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Chapter 4: Designing Secure Access and API Management Frameworks

4.1. Introduction

Given their widespread adoption, securing APIs is crucial for protecting sensitive data and functionality. The goals of API security are to safeguard API assets, ensure uninterrupted service, and uphold customer trust and loyalty. Threats to APIs stem from their accessibility, the underlying transport layer, and the business logic they expose. Successful API security implementation reduces risk to an acceptable level. Failure to adequately secure APIs is a dire concern; a 2021 survey of development, security, and operations professionals revealed that more than two-thirds of companies suffered an API security breach, resulting in major losses for over one-third of them.

API security encompasses the people, processes, policies, technologies, and practices that govern API access and usage. Four distinct areas, described using commonly accepted information security vocabulary, pose challenges: access, data in transit, application security, and detection. Policies covering these areas, along with the data and processes they govern, form an API security governance framework. Such policies articulate the organization's risk appetite, set guardrails that feed into compliance obligations, and provide the basis for threat-modeling exercises. The security architecture responsible for enforcing governance policies must manage API access using an API gateway and API access management system. Together, these two components translate the policy decisions into enforcement points at runtime.

4.1.1. Overview of API Security Challenges and Objectives

APIs, or Application Programming Interfaces, are sets of protocols, routines, and tools for building software and applications. They allow applications to communicate and utilize data and services of other applications, operating systems, or microservices. APIs are intrinsic to modern application development and web operations. For example, APIs

enable customers to use a travel platform to find flights and hotels by communicating with external aggregators; accessing weather data on a dedicated page without human intervention; or allowing customers with different payment preferences to complete their travel purchases. These operations rely on external APIs hosted by payment services, fraud detection companies, and meteorological agencies. Indeed, APIs are found virtually everywhere that web requests are performed. Their ability to offer agile, programmable access to useful information makes them highly sought after in the new digital economy. However, organizations that expose their systems via APIs also have a critical security challenge.

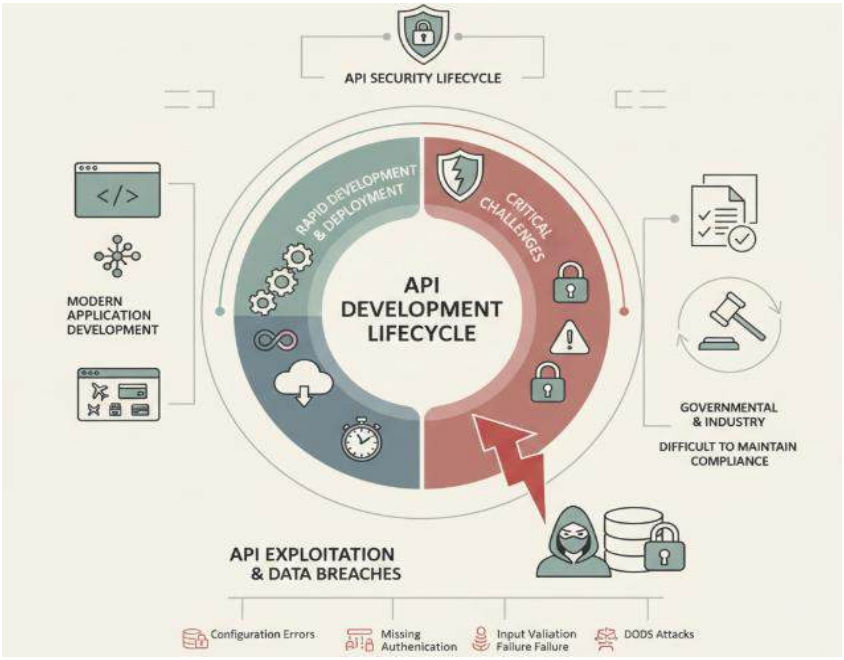

Fig 4.1: The API Security Paradox: Balancing Rapid DevOps Integration with Robust Governance and Regulatory Compliance in the Digital Economy

