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Chapter 8: Monitoring, Observability, and Operational Resilience

8.1. Introduction

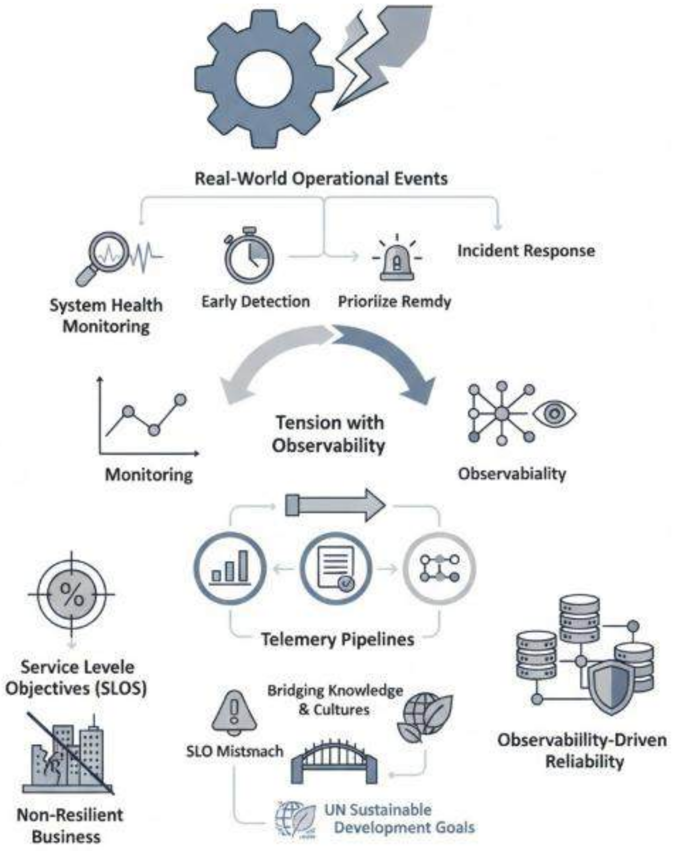
Sustaining operational resilience is widely discussed yet remains poorly defined. At times it has been suggested to denote the ability to respond to unplanned events, while at others it has been equated with disaster recovery, business continuity, or even just predictable outages. This paper takes the more detailed exploration of operational resilience introduced in Baker et al. under the term observability-driven reliability. This perspective stems from a thorough analysis of observing systems and the role they play in operational resilience

Experimentation is crucial to functioning and being able to learn. Environments that are primarily physical generally allow relatively simple experimentation. In cloud computing, not only development but even production systems can be treated like Test & Development systems. Indeed, many production systems are operated with "the economy of resources" approach; a new version of a web-based application runs while simultaneously being tested in pre-production development stage, something that was difficult to achieve when one had to use expensive hardware to host the system. Under this approach different scenarios are set up to automatically test designer-developer hypotheses. Observing security is primarily carried out using honeypots; systems and networks are monitored at best with anomaly detection software.

8.1.1. Overview of the Study

Real-world operational events can be costly and materially disruptive, and it is vital to obtain a surface understanding of system health to detect important issues as early as possible, to prioritise remedy efforts, and to support incident response efforts after the event. Monitoring provides these capabilities, though it exists in a tension with observability: whether a system is considered sufficiently observable depends on the nature and scope of the operational concerns during it entire life-cycle, from the run-up to production through to decommissioning. Achieving the correct level of observability for a system, especially one that is increasingly using event-driven or serverless architectural styles, places heavy emphasis on support for telemetry pipelines within observability-driven reliability vectors and on supporting mechanisms that integrate the three core data types metrics, logs, and traces needed for ols in a natural way.

With users increasingly reliant on service level objectives in production, emphasising the observability aspects of monitoring systems must be a key consideration for an architecture supported by enabling systems. A mismatch between an SLO and the ability to monitor it will result in a mute, but not deaf, warning noise to operations when SLOs begin to suffer; regardless of the associated set of indicators of impending failure that have been built and integrated, if it cannot be measured, detected and responded to, the business is in fact non-resilient.


