterns are split into categories to simplify their identification:

- **Authentication** These patterns deal with the authentication of the counterparts of an interaction.
- **Authorization** These patterns focus on controlling access to resources.
- **Secrets management** These patterns deal with how the solution manages the secrets.
- **Sensitive information management** These patterns focus on how to manage sensitive information.
- **Availability** These patterns deal with ensuring that resources are accessible by legitimate users.

In the following pages, we describe a few patterns, sorting them by alphabetical order within each category. This is not an exhaustive list by any means. It simply includes some of the most common patterns we have seen in our practice that focus solely on solution design. This chapter does not cover implementation and deployment patterns, like those related to the supply chain. Considerations that relate to those patterns are covered elsewhere in the book, in Chapter 9, "Secure coding."
By discussing some of the most important patterns here and clearly stating why you need to adopt them, we aim to provide you with a consistent view.

Note For a more complete list of patterns, see https://azsec.tech/kph.

Once you know about patterns and their importance in Azure, you might be able to identify other patterns in the services you use. This understanding of design decisions empowers you to design better solutions by adopting the same concepts and by using Azure Services correctly.

The Azure Well-Architected Framework

Microsoft has published a set of guidelines on implementing sound architectures on Azure. These guidelines are available as part of the Azure Well-Architected Framework, which is available here: https://azsec.tech/dm8. These guidelines cover multiple aspects of implementing architectures, including reliability, security, cost optimization, operational excellence, performance efficiency, workloads, and services. For our purposes, the section on security is the most interesting. It covers topics like governance, landing zones, identity and access management, and much more. Many concepts within the Azure Well-Architected Framework can be mapped to the design patterns discussed in this chapter, but it goes well beyond our scope. Therefore, our recommendation is to take a look at it.

Authentication pattern

Authentication is an essential property of any solution. It pertains to identifying your counterpart in a conversation with some certainty.

We typically refer to the degree of certainty as the *authentication strength*. For example, suppose someone declares who they are without providing any proof. This would not be an authentication, but rather an identification. If they do a little better and provide a password, this would be weak authentication. Of course, you can impose restrictions to ensure an attacker cannot easily guess user passwords, but this has a limited effect on security.

Authentication typically involves the use of one, two, or all of the following parameters:

- **Something you know** This might be a password.
- **Something you have** This could be your phone or a physical token.
- **Something you are** This might be biometric information.

If you base authentication only on the password—that is, something you know—you have single-factor authorization, which can easily be compromised. To increase security, you should pair it with a second factor—for example, your username and password (things you know) and your phone (something you have). The idea here is that although an attacker might easily compromise any one of them, compromising them both at the same time would be much more challenging. Finally, you could add the third factor—something you are—to improve security even more. This approach is typically called *multifactor authentication* (MFA) because it relies on more than one factor.

Note Chapter 5, "Identity, authentication, and authorization," contains more information about this topic.

Authentication does not represent a value per se, but it is instrumental in securing your application and data.

This section focuses on one common pattern for securing your solution through authentication: using a centralized identify provider for authentication.

Use a centralized identity provider for authentication

Intent and motivation

The cloud is a convenient platform for hosting applications—so much so that you might host many applications on it, all of which require authentication. It is only natural for organizations to seek a centralized approach for managing identity to access all different services with a single set of credentials. This requirement is not only for simplicity but also to retain control and visibility.

Centralizing identity allows for the adoption of tools like user and entity behavior analytics (UEBA). These tools enable you to determine whether any account or system represents a potential risk for the organization by analyzing its behavior, often adopting artificial intelligence (AI) algorithms able to identify changes in usage patterns.

Another advantage of centralized identity systems is they provide a single location for managing identities and grants. They also allow you to integrate identity management with HR processes—for example, to remove or disable a user's account as soon as that user ceases their relationship with the organization. Finally, these identity systems enable you to review assigned rights and remove them when necessary.

Description

Azure AD represents a complete and unified approach to identity management on Azure. It provides fundamental capabilities, like managed identities and access reviews, and can be extended with additional services to increase security. These services include:

- **Azure AD Identity Protection** This service determines which identities are at risk by analyzing signals from many sources, such as threat intelligence, leaked credentials, and Microsoft Defender for Cloud Apps (Microsoft's Cloud Access Service Broker, or CASB).
- **Microsoft Defender for Cloud Apps** You can use this service to control and limit the adoption of applications and to detect the presence of shadow IT in your organization.
- **Microsoft Defender for Endpoints** This is a user and entity behavior analytics (UEBA) solution that can be integrated with Windows 10, Windows 11, and various devices.
- **Azure AD Privileged Identity Management (PIM)** This service enables you to assign access rights when required, eventually requiring approval from a third party before executing the assignment.

Azure AD also provides zero-trust security for the implementation of identities through the use of conditional access. This defines policies to prevent access to services by users who are not trusted enough. For example, suppose Azure AD Identity Protection has identified a potential security risk related to a particular user. It can then force that user to authenticate with MFA when accessing sensitive resources.

Note Azure AD is not your only option for identity management. You could use a third-party tool instead. Indeed, there are various reasons to use a third-party identity provider. For example, your organization might have already adopted one for your on-premises environment or to support different clouds, like AWS or GCP.

Examples

- Adopt conditional access to require MFA for privileged users such as the solution administrators.
- Use Azure AD to define custom application roles to control how the solution is used. You can find out more about these here: https://azsec.tech/0g6.
- Although some services—like Azure SQL Database, SQL Managed Instances, Cosmos DB, and Azure Storage—provide different ways to authenticate, including using Azure AD credentials, you should use Azure AD credentials whenever possible, because they can be better controlled from a central location. Using Azure AD credentials also enables the adoption of the whole set of capabilities offered to secure these identities.