Hackers love APIs. Recent research into exposed APIs hosted by sanctioned Chinese government agencies indicated that at least 45 of these systems had been hacked, with breaches revealing the details of millions of Chinese citizens. Unlike traditional web servers that only serve HTML pages to end users, APIs can process dynamic data. The ease of modifying JavaScript and HTML content for website attacks has led to dramatically increased security measures. In the majority of organizations, however, APIs are still undocumented; hence, application security testing and filtering remain extremely difficult. Configuration errors, the absence of proper authentication and authorization, failure to validate input parameters or monitor denial-of-service attacks, and various other issues have resulted in soaring incidents of API exploitation. As organizations rush to adopt a DevOps culture to accommodate continuous integration

and rapid deployment of applications, the absence of security embedded in the API development lifecycle is placing organizations at high risk. APIs must also comply with an increasing number of governmental and industry regulations on security and privacy that are difficult to follow and maintain.

4.2. Foundations of secure access control

Secure access to digital systems relies on robust identity management mechanisms to associate user or service identities with the necessary capabilities in the corresponding access policy. Failure to properly manage identities can result in unauthorized access and actions by attackers, service accounts with excessive rights, or legitimate business partners abusing their privileges. Such risks require an assessment of the vulnerabilities of each access and authorization control mechanism used. There are several possibilities to ascertain whether a user is who they claim to be:

1. Something the user knows, such as a password or secret phrase.

2. Something the user possesses, like a security token or smartcard.

3. Something the user is, such as a fingerprint, face image, or iris code.

4. Something the user does, such as voice patterns or keystroke dynamics.

Approaches that rely on something a user knows are relatively cheap and easy to deploy but are also prone to multiple attacks (e.g., social engineering, phishing, clients' systems being infected on keylogging, reusing passwords across systems, etc.). The usage of something a user possesses is safer but might be inconvenient (e.g., carrying a smartcard and remembering to present it) and suffer from its physical possession being enough for impersonation. Approaches using biometric data are safer; however, they are more costly, technically demanding, and might cause privacy issues. A combination of two or more mechanisms is often seen in practice. Systems that require two or more of those mechanisms, such as a password plus a code sent to a mobile phone or a password plus a smartcard, are normally more secure.

4.2.1. Identity and authentication mechanisms

API security relies on the establishment of trust between parties such as users, applications, and services, with identity providing a fundamental assurance. The process of verification, or authentication, focuses on confirming credentials for declaration of identity across systems, in which credentials are data that support claims made by parties to a transaction. Appropriate identity and authentication mechanisms bolster the security posture of APIs and mitigate risk of unauthorized access.

Identity assurance levels helped characterize the effectiveness of these mechanisms. Methods with low assurance, such as static passwords, are ineffective if stolen or easily guessed, while high-assurance mechanisms such as smart cards or biometric signatures with liveness detection provide strong proofs of identity, but may incur high deployment costs. Organizations with high-risk or sensitive APIs should utilize stronger mechanisms such as token-based mechanisms (e.g., OAuth 2.0, OpenID Connect with FIDO2) or biometric signatures with liveness detection, while other APIs can still benefit from multi-factor authentication and username-and-password combinations with well-designed policies for password complexity and expiration.

4.2.2. Authorization models and policies

A wide variety of authorization models have been proposed in the access control literature. Most of the models vary with their appropriateness to particular contexts and their ability to express different policies. Yet they can be classified into a few main categories. The access control matrix model is often regarded as a conceptual cornerstone of authorization models because of its generality. It consists of a 2-dimensional matrix with subjects as rows and objects as columns. Subject-object pairs are assigned the right to perform a specific operation on an object. Practical realization of this model is more complex, and various alternative access control schemes have emerged to deal with different usage scenarios with better efficiency and ease of administration. The development of role-based access control a decade ago further popularized the idea of grouping users into roles with predetermined authorizations. Another popular authorization model is attribute-based access control, which policizes access decision based on user and resource attributes. These are generally queryable properties involving the specific user for an access request, the resource that is being accessed and the environment in which access is being requested. An access policy indicates what combinations of user and resource attributes grant or deny access. Further refinement results in combining the different types of components in a policy specification. Role and attribute-based access control mechanisms are often used simultaneously. The concept of the policy enforcement point has also been formally introduced into the literature and has become part of several respected firewalls and intrusion detection systems.