Real-World Operational Events
Incident Response
System Health Monitoring
Early Detection
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Monitoring
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Telemery Pipelines
Service Levele Objectives (SLOS)
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Non-Resilient Business
UN Sustainable Development Goals

Fig 8.1: From Monitoring to Observability: Aligning Telemetry Pipelines and Service Level Objectives (SLOs) for Resilient Architectural Reliability

8.2. Foundations of Monitoring and Observability

1. Distinguishing Monitoring from Observability

Monitoring and observability are often used interchangeably, but they represent fundamentally different concepts. Monitoring refers to the collection and management of information about a system's operating state, such that it can be used to assess its health and performance, and to respond to unwanted degradation. Observability, on the other hand, reflects the extent to which the internal state of a system can be inferred from its external outputs. Monitoring is thus a system function which reflects the implementation of an observability plan.

Monitoring is a specification of the information collected, and how it is used to assess whether the system is behaving as intended. It is guided both by the design constraints of production and the engineering constraints of operational cost, and whether or not the information has business value. Therefore, it is tightly coupled to telemetry pipelines. The goal of monitoring is to enable rapid detection and recovery from undesirable states, and thus prevent outages. If recovery is not possible, monitoring aims to mitigate user impact by alerting the relevant teams and triggering predefined response actions. Monitoring also contributes to historical record-keeping for post-incident analyses.

2. Core Principles and Objectives

The distinction between monitoring and observability has three implications. First, monitoring is a necessary condition for operational resilience, but not a sufficient condition. Just meeting the monitoring needs of production does not guarantee that the system is designed to be resilient—i.e. that it can recover quickly from unknown anomalies without suffering major degradation of service during the recovery. Second, while monitoring remains important, a greater goal is to improve the overall observability of production software. Achieving effective operational resilience demands balancing the cost of monitoring with the more costly—and more difficult—task of enhancing observability, so that systems can recover gracefully from unknown issues. Finally, monitoring is also only one aspect of building system capability to deal with incidents. Other design-time considerations—such as testing, training, and playbook creation—are also important enablers of incident response.

8.2.1. Distinguishing Monitoring from Observability

The concepts of monitoring and observability are often conflated in discussions of system behaviour. Monitoring, scoped broadly to include both the active review of signals and the associated alerting and response for abnormal conditions, is mainly interested in detecting, diagnosing and responding to conditions that are well understood.

That is, situations for which specific heuristics based on known error conditions can detect problems in real time. This is true at least at a high level, if not on an individual basis for all the signals. In many cases, engineers know the type, frequency and severity of errors (“known knowns”) that should invoke specific responses. Observability, in contrast, is about understanding system behaviour in situations where the software is not well understood, either due to lack of historical data or blind spots in the monitoring heuristics, or where the root cause is ambiguous, such as a performance or usability question.

Although they pursue different goals, the success of observability as a new architectural focus was initially driven by SRE and site-availability concerns. With the shift to service-oriented and cloud-native architectures, the coupling of observability with operational resilience has become prominent. The latter focuses on a system's overall capacity to cope with continuous change and find balance rather than stay in equilibrium, using concepts from resilience engineering to build incident-management processes that emphasise learning and improvement over speed and rigidity. Despite this growing usage, the relationship between operational resilience and observability-driven reliability remains understudied. This section examines operational resilience from several perspectives and reviews current research on how its engineering principles and practices relate to incident detection and response, specifically support for SRE, reliability engineering and chaotic testing.

8.2.2. Core Principles and Objectives

Monitoring offers insight into operational state and health through distinct sources at known locations. Observability is the capacity to discern a system’s inner workings through outputs alone and requires sufficient and appropriate observation signals from anywhere. For example, the logged messages output by microservices, containers, or the cloud are generally sufficient for understanding any faults, but it typically requires comprehending how these systems are instrumented and deployed.

The primary control objectives of observability are ensuring that alerts during demand exceedance increasingly hint at the causing burden and that there is sufficient evidence to drive prompt corrective actions. Good practices vary within situational constraints apply to telemetry pipelines in common, which means that SRE, DevOps and other incident management teams invariably benefit from good observability engineering with adequate adoption of the SRF. Also, the diversion of external and internal events is increasingly at risk of disconnect because many enterprise cloud workloads do not actively need a separate pipeline, which is treating another system as a simple service. Disconnection increases evident risk wherever others can enter or use the internal systems.