Related security principles

- Zero trust
- Complete mediation
- Defense in depth
- Economy of mechanisms
- Least privilege
- Leveraging existing components

Related patterns

- Adopt just-in-time administration
- Use role-based access control (RBAC)
- Use managed identities

Authorization patterns

Authorization is another fundamental property of any secure solution. It comes after authentication. Authorization focuses on allowing users to perform actions they are entitled to perform and on preventing them from performing actions they are not entitled to perform. This section focuses on some common patterns for securing your solution through authorization.

We mentioned that authentication does not represent a value per se, but it is instrumental in securing your application and data. The same applies to authorization.

Adopt just-in-time administration

Intent and motivation

Accounts are not all equal. Some have considerable privileges assigned to them, making them a juicy target for malicious actors. For example, highly privileged administrators, like those assigned the roles of Global Administrator or User Administrator, are powerful, and it would cause significant damage to the organization if their user accounts were abused. For this reason, the most common recommendation is to apply the principle of least privilege by assigning the various roles only to those users who require them for a legitimate business reason and only when there is no other alternative that would allow for the assignment of fewer rights. For example, suppose one user needs to read security reports because she works on the security team. In that case, you should assign her the Security Reader role instead of Secure Administrator or Global Administrator.

This approach is a critical best practice, so there is a good chance your organization already applies it. Still, too many organizations struggle to adopt this approach due to the many roles defined in Azure AD and Azure Services. That is to say, sometimes the "best" role for a user—the one that most closely meets that user's needs—is not the most secure one. This pattern ensures that no unnecessary rights are assigned that could be exploited by an attacker or a malicious insider. Still, the rights that are assigned could be enough to cause significant losses.

A study by IBM Security and ObserveIT, published in 2020, found that the average cost of a security breach caused by an insider was $11.45 million. The study also found that, on average, the companies interviewed during the course of the study experienced 3.2 such incidents per year. Finally, the study determined that it's possible to reduce these losses by about $ 3 million by adopting a privileged access management (PAM) tool.

Note You can download the study mentioned here from https://azsec.tech/56t. For a discussion of the study, see https://azsec.tech/au8.

The idea behind PAM tools is that users do not need privileges 24×7. Rather, they need them for only a limited time. So, a privileged account represents a potential risk only when someone uses it to perform necessary actions. Outside that period, a PAM tool can revoke the rights, such that the user in question has no assigned privileges. PAM tools also deter malicious use because they require users to specify a business reason to obtain a particular privilege. They can also be used to require the approval for a third party to assign a particular right, in accordance with the separation of duties principle.

Description

Azure AD PIM is the primary tool within Azure for just-in-time administration. This tool extends how you assign roles to users or groups. With plain Azure AD, you assign roles globally or within a specific context, depending on the scope of the role. The role is then assigned forever. With Azure AD PIM, you can mark a role as eligible and then assign policies to that role. An eligible role remains dormant until it is activated. Activation can be subject to approval and could require additional authentication with MFA as well as the specification of a business reason. Activation can also be temporary and automatically removed after a set time.

Tip Azure AD PIM is not something you implement for the purposes of application development. It is part of a broader initiative that is typically the responsibility of those who manage your Azure AD tenant. If you decide you need Azure AD PIM to limit the exposure of privileged accounts for your application, you might want to ask the owners of the tenant to adopt it. If your organization has already adopted it, you can ask to define the rules you require for your application.

Example

Sometimes developers need access to production data to troubleshoot problems. While this is understandable, you should try to avoid it. That being said, in an emergency, you might not be able to avoid this, as developers will need to access this data to quickly identify a solution. The best way to handle these types of situations is to plan for them. In this effort, Azure AD PIM may play a significant role by enabling you to define an authorization process that requires a valid reason and approval by a third party.

Related security principles

- Attack surface reduction
- Defense in depth
- Least privilege
- Leveraging existing components
- Separation of duties

Related patterns

- Use a centralized identity provider for authentication
- Use role-based access control (RBAC)

Assign roles to groups

Intent and motivation

Let's face it: determining what access rights are required is not always a trivial matter. In many cases, identifying the right blend of rights is a matter of trial and error. It's very tempting to assign full rights and call it a day!

This behavior is a consequence of many factors, not least of which is the number of built-in roles provided with Azure. There are currently more than 80 built-in roles for Azure AD and more than 240 built-in roles for Azure services! No wonder it is so difficult to find the right roles to assign.

Still, it is imperative to identify a feasible approach to guarantee that users are assigned the most limited rights possible. Focusing on feasibility might be the difference between having an academic requirement and effectively making a difference.

Description

The critical point here is to apply least privilege without sacrificing manageability. One way to achieve this is by using groups. The idea is to define whatever usage scenarios you need and then create groups to support them. Once that's done, you can assign the required roles to each group and then assign users to groups as needed.

This approach is helpful for two reasons:

- It minimizes management because it aligns groups according to how the organization works.
- It enables you to minimize the number of role assignments. This is essential because Azure restricts you to 2,000 role assignments per subscription. For more on this, see https://azsec.tech/ad8.

Common exceptions to this rule are service principals and managed identities, which are typically assigned the required roles directly.

Tip Designing a suitable authorization model is a matter of business requirements, which must be agreed upon in advance among business, architecture, and operations stakeholders, per the organization's current policies and with requirements from security and operation. Many aspects are common to all projects, but the details will depend on your solution.