Access controls are enforced by components called Policy Enforcement Points (PEPs). They are deployed at the boundary of a trusted domain and enforce authorizations for all access requests that are entering or exiting the domain. When a request is made from an external source, the PEP queries the appropriate Policy Decision Point (PDP) to obtain an authorization decision based on the access control policy. A PDP examines the access policy and any additional context information to decide whether to grant or deny the

request. Specified attributes of the user making the request, the resource that is being accessed, the action being taken against that resource and the requesting environment can also be sent to the PDP to enrich the policy decision. A logical form of the decision from the PDP is sent back to the PEP, which enforces the action based on that decision. The redundancy of information exchange is reduced if the same PEPs establish and maintain a trust-based relation with each other.

4.3. API security governance

API security governance provides a top-down structural layer that ensures a coherent and appropriate set of security policies precedes and guides the design and deployment of API security solutions and capabilities. Security policies and capabilities—together with the security and compliance obligations of the organization, the associated risk assessment, and the security architecture—form the wider security governance framework. Governance frameworks for other disciplines or domains, for example those covered by ITIL, can also be relevant. Organizations should ensure that security investment and effort match their actual security requirements, not just their desire for security.

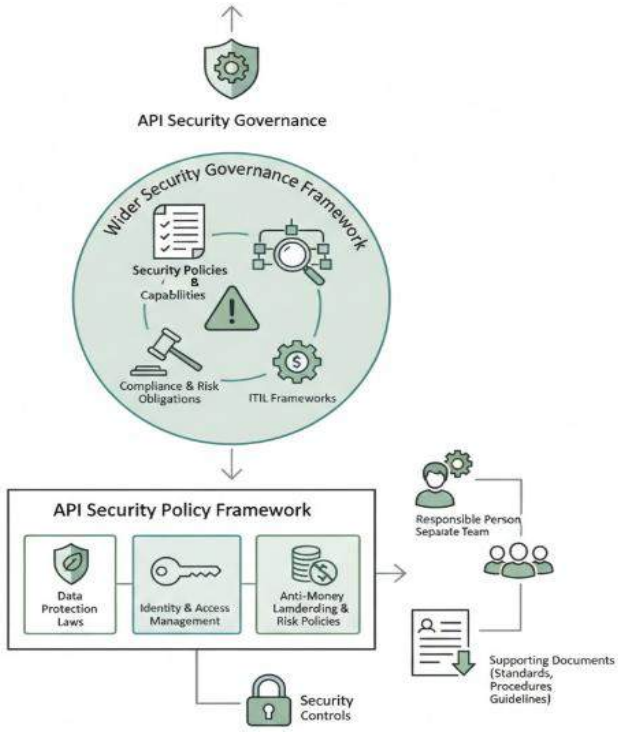

Fig 4.2: Top-Down API Security Governance: Aligning Policy Frameworks with Regulatory Compliance and Organizational Risk Architecture

The API security policy framework includes policies that govern the use of APIs and API connections, together with identity management and access management policies. These directly support regulatory and compliance obligations, including data protection laws, anti-money laundering legislation, and internal risk policies, and provide the basis for the corresponding supporting security controls. The high-level API security policies should be assigned to an appropriate responsible person and should reference the relevant underlying supporting documents—standards, procedures, guidelines, baselines, and definitions—controlled by other parties. In larger organizations, the maintenance of the supporting documentation often sits with a separate team, and the high-level policies simply specify the team responsible for individual documents.

4.3.1. Policy frameworks and compliance

API security governance policies clarify how APIs and their use are enabled, restricted, and monitored. API security policy frameworks define how APIs, their provisioning, and their use are governed and managed. These frameworks reference and incorporate supporting procedures, standards, and guidelines associated with API use. Policy frameworks define mandatory behavior and requirements for policy compliance; failure to comply exposes organizations to risk. Noncompliance may result from executive or management actions; incompetent, negligent, or malicious behavior; or deficiencies in people, process, technology, or compliance management. Some security policies are related to regulatory compliance. Security standards are also used to ensure that security controls support compliance with regulatory obligations.