8.3. Architectural Considerations for Observability

An enterprise's observability requires particular attention to its telemetry pipeline (the analytic backend responsible for aggregating and analyzing the telemetry data) and to the ways in which systems generate and utilize telemetry data. The metrics, logs, and traces of observability need to be considered not merely as distinct, complementary data types, but also as collected data viewed from multiple perspectives, which must work together to establish a coherent picture of system states over time and by which different types of analyses of system behavior can expand on analysis of single types of data.

Telemetry Pipelines and Data Pipelines

The telemetry pipeline, as defined in Chapter 1 of this book, is a specialized type of data pipeline namely, the analytic backend that consolidates monitoring and observability data for examination, exploration, and analysis. Like a data pipeline, the telemetry pipeline requires effective engineering before any data is moved into it. However, data-flow management becomes especially important in the telemetric context as that data passes beyond disposal and classification, and enters the control and utilization phases. The telemetry pipeline's control phase is determined by how the data are transformed "cleaned, enriched, compressed, anonymized, and so on" and also configures the resources used. The utilization phase concerns how the final data are made accessible for further exploration, querying, and analysis. These control and utilization tasks are usually performed by specific tools such as metering and billing solutions, seam analysis products, and internal or external regulatory compliance engines. An effective telemetry pipeline also assures that data reside in the right consumer-space location and also considers storage for machine-learning data sets, such as that needed to implement anomaly detection.

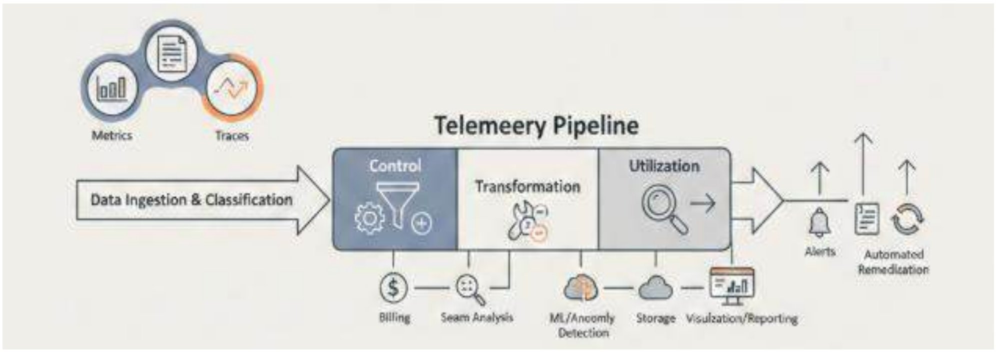

Fig 8.2: Multidimensional Telemetry Architectures: Optimizing Control and Utilization Phases for Enterprise Observability

The telemetry pipeline also requires particular focus, because evidently high-value types of alerts, reports, detections, visualizations, recommendations, or any other predictive decision-making or automated remediation or correction operations that consume monitoring and observability data most immediately depend on the data being in a usable form and readily accessible in the right contexts.

8.3.1. Telemetry Pipelines and Data Pipelines

Telemetry and data pipelines should be regarded as distinct, albeit interconnected, systems. Telemetry pipelines transport telemetry data metrics, logs, or traces from the origin through one or more processing stages to storage or other consumers. Data pipelines move data to be analyzed either a batch of data from telemetry or data from a different source. Certain tasks that are traditionally regarded as specific to telemetry pipelines may be more closely aligned to those of data pipelines: for example, experimentation through A/B testing and self-service analytics.

Extensive telemetry pipelines, processing data to serve multiple consumers with diverse requirements, have been made practical through cloud-computing technologies. The large-scale availability of cloud bookmarking with sufficient capacity for storing, retaining, and serving telemetry data creates opportunities for organizations to augment traditional analysis of telemetry by investigating the telemetry data deeper. Such analysis has traditionally been limited to specialists due to the cost of storage and difficulty configuring systems such as data lakes. Cloud-computing technologies have also made integrated cloud-native platforms available as managed services, allowing organizations to focus more on the analytics than the plumbing.

8.3.2. Metrics, Logs, and Traces: Integration Patterns

An ideal observability architecture provides a storage and analysis model for metrics, logs, and traces based on denormalized data organization, stores that allow potentially heavy and expensive operations to be performed more efficiently, and access controlled and optimized for scale. Event-oriented systems, users of fully managed observability services, and organizations just starting their telemetry-driven observability journey can achieve many of these advantages by using the frontend design pattern, which integrates logging and tracing to reduce the amount of data stored.