Example

If you have a data lake, you might want to guarantee different levels of visibility, depending on your area. You can address this requirement by assigning the required permissions. The easiest way to do this is to define a group for each category of users—like HR, research, and marketing—and then assign the required rights to various branches in the data lake, based on the desired visibility. You can even reuse the same groups for many applications simply by assigning additional rights to them when required.

Related security principles

- Least privilege

Related patterns

- Use a centralized identity provider for authentication
- Use role-based access control (RBAC)

Isolate from the internet

Intent and motivation

Chapter 2 showed that zero trust has been designed to address the many shortcomings of walled-in defenses. For example, suppose that for your security, you rely only on controls blocking external users from accessing the internals of your solution. In that case, you could be compromised as soon as someone figures out how to circumvent your layer of protection.

So, the answer would be to *not* rely on firewalls and similar protections, right? Wrong! The defense-in-depth principle states that every single control you can put in place can be circumvented. This principle doesn't imply, however, that you should give up your hopes of protecting your solution or that you should ditch controls like firewalls because they can't fully protect you on their own. It simply means that you need to integrate them with other controls to make your solution more secure. The bottom line is that network isolation still plays a significant role in Azure.

Description

So, how can you protect your solution using network defenses? The first step is to identify the parts of your solution that you must expose to the internet, as well as the parts of your solution that must remain internal. Then, you need to focus on these parts that should not be exposed to ensure that no unauthorized entities can reach them from the internet.

There are a couple of ways to achieve that:

- **Define firewall rules** Most services can define firewall rules. Once these rules are defined, you can use them to block access from the internet. This approach is simple and requires minimal configuration. But it has a downside: your resource or service is exposed. In other words, the firewall rules blocking unwanted traffic are your only protection against external malicious actors.

- **Define private endpoints** As with firewall rules, most services can define private endpoints. With private endpoints, there is no exposure over the internet, because the endpoint gets a private IP address. You can then connect to the private endpoint using private links. Configuring private endpoints and private links requires more work than configuring firewall rules, but it is more secure.

Note Chapter 15, "Network security," includes additional information and details on implementing this pattern and on networking in general.

Examples

- If you have a web application or a web API that is internal to your organization and you do not want to expose it on the internet, you can host it with App Service Environment (ASE). An ASE is a high-performance isolated environment to host your web applications and APIs. ASE is the only way to deploy web applications and APIs based on App Service to a VNet.
- You can configure Azure SQL with firewall rules to prevent direct access from the internet as a whole but still allow access from specific IP addresses. If you instead want to prevent all access from the internet, you might want to use a private endpoint.

Related security principles

- Attack surface reduction
- Defense in depth

Related patterns

- Create secure channels
- Isolate with an identity perimeter

Isolate with an identity perimeter

Intent and motivation

You learned from the preceding pattern, isolate from the internet, that network isolation is a key mitigation that you should not disregard. The same goes for identity. Both should be applied simultaneously, per the defense-in-depth principle.

Note This pattern is specular and complementary to the previous one.

Description

Identity can represent a perimeter that a user must cross to access protected resources. In this way, it is similar to networking. With networking, you can use rules to allow specific IP addresses to access your solution but not others. Similarly, you can use identity authentication and authorization to control who can access your resources and what they can do with them.

These approaches are both different and complementary, providing different capabilities due to their respective limitations. For example, with IP filtering, you can allow requests from specific geographies or buildings and deny everything else. With authentication and authorization, you can define rules for a specific user or account and establish its rights with regard to your solution or its components.

Example

Azure Front Door, App Gateway, and API Management Gateway are three network virtual appliances (NVAs) that you can configure to provide network perimeter defenses via private networking. The private networking approach is often considered enough for many solutions, but is that really so? As usual, the defense-in-depth principle says no. Rather, the recommendation is to add an identity perimeter defense as an additional layered defense. Adding an identity perimeter is typically achieved with TLS mutual authentication. With this approach, the NVA presents its client certificate to the back end. In turn, the back end verifies the certificate and its validity to ensure that the connection comes from the expected NVA and not from a malicious or accidental source.

Related security principles

- Zero trust
- Defense in depth

Related patterns

- Use a centralized identity provider for authentication
- Isolate from the internet

Use role-based access control (RBAC)

Intent and motivation

Managing authorization can be complicated. There are many resources and applications, and each of them defines multiple actions that must be authorized. With thousands of actions that can be authorized, you need some way to group and manage them. Moreover, you need a mechanism for use with custom solutions. The idea is that by taking a widely used approach, you can have a more reliable and secure method for authorization than what you could have with a custom authorization process.

Description

Azure RBAC is a common approach that you can use for Azure AD and Azure Services. It provides a structured way to assign users prebuilt sets of rights designed to address everyday needs. Azure AD currently provides more than 120 built-in roles you can choose from. For example, the Reader role allows the user to read the configuration of a service but typically not its data. In contrast, the Contributor role allows the user to change the configuration of a service or create new resources, depending on where the role is assigned. You can also create custom roles, but these are rarely necessary and often create management issues.

A fundamental advantage of using Azure RBAC is that it allows for a centralized view of all the rights assigned to users. This is essential in the event of a compromise because it enables you to browse for affected user accounts to grasp the security implications of their compromise. If you instead use credentials local to the resources and assign rights without using RBAC, you must inspect each resource to obtain the same information. Using RBAC also enables the execution of access reviews to periodically verify that the granted access is still required. And adopting Azure AD credentials and RBAC allows you to leverage a growing set of tools to analyze identities, like Azure AD Identity Protection and Sentinel.

Tip Azure RBAC is not the only approach to authorization. Sometimes you might need something different, like a custom database representing your authorization matrix. Before searching for an alternative solution, however, you should determine whether you can leverage Azure RBAC to achieve the desired result.