Common security governance frameworks, standards, and regulations include COBIT, NIST SP 800 Series, ISO/IEC 27000, PCI DSS, HIPAA, and GDPR. Threat models and risk assessments identify business objectives and compliance obligations associated with risk appetite. These goals also inform, guide, and support the development of policy frameworks for API governance and management. Key enterprise risk areas associated with API security include the following: eroding brand reputation, loss of revenue and business opportunities; regulatory noncompliance resulting in financial loss; identification and exfiltration of sensitive or regulated data; identity theft; unauthorized access to privileged functionality; permissive API access; and violence against the organization, customers, employees, or partners.

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management actions; incompetent, negligent, or malicious behavior; or deficiencies in people, process, technology, or compliance management. Some security policies are related to regulatory compliance. Security standards are also used to ensure that security controls support compliance with regulatory obligations.

4.3.2. Threat modeling and risk assessment

Institutions must undertake threat modeling and risk assessment to evaluate security weaknesses throughout the API lifecycle. Threat modeling consists of identifying the APIs' asset owners, which functions as the basis for delineating the assets most critical for those owners, possible threats against those API assets, and appropriate mitigating measures. Analysts typically distinguish nine broad threat categories: malformed messages, insufficient input validation, credential-related weaknesses, misconfigured API gateways, entities impersonating either users or the system, excessive privileges allowing users to take actions beyond their normal entitlements, lack of operational controls, sensitive data exposure, and denial of service. For each category, the threat modeling exercise should enumerate the business processes and flows that are most susceptible to attacks leveraging the category, together with the business impact of successful exploitation.

Risk assessment evaluates the API portfolio's overall security posture from a risk-based perspective. It requires the definition of a risk appetite, which translates the organization's compliance and business obligations into a set of risk scenarios against which the organization desires to assess its exposure. The API portfolio is then scored against each of these risks, indicating the adequacy of existing mitigating controls using qualitative or quantitative risk metrics. The output, ideally presented as a heat map, categorizes APIs by the sensitivity of the data they expose, the criticality of the processes they support, and the risk mitigation controls that remain inadequate. High business-impact APIs with high residual risk exposure must be prioritized for additional hardening, be it by means of design and development principle enforcement, runtime protection, or ongoing monitoring.

4.4. API gateway and access management architectures

Centralized designs promote API management while also providing a single mechanism for enforcing policies relating to API security. Conversely, decentralized approaches are usually advantageous for performance-sensitive applications, as they cut out a hop in the request chain. By offloading complex authorization checks to local components, they can also reduce the latency of the overall API call. Yet, for deployments in heavily regulated sectors—such as finance and healthcare—centralized models remain

predominant. Centralization facilitates salient features, such as token revocation, orchestration and propagation of OpenID Connect identity tokens, or continuous verification using OAuth 2.0 Device Authorization Grant. Regulatory mandates also drive the uptake of specialized API gateways that act as Policy Enforcement Points.

Secure Access and Identity Management Architecture

OAuth 2.0 is the de facto standard protocol for delegating access to web APIs, while OpenID Connect builds on it to provide federated user identity across services. Both specifications follow a token-based approach, where the client receives an access token that it presents with every API call. Token orchestration can be leveraged to minimize the number of tokens issued to a user for an application. Authorization scopes allow for fine-grained access control, and the OAuth 2.0 Revocation Endpoint provides a simple means to revoke tokens before their expiration. However, no standard mechanism exists to revoke the access tokens issued for Azure's Device Code Flow or verify that the user's authentication context has not changed after an access token has been issued. An authentication service acting as a Policy Enforcement Point implementing additional OAuth 2.0 flows and orchestration for Azure Device Code Flow could address both concerns.

4.4.1. Centralized vs decentralized models

Centralized API gateway and access management models simplify architecture, security policy enforcement, and maintenance but can create single points of failure and performance bottlenecks. Decentralized designs, such as native service-to-service security, enable greater resilience and performance but require additional effort to implement and manage security and identity policies. The choice of approach should reflect organizational risk appetite, the criticality of the service, and performance expectations.