Establishing the integration patterns is an important step to realizing the advantages of an observability-driven reliability approach. All telemetry pipeline designs pooling telemetry generated in different service layers can help build a well-structured observability platform that supports dense service layers and uses logs and traces as means of operational optimization rather than permanent records of all events in the system.

8.4. Observability-Driven Reliability

No consensus exists on the meaning of operational resilience, nor is such consensus, especially a precise one, necessary. Consistency within roles performing operations (i.e., reliability engineering) and supporting observations and predictions (such as Site Reliability Engineering) suffices. Nevertheless, differentiating resilience from related concepts can clarify its objectives and desired outcomes. Resilience refers to the ability to withstand adversity without losing essential capabilities, recovery describes returning to operational status as quickly as possible, and a downgrade is the ability to continue service delivery while sacrificing some capabilities. Resilience engineering explicitly focuses on defining, measuring, and enhancing operational resilience.

Operability is another related concept that centers on the attention and knowledge necessary for safe and reliable execution of production software by operations. SRE, a set of practices and principles for reliability engineering in a cloud-native, service-oriented architecture, is an implementation of resilient engineering within modern technology companies such as Google. SRE's goal is to enable high availability of production services through the management of reliability risk, which is determined and constrained using Service Level Indicators (SLIs), Service Level Objectives (SLOs), and Service Level Agreements (SLAs). The relationship between resilience and SRE is straightforward; enhancing an SRE's ability to reliably and safely execute production software improves an organization's operational resilience by supporting the timely resolution of incidents.

8.4.1. Definitions of Operational Resilience

Operational resilience emerged as a concept in the financial services sector around 2013 to address the growing risk of systems and services failing from externally directed adversarial actions. The Financial Stability Board defined operational resilience as the "ability of firms to withstand severe operational disruptions" and said "firms need a strategy to safeguard operational resilience, testing it as they would for the recovery of their data and IT systems." In 2016, the UK regulator Bank of England posited that "an Omnibus Understanding of Operational Resilience must be based on three core ideas": disruption to critical services can have severe consequences for society and the economy; many of these consequences are not reversible at any appropriate time horizon; and firms cannot fully eliminate resilience in their products or business operations.

Another definition put forward by a panel of the Financial Stability Institute was that "operational resilience for a firm is its capacity to absorb internal and external shocks while continuing to deliver its critical products and services." The essential components of such definitions are the notion of "resilience" – enabling systems and services to withstand failure – together with an emphasis on the consequences of failure – the inability to deliver critical products and services to customers.

8.4.2. Resilience Engineering and SRE Practices

Operational resilience, according to the NIST definition, extends the concept of reliability to include non-availability caused by cybersecurity events. Consequently, an SRE perspective requires a broader focus. Reliability was once simply equated with uptime, but it has evolved into a multifaceted concept that considers how systems should behave during failure states, including non-standard scenarios. Similarly, operational resilience encompasses successful response to defined failure modes, not just degree and duration of outages. Resilience Engineering, a field developed by Erik Hollnagel, David Woods, and Nancy Leveson, shares this focus; the principle of focus on success extends to the design of monitoring and observability strategies.

Successful failures, or incidents that produce useful information, are central to the NIST description of operational resilience. Idea generation through "after-action" discussions is common; less so is direct cross-team sharing of information contained in runbook and playbook descriptions. Post-exploitation kill chains provide a framework for examining and categorizing information contained in incident response documentation, enabling its potential use as training data for domain-specific models for systems less amenable to traditional knowledge management approaches. Resilience-boosting strategies also offer fertile ground for language model experimentation.

8.5. Monitoring in Modern Architectures

Modern architectures, particularly cloud-native, microservices-based environments, introduce operational complexity that makes effective monitoring increasingly challenging. The aggregate volume of events across an environment can be overwhelming. Each component naturally generates its own operational data, but these components also respond to events generated by other components, adding further to the volume of operational data and noise around any incident. Additionally, running many components increases the chance of observing a coincidence of failures. The data pipelines used to collect, transform, and load operational data into data stores for subsequent analysis can experience overloads similar to the overloads seen in telemetry pipelines.