Roles for applications

You might want to apply something similar to RBAC for your applications. For example, if you are creating a web portal and you want some users to provide content, it would be great if you could define a role called Editor and then have that role sent back to the application as part of the authentication token.

Of course, you could use an Azure group to do that, but this might not provide you with the right granularity. For example, maybe you want to have multiple distinct groups of users with the Editor role, one for each structure in your company. This is where defining a role would come in handy because it allows you to create as many groups as you want and then assign the role to all of them. Your application could then check if the role is present, not whether the user belongs to one of the groups.

Azure provides this capability through the app roles. App roles can be assigned to users and groups and are sent to the application when a user accesses it. App roles can also be assigned to client applications to access your application. App roles are a great way to structure access control for applications, using a secure approach that is integrated with the platform. You can find additional information about app roles here: https://azsec.tech/0g6.

Example

Suppose you need to create a multilevel authorization hierarchy. Your organization has multiple departments, including one called the Commercial department. The top level of this department is Global Commercial, which controls various regions. For example, as shown in Figure 3-1, there's a region called ATZ, another called Europe, and others. Several countries comprise each region. So, for instance, ATZ includes the USA, Canada, Mexico, and other countries. Each user in Global Commercial has complete visibility; each user associated with a particular region can see everything within that region; and users associated with a particular country can see only the information pertaining to that country.

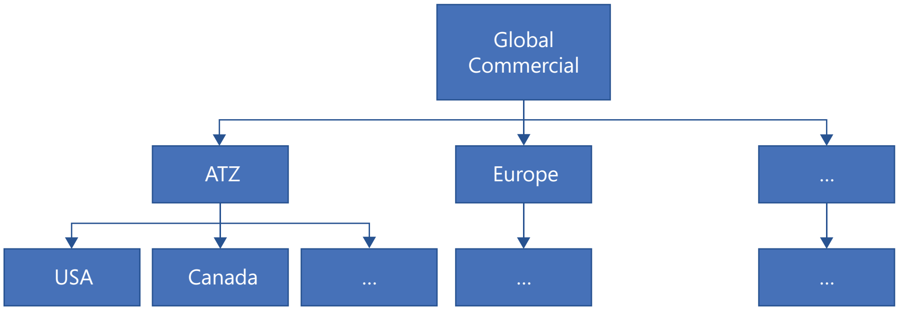

FIGURE 3-1 The hierarchy of the Commercial department.

How might you handle this scenario with Azure RBAC? At a minimum, you would need to rely on a database to represent the hierarchy and on custom code to enforce it. But you can do better. For example, you could do the following (see Figure 3-2):

1. Create a group for each country, a group for each region, and a group for the "global" level.
2. Make the group for a particular region a member of each country group within that region.
3. Make the global group a member of each region group.
4. Use RBAC to assign the required rights to each country and region group, as well as to the global group. This way, each region group will inherit the rights of the country groups within it, and the global group will inherit the rights of each region group.

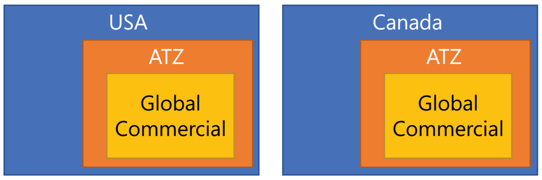

FIGURE 3-2 How the groups must be nested: Global Commercial is a member of ATZ, which is a member of both USA and Canada.

Related security principles

- Leveraging existing components

Related patterns

- Use a centralized identity provider for authentication
- Assign roles to groups

Secrets management patterns

Secrets are important because they are the keys for accessing services and data. Protecting secrets is therefore essential. You could have the most secure authentication mechanism, but if you do not protect the credentials, then you could be compromised.

Unfortunately, protecting your secrets can be complicated. At a certain point, you need them, and that is exactly when a malicious actor could attack you. Therefore, this is one of those situations where sticking with known secure patterns is most important.

Use managed identities

Intent and motivation

Most applications contain multiple components and require some type of interaction among them. This communication typically involves some form of credentials or sensitive information.

For example, suppose you connect to a database. In that case, you need a connection string specifying the name of the server or of the cluster exposing the database and the credentials to access it. Here is the problem: how can you store these credentials securely?

One obvious answer is to store them in configuration files. Unfortunately, this is not secure, because someone could steal them. Of course, you could encrypt the files, but then you have the problem of protecting the encryption key, and so on.

Alternatively, with an IaaS, you could use Data Protection API to encrypt the configuration file. Unfortunately, this approach has a couple of drawbacks, too. First, DPAPI provides only partial security because users with enough rights access secrets protected by DPAPI. Second, it does not protect the secrets in memory.

If you base your solution on App Services, you could use the application settings. These provide some protection and eliminate the need to store secrets in configuration files. Still, they do not protect the secrets in memory. And again, users who have enough rights can read the secrets—for example from the Azure Portal.

Description

A better way to store secrets is to use managed identities. These are service accounts that are entirely managed by Azure AD.

With managed identities, you have no access to the password, and your application doesn't either. The platform automatically injects it when you send out a request using the managed identity.

Not all possible callers on Azure support managed identities, nor do all possible callees. For a list of callers and callees that do, see https://azsec.tech/hia. This list is updated continuously, so you'll want to check it often. For example, Azure Cosmos DB didn't support managed identities until recently.

Note See https://azsec.tech/laf and https://azsec.tech/akg for information on using RBAC and managed identities with Cosmos DB.

Managed identities can be system-assigned or user-assigned. The main difference is that system-assigned managed identities are dedicated to the service, while user-assigned managed identities can be shared with various services. Therefore, if you want to minimize management and have many instances of the same application, you can simply assign the same user-assigned managed identity to all of them.