Centralization enables uniform policy enforcement and infrastructure maintenance. Organizations with limited experience implementing secure APIs may initially seek a shortcut by deploying a single API gateway to protect all services. Although this strategy can simplify exposure of the services to the Internet, a centralized gateway creates a single point of failure that attackers can target. Performance concerns may arise in high-throughput scenarios. Organizations that accept the trade-offs may consider adopting a centralized gateway in the initial phases of API exposure and subsequently migrating to a decentralized architecture as skills, processes, and tooling mature.

4.4.2. OAuth 2.0, OpenID Connect, and token orchestration

OAuth 2.0 is a delegated access framework allowing consolidation of authentication services within ecosystems comprising an originating, resource-providing, and identity-provider organization. External applications or services can then leverage resources exposed by a provider organization without requiring separate credential provisioning. It relies on a token-based model, where a token is tied to a specific flow that entails a precise set of scopes. The use of scopes allows the provider to finely tune the access permissions granted to the third-party application. Tokens can also have configurable lifespans.

The role of OpenID Connect (OIDC) is to extend OAuth 2.0 by adding an authentication layer on top of the simple authorization framework, and it uses OAuth 2.0 for its base role. With OpenID Connect, the identity provider generates an ID token that can be used to obtain additional user information. OIDC explicitly defines discovery capabilities so that the relying party can know the endpoints exposed by the identity provider and the metadata associated with it, including valid signing keys.

Token orchestration is an extension to a single tenancy OAuth implementation designed to support multi-tenancy deployments where multiple customer instances of a solution reside in a single environment, and the creation of customer specific OAuth providers to supply the identity management for each individual solution and its users. Without token orchestration, service-to-service calls within the environments would not have the relevant tokens to execute without generating a new token through the external provider for each call.

4.5. Secure API design and development practices

API security is built upon the principles, processes, and controls secure-by-design principle that apply to any system. Following security principles during design and implementation significantly reduces the number of vulnerabilities residing in the deployed software. Such principles, derived from accumulated security experience and knowledge, include:

1. Security-by-design The system is secure from the ground up. Security features and controls are necessary for the API to serve its purpose correctly and securely.

2. Defense-in-depth Protection against incorrect use and abuse is provided at multiple levels. Successful exploitation requires multiple conditions to be met by attackers, who cannot rely solely on hidden API endpoints or poor input validation to succeed.

3. Secure defaults Access control policies and mandatory security features that deny and prevent misuse by default are provided. The feature set represents the minimum required for service delivery. Sensitive features are disabled or hidden when not actively used.

4. Input validation Consistency checks and input validation are performed. Parameters are inflated so attackers cannot introduce invalid states through malicious arguments.

5. Cryptographic protection Protection mechanisms are applied. Secrets, tokens, and sensitive data are protected against unintended disclosure.

6. Auditability Assurance that the truth can be discovered is built in. All security-related events are logged in sufficient detail for forensic investigation while respecting privacy considerations.

Controls and standards for the protection of sensitive information are applied during all phases of the software development lifecycle. Secure design is validated through code reviews and testing.