Modern architectures that embrace the Event-Driven Architecture (EDA) style present similar challenges. Event storming can result in a very large number of events being processed across a system. In a serverless environment where stateless microservices (such as AWS Lambda) automatically scale in response to incoming requests, each service automatically scales according to the demand placed on it at any point in time. Although traffic jams and road vehicle accidents are investigated only when the real cause of the accident is established, the possibility of coincidence of failures remains. Maintaining awareness of the health of the myriad services, particularly in terms of their latency and error rates, remains fundamental, but these aspects cannot be monitored in isolation.

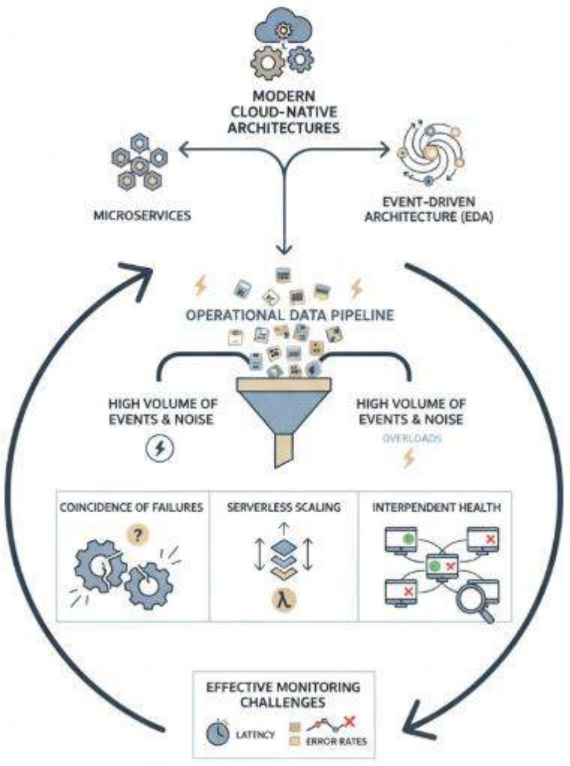
MODERN CLOUD-NATIVE ARCHITECTURES
MICROSERVICES
EVENT-DRIVEN ARCHITECTURE (EDA)
OPERATIONAL DATA PIPELINE
HIGH VOLUME OF EVENTS & NOISE
HIGH VOLUME OF EVENTS & NOISE
OVERLOADS
COINCIDENCE OF FAILURES
SERVERLESS SCALING
INTERPENDENT HEALTH
EFFECTIVE MONITORING CHALLENGES
LATENCY
ERROR RATES

Fig 8.3: Navigating Observability in Cloud-Native Ecosystems: Addressing Event Overload and Failure Coincidence in Serverless and Event-Driven Architectures

8.5.1. Cloud-Native and Microservices Challenges

Natural difficulties arise when deploying applications as cloud-native. Initially, the process ought to be relatively trivial; any properly constructed application should behave normally when deployed to a cloud offering—indeed a major selling point of cloud providers. Sufficient early cloud successes in deploying what were originally monolithic back-end applications for web front-end clients fostered the misconception that simply using containers or microservices would magically simplify the engineering burden and operational requirements of applications. However, achieving cloud-native status is not just a matter of using containers appropriately; cloud-native encompasses thoughtful architectural and infrastructural design decisions, reflecting the natural associate pattern and the added considerations that architectures must support.

Microservices adoption has added to the difficulties. The natural difficulties attendant on separation of concerns, different development and deployment cycles for services, location transparency, interface management and stability, and overwhelmed remote-system dependencies between microservices have been widely discussed. Yet these aspects and the inherent complexity of such systems have not much dulled the rush to adopting microservices, nor diminished the difficulty of operating such systems reliably.

Microservices and cloud-native computing respond naturally to massive increases in system scale and functional complexity, and to the consequent operational pressures; yet the complex interactions between scale, error activity, and monitoring make it difficult to detect when the system requires wider visibility or deeper insight at a given time; justify the provisioning of centralised solutions; or ascertain the best way of configuring such solutions. As external operations demand greater engineering investment, and engineering resources are increasingly stretched, sound priorities are essential. Continued unsound priorities lead to broken views that are out of touch with why monitoring exists.