Tip There is one scenario in which system-assigned managed identities are preferable to user-assigned managed identities: for root cause analysis after an incident. That's because system-assigned managed identities are specific to an instance of a service, which makes it easier to identify the instance affected by the attack.

You can assign managed identities to virtual machines (VMs). This doesn't mean that all applications hosted by the VM can automatically access resources using the assigned managed identity, however. You must write code to leverage this possibility. This typically involves sending a request to the Azure Instance Metadata Service to obtain a token for the required resource. See https://azsec.tech/dff for details on using managed identities with Azure VMs.

Note The URL to call to obtain a token from the Azure Instance Metadata Service is http://169.254.169.254/metadata/identity/oauth2/token. The Azure infrastructure automatically injects the assigned managed identity, without ever exposing them, even in the message metadata.

Examples

- Suppose your code can use managed identities and needs to access a resource that supports managed identities. In this case, you should not store the credentials anywhere. Instead, it would be best to directly use the managed identity to access said resource.

- If your code supports managed identities but not the resource, check whether the resource at least supports managed identities for administrative purposes. If so, you might still be able to use managed identities to retrieve some credentials that grant access to the data from the resource. Therefore, it might be possible to have an initialization phase to gather the credentials from the service with your managed identity via the control plane and then use them for any ensuing calls. For example, Microsoft recommended this approach for accessing Cosmos DB data before it introduced support for managed identities.

Note You might prefer this option to the alternative, which is to store the credentials in Azure Key Vault, because it reduces the exposure of the credentials and simplifies management.

Related security principles

- Attack surface reduction
- Economy of mechanisms
- Leveraging existing components

Related patterns

- Use a centralized identity provider for authentication
- Protect secrets with Azure Key Vault

Protect secrets with Azure Key Vault

Intent and motivation

As discussed with the previous pattern, you need some place to store your secrets. For example, you might need to store a private key associated with a certificate instead of a username and password. A typical example is a bring-your-own-key (BYOK) scenario, where you provide a key to be used in some way, like for encrypting an SQL Database using Transparent Data Encryption (TDE).

You cannot always use managed identities to achieve this. For example, a compute service or called resource might not support managed identities. Or if you have an off-the-shelf application hosted in IaaS, it might not have been modified to support managed identities, and therefore it cannot use them. For example, it sometimes takes Microsoft some time to implement support for managed identities in open source solutions, like Redis Cache, that are incorporated as Azure Services.

So, what to do?

Description

Whatever your situation, if you cannot use managed identities to access a resource directly, the best approach is to use Azure Key Vault—a secure and centralized storage for secrets and encryption keys. Azure Key Vault is more secure than the alternatives because it can be isolated and made inaccessible from the internet, even if your application needs to be exposed using private links. You can rely on various services to secure Azure Key Vault, like Microsoft Defender for Key Vault, which—among its other capabilities—can help identify anomalous interactions. It is also more secure than many alternatives because the Premium SKU provides hardware security module (HSM) capabilities to prevent attackers from stealing private keys.

Leveraging Azure Key Vault is not enough to make your solution secure. For example, as discussed in our coverage of the prefer managed identity principle, if you host code in an environment supporting managed identities, like a VM or an App Service, you should use a managed identity to call Azure Key Vault. If you need a key to access Key Vault, you have the problem of protecting that key, which becomes very difficult. With VMs, you can use DPAPI, but this is not possible with a PaaS solution, because they might be occasionally moved to other servers by the Azure infrastructure, rendering your secrets inaccessible.

Another critical decision you need to make is how many Azure Key Vault instances to use. Microsoft recommends dedicating multiple instances for your application—one for each environment. Our recommendation is to have even more of them, particularly for production environments. If your application has multiple layers, you might dedicate an Azure Key Vault to each of them to ensure that an attacker can get hold of only a few secrets in the event of a compromise. (See Figure 3-3.)

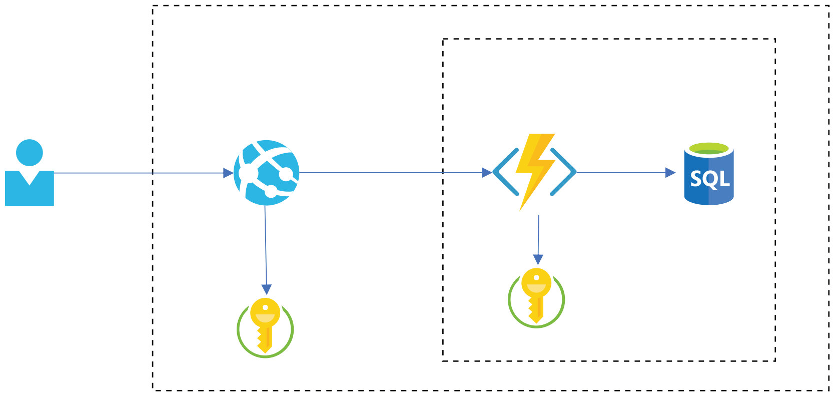

FIGURE 3-3 An example of a system with two Key Vaults: one for the front end and one for the back end.

This approach might seem radical and sometimes unnecessary. After all, having multiple Azure Key Vaults results in a more complex solution, introducing additional management burdens and increasing the possibility of mistakes by expanding the attack surface. So, the approach you decide to adopt depends on the characteristics of your solution.

Azure Key Vault for microservices

Microservices architectures present an interesting scenario. They are characterized by many small applications interacting with each other. If you had to apply a Key Vault for each microservice, the system would quickly become unmanageable. In this case, it might be best to avoid the fragmentation of the AKVs and dedicate just a single instance. Remember, per the economy of mechanisms principle, simpler is typically better.