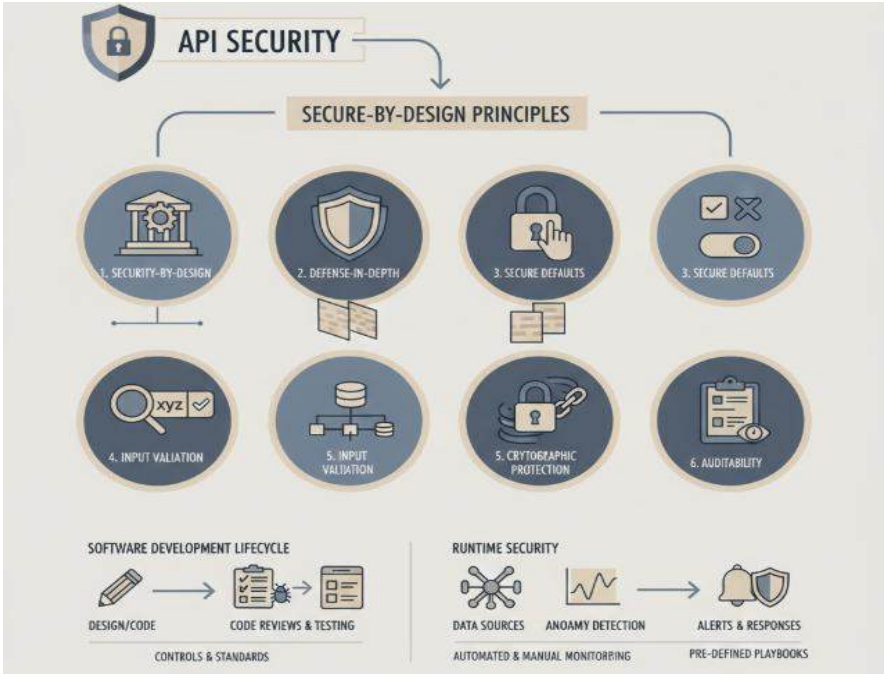

Fig 4.3: Holistic API Resilience: Integrating Secure-by-Design Principles with Proactive Runtime Anomaly Detection

Runtime security is implemented through automated and manual monitoring for anomalous activity. Anomaly detection systems use a variety of information sources. Discrete signals are merged or consolidated to form a comprehensive baseline of normal activity. When activity deviates beyond a pre-defined threshold, it is considered

suspicious. Suspicious activity triggers alerts or invokes automatic responses according to pre-defined playbooks.

4.5.1. API design principles for security

Security-at-a-glance principles, like those developed by bibliographer Jonathan Shapiro or the general principles of information security articulated in ISO/IEC 27002:2005, can be valuable touchpoints early in security-focused design. However, deeper security guidance can be drawn from a tiny fraction of the trove of software-specific guidance published under the auspices of the OWASP Foundation, the organization behind the security of the Web Application Security Testing Guide. Its Application Security Verification Standard covers Advanced API Security topics. Information security metapolicies, such as security by design, operation-value valuation, and cyclic design, are also relevant. These security-at-a-glance principles remind designers to incorporate security concerns into system design, to address expected failures as well as expected uses, and to recognize that appropriate measures can fail.

API Security-by-Design principles—security is considered during all phases of design, development, testing, staging, and production; validation checks are performed for every API input; cryptographic protections are applied to all sensitive data; and security controls and standards are defined in relevant policies—help counter the reality that not all software can be expected to be secure at first launch. One of the hopes underpinning security-by-design is that proper considerations can result in services exposed in such a way that additional external protective technologies (eg WAFs) are rendered largely redundant, or at least reduced.

4.5.2. Input validation, cryptographic protections, and auditability

Implementing input validation, cryptographic protections, and auditability requires determining necessary controls, relevant standards, and verification methods. Such controls are among the most commonly tested areas during application security assessments, regardless of security maturity. Various high-profile, public breaches can be traced back to overlooked or weak input validation and cryptographic controls. Moreover, auditing and monitoring controls help facilitate incident detection and response. When these do not meet established standards, organizations must put them in place or in line to mitigate risk.

Analysts performing web application security testing and source code review want to verify the presence of proper input validation, cryptographic protection of sensitive data, and auditing or source code review logging of security-relevant actions. For input

validation, specific controls vary but usually include verifying that a whitelist of allowed types, formats, lengths, and values have been implemented for known attack vectors that can affect either application integrity or confidentiality of sensitive data. They seek evidence that libraries supporting input validation have been incorporated, particularly ones that help ensure correctness or resistance for XML, HTML, JSON, and similar data types—for instance, XML-Schema or Relax NG. Such controls consider both positive and negative testing and, ideally, web application firewall validation.

The Web Application Security Consortium's Application Security Metrics provide an extensive set of best practice recommendations, addressing many of these areas with metrics that businesses can calculate for web environments. Additional best practice documents are also available from OWASP and others, covering specific areas of concern. Certain metrics have been compiled into the Payment Card Industry Security Standards Council's PCI Metrics Data Security Standard. Given their mission-critical status, Payment Card Industry-related e-commerce sites are also urged to conduct regular forensic audits by third parties approved by the credit card networks.