8.5.2. Event-Driven and Serverless Environments

The asynchronous nature of event-driven and serverless architectures makes monitoring a challenge. Requests are not inherently monitored from beginning to end, and other service-level contract guarantees (when they exist) are often limited to bursts of invocations due to scaling. This may easily lead to performance regressions being masked by monitoring that is based on purely historic analysis.

Some solutions exist for identifying regressions using past usage patterns. Outlier detection algorithms can also be successful in identifying anomalous service behavior. Marking an entire component as being Laplacian (shaped like a Laplacian distribution) and looking for degradation of the service under heavy load conditions can trip an alert or initiate a runbook. Simple distribution-based methods are typically not enough, as performance really depends on the actual request distribution experienced at any point in time. These approaches can also lead to excessive alert noise. As is the case for microservices, heavy load situations (or apparent queuing behavior) should be monitored very closely as well, since they usually expose weaknesses in implementations. Combining the written alert rules with known amplication factors and scaling frequencies of the volumes may significantly diminish alert noise. When possible, offering a DoS protection surface can warn about excessive triggering.

8.6. Incident Detection, Response, and Management

Response and management relate to the strategy for dealing with potential or actual failures in systems, services, or business processes. Alerting strategies provide a high-level view of what is being proactively monitored and whether alerts result in beneficial and timely action. Runbooks, playbooks, and post-incident review documents provide a lower-level view describing the procedures and steps undertaken at the moment of response and the retrospective learning from the systems' observed behavior.

Once again, the sources covering this area are not concerned with alerting policies, alert fatigue, runbooks, or playbooks. It is recommended, therefore, to look at research and publications arising from resilience engineering (Hollnagel et al., 2006) and those focusing specifically on operational resilience, as defined by Hill, (2022). In the case of Servicenow, for example, the definition is "operational resilience is the ability to withstand disruptions and improve customer and employee confidence. It encompasses all aspects of business, from people and processes to technology, cyber security, supply chain, and beyond." Servicenow also establishes how monitoring and observability enable the practice.

8.6.1. Alerting Strategies and Noise Reduction

Incident response is often thought of only in terms of incidents that are severity level three or higher (severity level one normally being a significant outage). Many organizations adopt the first early warning stage of response – alerting – but often neglect to define responses to information-only alerts. Simply adopting and putting runbooks into place for severity level one alerts is an area of concern itself.

From a wider-level perspective, severity level three incidents often receive the majority of attention from operational teams. This includes fielding the initial incident response, restoring service, problem management activities, and post-incident reviews. Severity level one incidents are typically churned through without substantial thought, resulting in fatigue, burnout, and ultimately reduced trust in operational teams and the tools they provide.

For increasing trust in warning signals, separating information alerts based on observability, telemetry, and job completion is sensible. The observability framework could, for example, generate early warning signals for high error rates in an application, automatically advanced health checks to external partners, and raise information alerts when failures occurred in batch job completion. Having clear owners of information alerts is still important, but it is equally important not generating excessive informational noise.

Against that background, using noise metrics during incident review can introduce a data-backed approach to mitigation. Low noise events quickly grow in level of attention, tripping more alerts which leads to more noise which in turn causes subsequent events to be ignored or missed altogether.

8.6.2. Runbooks, Playbooks, and Post-Incident Review

Runbooks provide document-level details on manual procedures, leaving critical tools under-applied. As primary user guides for operational staff, playbooks centralize for attached incident contexts. Sharing with reliant teams invites civility and ownership outside core operation. Such comfort leads easy assistance in critical situations like alerts and outages.

A properly structured post-incident review process forms a core activity for any reliable and reliable setup. The review assembles the diverse participants, supplying a forum that invites multiple perspectives and addresses blame and issue ownership. Early selection of participants and assurance of prompt schedule encourages openness. Key documents fill early, replaced, or complemented by recall and discussion once the active environment begins to fade. Referencing notes, runbooks, playbooks, roadmaps, and observability sources keep focus and environmental details close.