Be aware that you might achieve significant compartmentalization even without dedicated instances. This is typically achieved by leveraging authorization. Azure Key Vault supports two authorization models: access policies and RBAC. With access policies, you assign access rights to whole categories of objects, like secrets or private keys. This means you cannot discriminate between secrets; you can read all of them or none of them. In contrast, with RBAC, you can assign roles even at a single object level. You can then have a single instance, because the object-level RBAC role assignment provides the granularity needed to determine what anyone can access.

Important The ability to assign access rights so granularly is excellent, but it has one significant downside: Azure supports up to 2,000 role assignments per subscription. So, it might be best to adopt RBAC (because it provides the greatest flexibility and control), but use it sparingly.

As discussed with our coverage of the use RBAC principle, you should use RBAC because it enables you to verify and manage role assignments centrally. Moreover, this comprehensive visibility enables you to adopt tools to identify potential risks and processes to manage role assignments more or less automatically.

Note Chapter 10, “Cryptography in Azure,” has more details on Azure Key Vault.

Examples

Azure Key Vault is great for storing secrets to access resources that don’t support managed identities, like Azure Cache for Redis. Azure Key Vault is also effective for storing secrets that you cannot replace with managed identities, like connection strings or private keys. When you store private keys, you should choose the Premium SKU to leverage its HSM capabilities. The Standard SKU is enough for all other scenarios.

Related security principles

- Fail secure
- Least privilege
- Leveraging existing components

Related patterns

- Use role-based access control (RBAC)
- Use managed identities
- Use bring your own key (BYOK)

Sensitive information management patterns

Secrets are important, but the information they protect is even more critical. There are many options for securing your data, but not all options are born equal, and it can be tricky to choose the right ones. Consider, for example, data protection at rest: all storage options from Azure allow or even enforce encryption of data at rest. For example, Azure encrypts Azure Managed Disks automatically. You have only a few options to determine how they are protected and who provides the encryption key. But do you need this type of encryption? Of course, the answer is yes, but things aren't so simple. You have to satisfy multiple needs for encryption, and this sort of protection addresses just a few of them. Again, relying on patterns is important to correctly address the most significant problems.

Create secure channels

Intent and motivation

Communications are usually the main risk for a solution. If you have a closed box that does not receive any input and does not provide any output, it is fully protected and will not be attacked. Unfortunately, such an isolated system makes sense only as an intellectual exercise.

All practical applications of technology are connected to *something*. It could be the internet, a local network, or even just a power outlet. Even devices that aren't connected to anything, because they use a battery and have their Wi-Fi connectivity disabled, still send out information through screens or simply through the electromagnetic field emitted by their electronics.

In Chapter 2, you learned that the Azure security model assigns customers partial responsibility for the security of the solutions it hosts. But whatever model you choose—IaaS, PaaS, or SaaS—it is Microsoft's responsibility to protect the physical devices. Good news, then: you do not need to be concerned about power connections and electromagnetic fields! Still, all the other concerns are well within your scope.

Description

What does it mean to create secure channels? Or better, how can you determine whether a channel is secure? There are a few requirements that must be satisfied:

- **Confidentiality** The channel must preserve data confidentiality. Transmission over the internet moves through many systems, and each of these systems could potentially read and disclose the contents of the communication. To preserve confidentiality, you must wrap the content such that unauthorized parties cannot read it, typically through encryption.

- **Authentication** The channel must authenticate with certainty all parties that are privy to the communication. In most situations, the main concern is the authentication of the caller, but this should not be the case. You also need to ensure that the called service authenticates itself. Fortunately, the adoption of TLS provides the authentication of the service implicitly. Still, you might need to ensure that your callers perform additional checks on the provided certificate—for example, checking whether the certificate has been issued by the expected certification authority.
- **Integrity** You must confirm the integrity of transmitted information. In other words, those who receive it must check whether it has been modified by some third party while in transit. Transmission protocols usually split big messages into multiple packets. Therefore, some of these packets may be lost in transit or received in a different order than expected. To preserve integrity, you must ensure that what is received matches what has been sent.

Azure addresses some of these requirements by imposing channel encryption for most communications. With channel cryptography, like TLS, you can provide confidentiality, integrity and server authentication. But you still have to address client authentication, which is optional in TLS..

There are various ways to authenticate the client—too many to include them all here. But it might be helpful to talk about one of them in particular: client certificates. These establish a strong connection that prevents man-in-the-middle attacks. If you don't use client certificates, an attacker can intercept a communication, terminate the TLS channel at its end, and create a new, false one directed toward the server. If you do use client certificates with TLS, however, this would not be possible because the man in the middle would not present your certificate to the target server. (Admittedly, we rarely use client certificates because they involve a high cost.)

Another approach is to create secure channels and isolate them from the internet. You can then use these secure channels to prevent the exposure of your resources and services over the internet. You can typically achieve this by using VPNs or ExpressRoute.

The likelihood of interception

How likely is it that an attacker will intercept your traffic? After all, the internet is vast, with billions of messages sent every second. Intercepting *your* traffic isn't like finding a needle in a haystack; it's harder! So, how big of a problem is it, really?

The truth is, there are a couple situations in which the chances of your traffic being intercepted raise significantly:

- The attacker might just be in the right place at the right moment, and you might unknowingly send your traffic their way. This could happen if you use an easily intercepted channel, like Wi-Fi, when the attacker is near you. This type of attack occurs more frequently than you might imagine—particularly in specific situations, like at security conferences.
- You might unknowingly send your traffic through malicious nodes. A typical example of this situation is when you use Tor or some free VPN. Malicious actors host many of these resources, and they use them to tap into your traffic and potentially perform malicious actions.