4.6. Runtime protection and monitoring

IAM systems continuously enforce policies on API calls. Despite this, there is a limited ability to respond to policy violations that could arise from legitimate users abusing their authorizations or their accounts being compromised. Anomaly detection and behavioral analytics complement IAM and API security capabilities. They help identify such threats, irrespective of whether a malicious insider or an external attacker with stolen credentials is involved. Discovering new attack patterns and unexpected asset behavior is critical to disrupting breaches-in-progress and identifying misconfigurations, vulnerabilities, and resource misuse.

For a behavioral detection scheme to operate effectively, the attackers' behavior should differ from that of authorized users or trusted entities. Security teams must identify the relevant signals and parameters specific to their environment, analyze API utilization patterns—by user, service, or an entity combination—and define baselines for normal, abnormal, and malicious usage. Based on these models, detection rules can be built, and response playbooks established.

In addition, scrutiny of the logs emitted by API gateways and services can reveal attempted misuse and actual breaches. Unauthorized calls can be flagged for follow-up. To clarify, such flagging is a crucial part of a detection system, but it alone does not constitute detection. Forensic investigation should include careful logging on APIs and services—logging everything that could be needed—but keeping in mind storage needs, privacy issues, and the gap between usage and investigation. A detailed, authoritative

statement of the forensic evidence expected in the event of an incident should be developed beforehand. Traceability mechanisms provide the ability to reconstruct what happened on assets during a breach. Vulnerable assets and attack vectors are prime targets for behavioral analysis.

4.6.1. anomaly detection and behavioral analytics

Behavioral anomaly detection identifies unusual behavior in API traffic using a range of data signals. These typically include A) popular APIs and average usage patterns in terms of requests per minute/week/month, B) risk ratings for API endpoints that reflect external exposure, security controls, and architectural role of each endpoint (see, for example, the data classification of the NIST API security guidelines), and C) recent usage patterns for a key set of APIs. A baseline for normal usage is required, and a scoring mechanism assigns a risk level to the current state of API usage. Anomalies may suggest illicit activity, such as API abuse, automated API attack tools, account takeover, internal exploration by a compromised user account, and malicious insider activity, though they may also reflect perfectly legitimate events such as unusual spikes in legitimate application usage (for example, a marketing campaign driving extra traffic to an application). These false positives need to be resolved in a timely manner, as excessive false positives will wear out the analysts inspecting them.

Timely resolution of anomalies is best achieved through a pre-defined detection response playbook that lays down the recommended next steps for investigating anomalous API usage. Playbook steps will vary from organization to organization and are likely to include options such as A) running a full audit of the user account or application ID associated with the triggering usage especially in cases where the user account's risk level is high or very high; B) scanning the code of the consuming application for security flaws; C) inspecting application logs to verify the actions being performed; D) reaching out to the owner of the application to verify the behavior; and E) disabling risky user accounts or application IDs. Anomaly detection will remain the primary means of discovering abnormal behavior in API traffic, but it will be bolstered by intensive traffic replay during security incidents.

4.6.2. logging, tracing, and forensics

Logging and tracing capabilities are indispensable for incident forensics and enabling rapid, effective responses to API-related security incidents. These capabilities furnish the essential data absorbers for anomaly detection, behavioral analysis, and incident response playbooks described in the previous section. Log data from API proxies and related components are among the most important data sources feeding forensic

investigations; events generated throughout the API ecosystem—external systems consuming APIs, internal systems serving API requests, resource servers responding to requests for protected resources, and the service filler/operation implementing the business logic for request processing—often provide the most relevant and precise data required for incident investigation and damage evaluation.

Forensic and incident-response considerations include the volume and type of log data retained, retention timeframes, privacy implications, and the ability to preserve evidence required to support law enforcement investigations as part of the act of contrition for providing insecure APIs. Detecting security incidents is relatively useless if effective response cannot be provided rapidly. Forensics and root-cause determination are important for all security incidents, but systemic problems can sometimes be detected through detection-and-response playbooks utilizing only the most relevant signals. Combining automated detection with forensics and incident response playbooks that equip and prepare the organization for the most common incident types allows security teams to achieve maximum agility while minimizing resource expenses.