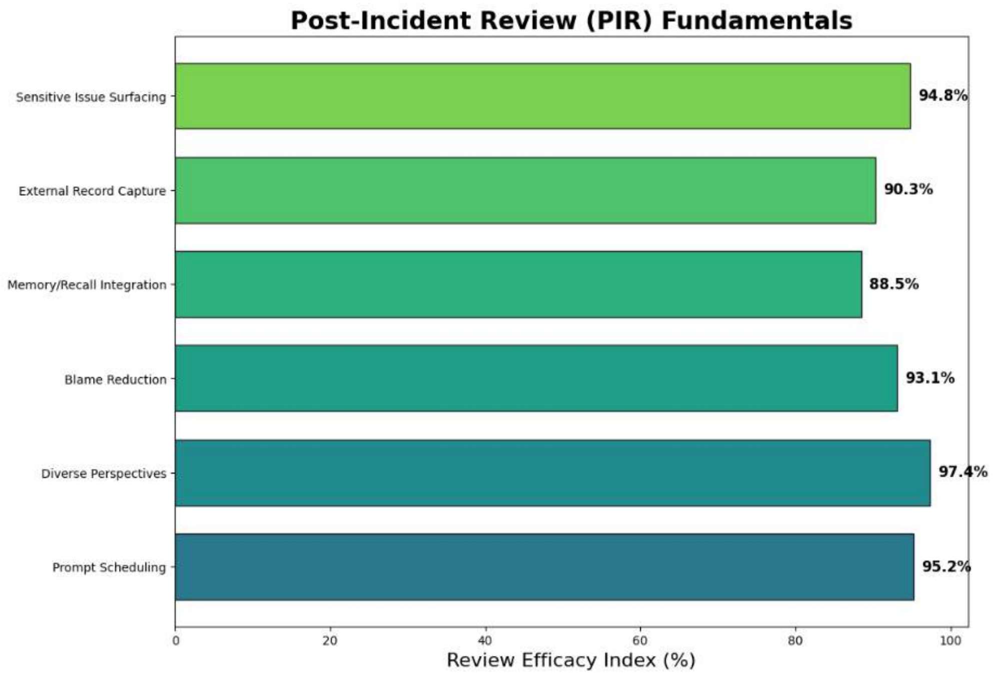

Fig 8.4: Post-Incident Review (PIR) Fundamentals

Capturing successive stages within external records, the discussion observes comfort-disabled aspects, general surfacing, event timing, and response choices comprehensively yet concisely. Transitioning context lets sensitive issues appear. Traffic spikes often mask yet cause other key issues, such as untrustworthy throughput.

8.7. Conclusion

Moore proposed that systems should be accurately modeled and that control operators should always have full knowledge of the current configuration of the entire system and its expected behavior if everything were functioning correctly. Despite the challenges of maintaining such an ideal state, Society 5.0 can be achieved. Significant advances in monitoring and observability, including real-time online simulation of service behavior and automated analysis of behavioral discrepancies, make Moore's proposal increasingly pertinent.

The overview covers the basic dimensions and various interpretations of monitoring and observability and their roles in ensuring operational resilience. Definitions, concepts, and pillars for operational resilience are presented and then examined in the context of both approaches. The different monitoring challenges that arise for modern architectural patterns, including cloud-native application development and event-driven, microservices-based, and serverless architectures, are identified. The objective, formal approach benefits different types of systems and architectures since an extended definition of operational resilience and the associated engineering discipline can provide an integrated framework for the evolving area of Site Reliability Engineering (SRE), regardless of whether SRE is in charge of a service or simply responsible for ensuring its reliability.

8.7.1. Final Thoughts and Future Directions

Resolving the ongoing debate on the terms monitoring and observability, this work examines the respective instrumentation solutions a system architect must apply to achieve operational awareness, resilience, and reliability across different architectural designs. The discussion considers monitoring in a cloud-native microservices architecture built around containerisation orchestration, a composite event-driven design employing messaging, and an event-driven serverless model. It concludes with an analysis of incident detection, response, and management, as supported by monitoring.

Resilience, according to NIST SP 800-160, is the ability of a system or organization to prepare for, respond to, and recover from incidents. Recent years have seen an upsurge of interest in observability and operational resilience following the publication of the

Site Reliability Engineering book series. Yet many definitions are vague and few papers consider observability or operational resilience across architectures. Distinctions, principles, patterns, and patterns' interplay are clarified and consolidated in an extensive taxonomy chart.

Monitoring, in every case, is a necessary part of the telemetries of a resilience-capable and observability (test) capable architecture, but observability is a requirement for monitoring-driven resilience.

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