Examples

- Configure end-to-end TLS with Azure Application Gateway to ensure that TLS encryption is provided internally between Application Gateway and the target service or resource.
- Use a point-to-site VPN to connect a single workstation to resources on Azure to avoid exposing them over the internet.
- Use a site-to-site VPN to connect a site, which could be your office, to cloud resources not exposed over the internet. This typically requires the installation of VPN gateways to collect the traffic on both sides.
- Use ExpressRoute to connect a site similarly to the site-to-site VPN. The main difference is that ExpressRoute is based on a dedicated infrastructure, so the connection is typically faster and more reliable.

Related security principles

- Defense in depth

Related patterns

- Encrypt data client-side
- Use bring your own key (BYOK)

Encrypt data client-side

Intent and motivation

As discussed at the beginning of this section, Azure uses encryption to protect all storage. This is obviously a great feature, but does it address all your needs? To answer this question, you must first identify exactly what needs this sort of encryption *does* address.

The encryption at rest provided by Azure for most storage options falls under the category of transparent encryption. In other words, it ensures that if you access the storage using one of the sanctioned channels, data will be available in unencrypted form. If you access the storage using any other means, however, the data will unreadable. For example, if you try to access the data by stealing the virtual or physical disks, you will wind up with encrypted content that is not readable, even if you have the required rights.

So, transparent encryption increases the isolation of the customer data from Microsoft management environments. More specifically, it makes it more difficult for Microsoft's administrators to get to your data. However, there are other needs that transparent encryption does not address. For example, data in memory remains unencrypted.

Data can assume three states, and you have to protect all three of them:

- **At rest** This is when the data is stored somewhere.
- **In transit** This happens when you transmit the data between two locations.
- **In memory** This is when the data is temporarily stored in computer memory, ready for processing.

Transparent encryption only protects data at rest. When you use transparent encryption, the data is unencrypted in memory for both the database or storage server and the client. So, you typically protect data in transit by adopting TLS, which Azure enables by default.

Still, if a malicious actor manages to get hold of some authentication material, that person could access the data stored in some repository. Of course, there are a few conditions for this to happen. For example, the malicious actor must have access to the repository. But when these conditions are met, the malicious actor can read the data. This is a scenario that, in most cases, could be safely considered "already mitigated." Still, if your solution requires a higher level of security assurances, you need to consider something else, like client-side encryption.

Description

The idea behind client-side encryption is that you encrypt the data on the client before sending it to the storage system. This ensures that the data is encrypted from that point on, including in the repository memory. Of course, the application must decrypt the data to consume it. At that point, the data would be potentially at risk.

If your storage system is a database server, things become interesting. Because the client-side encrypted data is not readable by the logic executed on the database server, it would be impossible to perform typical activities like searching its content. Still, with some implementation of client-side encryption, like Cosmos DB and SQL Server Always Encrypted, it is possible to perform limited comparisons.

The implementation of client-side encryption is possible when the platform supports it, and it might still be achievable as a custom activity. But in that case, it should be treated as a delicate task, requiring thorough testing and in-depth validation by experts, because it is possible to make fatal mistakes. And even under the best conditions, client-side encryption can have a significant impact on the performance of the system, due to computational costs and because it may be impossible to index data to improve search speed.

TIP When you implement client-side encryption, a typical pattern is to consider adopting Azure Key Vault for storing the cryptographic keys.

Examples

- Cosmos DB and SQL Server Always Encrypted provides a way to encrypt data client-side. It includes a mode called *deterministic encryption*, which allows to search for records having some specific value. For example, if you encrypt a tax code with deterministic encryption, you can get all rows in a table where a field has the same tax code.

Note The very characteristic that makes deterministic encryption worthwhile is also its main weakness. For example, an attacker could group all the records associated with the same tax code, which could provide them with enough information to identify a person from the other metadata. For this reason, consider *randomized encryption* as the first option and revert to deterministic encryption if necessary.

- Some libraries that provide programmatic access to Azure Storage implement the necessary logic to perform client-side encryption for Azure Storage. For examples of this with .NET, Java, and Python code, see https://azsec.tech/ci5.

Related security principles

- Defense in depth
- Fail secure
- Leveraging existing components

Related patterns

- Protect secrets with Azure Key Vault

Use bring your own key (BYOK)

Intent and motivation

Data encryption has multiple roles. One of the least commonly considered is crypto-shredding. Crypto-shredding involves deliberately deleting or overwriting encryption keys used to secure sensitive data. In this way, you can ensure that nobody can read the data you no longer need, or you can block data exfiltration in an emergency. With crypto-shredding, you can make it impossible for anyone to access your data.

Description

One of the best ways to do this is to use BYOK. With this approach, Azure Key Vault stores the key, which is under your control. So, to crypto-shred your data, you simply purge your key from its Key Vault. When you do, all that data becomes immediately unrecoverable.

More on BYOK

One of the primary purposes of BYOK is to increase users' control over their keys. The idea is that by introducing their own keys, users make it harder for the cloud service provider to access their data. Unfortunately, that's not why BYOK is useful. If you do not trust Microsoft with your data, why should you trust it to handle your key securely? You are storing it in its systems. In other words, if you assume that a malicious administrator could access your data, you should also assume that person could access your keys, too. Fortunately, Azure includes many other controls to prevent this from happening, including strong physical controls and various isolation layers that require escalation paths under the control of the customer to access the data.

Of course, this is a two-edged sword, because a malicious actor could leverage this approach to cause a denial of service. Some SaaS solutions like Microsoft 365 implement mechanisms to prevent losses due to the destruction of the BYOK. One such feature is called Availability Key and is discussed here: https://azsec.tech/89t.