4.7. Conclusion

APIs are a core technology in contemporary applications, serving several vital roles that vary by use case. Organizations recognize that APIs are not immune to attack and have been investing in health monitoring (for example, throttling and rate limiting), but not necessarily for better overall API security. Governance frameworks for API security are beginning to emerge, but concrete implementations are still lacking. Due to their critical roles, firms can evaluate their information assets' respective security risk profiles and then correlate API-specific threats and risks to identify required mitigations.

An API security policy should ultimately organize guidance for an organization's APIs in harmony with industry guidance, regulatory requirements, and organizational risk tolerance. A secure orchestration architecture can help organizations gain some benefits of delegation without suffering identity exposure. If multiple partners are involved, the burden is greater, especially in managing token lifecycles and ensuring that authorization tokens are kept small. Different alternatives should be weighed for a particular deployment with attention on overall performance. Access management options can also include out-of-band administration, where trusted parties rely on API-defined side channels for sharing credentials while access management decisions reside strictly at the API endpoint as a security control necessary for ensuring least privilege.

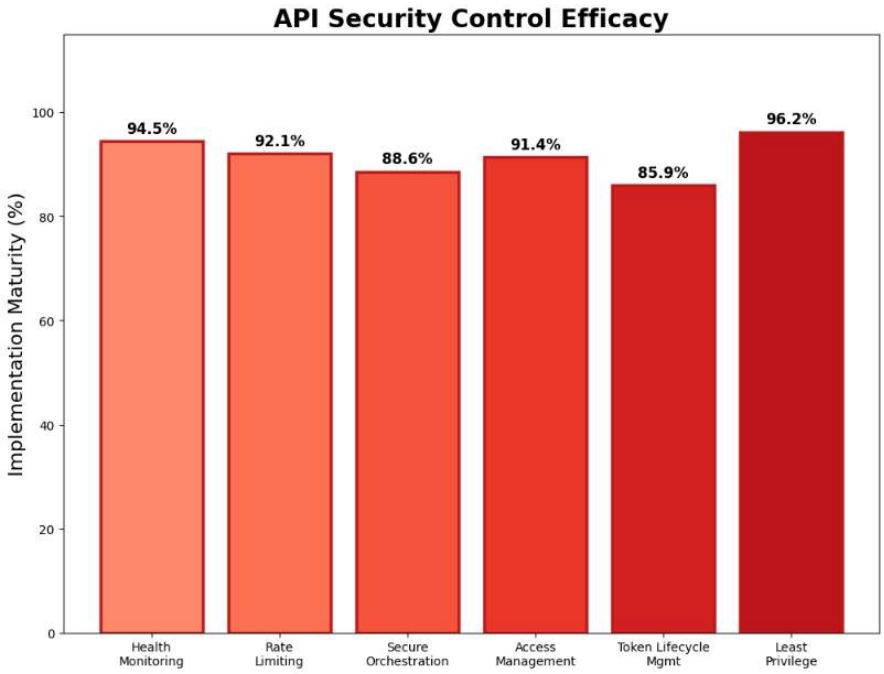

Fig 4.4: API Security Control Efficacy

4.7.1. Summary and Future Directions in API Security

API security is an emerging area of research and practice, driven by the growing reliance on APIs in enterprise architectures, the introduction of serverless applications, and the prevalence of distributed microservices implementations. An API security governance framework maps organizational compliance obligations to the risk posture and establishes the foundations for secure API architecture and runtime monitoring. Moving beyond API traits and vulnerabilities, it specifies threat categories, asset criticality, and risk treatment for API exploitation within the context of a threat model. API gateways and access management frameworks are central to safeguarding against the identified risks, automated API testing remains essential, and support for mutability and resilience is a recurrent theme.

API security will continue to be an active area of investment and research. Future directions include providing specialized tooling for managing the entire API lifecycle, from design and consumption through development and publishing to retirement, in a coordinated manner that incorporates security, automates compliance, and eliminates manual tasks; developing libraries for building APIs securely, incorporating reusable design patterns and prebuilt validations that are applied automatically; undertaking

empirical research to enhance API design principles; and standardizing an API threat model.

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