Example

If you have an Azure SQL or Azure Storage and have used BYOK to encrypt them at rest, you can remove the key from Azure Storage to crypto-shred the content.

Related security principles

- Defense in depth
- Leveraging existing components
- Separation of duties

Related patterns

- Protect secrets with Azure Key Vault

Availability pattern

Availability is often considered a given. You expect your solution to be there when needed and provide its services to every user. Unfortunately, it is not so automatic to achieve this, and you have to work hard to guarantee that your solution is up and running.

In the cloud, the situation is even worse, if possible. When you develop a complex system integrating many services, you rely on all of them to be available. The unavailability of any service may cause your solution to be partially or entirely unavailable. When each of these systems is managed at least in part by a third party, you lack control over the maintenance activities. Therefore, you have to design your solution to be more resilient than you used to do with on-prem solutions.

Important It would be a mistake to think that this problem is specific to the cloud or to Azure. On the contrary, the pervasive adoption of automation you have with these platforms has dramatically reduced the prevalence of the incidents compared to on-prem. Still, incidents are a possibility and maintenance a necessity. The new approach gives you this awareness and the tools to design and implement your solutions in a resilient way to meet your availability requirements.

Let’s see what you can do to improve the availability of your solution.

Design for denial of service

Intent and motivation

Denial-of-service (DoS) attacks are common occurrences. They happen when someone creates the conditions for your solution to fail by bombarding it with more requests than it can handle or by sending artfully crafted messages causing your solution to crash. In any case, these attacks cause the unavailability of your service. A variant of DoS attacks is called *distributed DoS* (DDoS). DDoS attacks are characterized by the generation of the attack from multiple points, sometimes in the order of the thousands or tens of thousands.

DoS and DDoS are some of the easiest attacks to execute. Some organizations even provide DDoS attacks as a service. You tell them who the target is, you pay them, and they do the rest! Very convenient and powerful.

You can address this problem in various ways, but the easiest is to simply add more resources to your application. One of the characteristics of the cloud is elasticity, which means you can allocate resources dynamically, as you need them. However, although this is easy and fast, it can be expensive and unfeasible in the long run. Here is where this pattern becomes useful.

Description

All public cloud platforms, including Azure, offer a base level of protection from DoS attacks. Azure also offers Azure DDoS Protection Standard (https://azsec.tech/s1h), designed to protect public IP addresses from potentially massive DDoS attacks.

The documentation for this service uses some specific wording that you should be aware of:

> “Azure DDoS Protection Standard, combined with application design best practices, provides enhanced DDoS mitigation.”

Note that it says *enhanced*, not *complete*. In other words, as with any other anti-DDoS system, Azure cannot represent your only line of defense against DDoS attacks. These systems complement a more comprehensive strategy, which starts with the design of your solution. For this reason, you should not design a system without thinking about how your architecture might respond to a DDoS attack.

Consider this real-life example: a customer with nearly 100 public IP addresses protected by the Azure DDoS Protection Standard service suffered severe service degradation. This was due to a DDoS attack, but it went undetected because the attack was "low and slow." That is, it fell below the triggering threshold for Azure DDoS Protection Standard, so none of the service's mitigation policies were triggered. As a result, the combined traffic flow across all IP addresses overloaded the back-end NVAs, which forced them to drop part of the traffic. The security anti-pattern in this design takes data from multiple untrusted sources and concentrates that traffic on a single, internal endpoint. In this case, all that data was concentrated on a single VM running the NVA, which is where the impact of the attack became evident. The customer quickly applied the NVA's built-in auto-scaling capabilities to bring more network bandwidth and compute online. In this scenario, a range of one to three NVAs mitigated the attack.

Note To see Microsoft documentation on including DoS and DDoS protection support in your designs, see https://azsec.tech/xin.

One final note: many Azure services can throttle requests. For example, Azure Key Vault allows 4,000 secret transactions (for example, reading an SQL connection string) per 10 seconds. If your code goes beyond this threshold, further requests are throttled and return a 429 ("Too Many Requests") response. To remedy this, cache data if possible. In the Key Vault example, you could cache the connection string in memory for 15 minutes and read from Key Vault only four times per hour, which is way under the threshold. You can find a list of Azure subscription and service limits, quotas, and constraints at https://azsec.tech/9it.

Examples

- Many services can be configured with networking rules or private endpoint connections. One such service is Azure Storage. If you opt to adopt the networking rules, the service itself is still exposed and can receive requests; you just have a high-speed mechanism to reject the requests because they are not from an acceptable IP address. While fast, this mechanism can still be overwhelmed or bypassed—for example, by an IP spoofing attack. Therefore, it is typically better to use private endpoints.
- Consider the availability requirements of your solution. If you have strict availability requirements that do not allow for partial unavailability, it's best to design the solution accordingly. For example, you could use a content delivery network (CDN) to serve the static content and a distributed and redundant architecture to provide the service to the relevant geographies.

Related security principles

- Attack surface reduction
- Defense in depth

- Single point of failure
- Weakest link

Related patterns

- Isolate from the internet
- Isolate with an identity perimeter

Summary

This chapter introduced Azure security patterns. It started with a discussion of why the concept of patterns is so essential. It then introduced a few of the most common patterns to secure your solution on Azure.

This list is limited, and you might be able to identify one or two significant ones that are missing. The intent here is not to be comprehensive but to introduce you to an approach for building secure software on Azure based on the adoption of renowned patterns.

The next chapter goes beyond this to introduce a different way of thinking about security and designing secure solutions: threat modeling.

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