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Insight Log: A Lightweight Framework for Explainable Incident Detection in Linux System Logs

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Abstract: ***Modern Linux systems generate massive volumesof authentication and system logs that capture critical security events. However, traditional log analysis methods struggle with the high volume, unstructured format and noisy nature of these logs, making timely detection of suspicious activity difficult, especially in small-scale and resource-constrained environments. EnterpriseSecurityInformationandEventManagement(SIEM) solutionsareoftentoocomplexandexpensive,whilebasiclog viewers offer no automated analysis. This paper presents InsightLog, a lightweight, rule-based framework for explainable incident detection in Linux environments. The framework per- forms structured log parsing using regular expressions, rule- based anomaly detection with temporal window analysis,and incident correlation to transform unstructured log data into coherentincidentcontexts.Ahuman-in-the-loopdecisionsupport interface provides explainable summaries and evidence-linked recommendations, requiring explicit operator approval before response execution. Experimental evaluation demonstrates that InsightLog processes 5,200 log entries per second with 99.2% parsing accuracy, achieves a 96.5% detection rate with 2.3%false positives, reduces alert noise by 78% and consumes only 120MB RAM and 8-12% CPU on standard hardware. The framework provides a practical, accessible security monitoring solution ideal for academic institutions, small organizations and security research applications.***

Index Terms—Log Analysis, Anomaly Detection, Linux Se- curity, Incident Detection, Rule-Based Detection, Human-in-the-Loop, Explainable AI

I. INTRODUCTION

Inthemoderndigitallandscape,Linuxsystemsserveas the backbone of countless servers, cloud infrastructures and critical applications, generating massive volumes of log data that capture system activities, security events and operational metrics.Authenticationlogs(auth.log)recordloginattempts, authentication failures and user access patterns, while system logs (syslog) capture service events, hardware status and system-level operations. These logs contain critical forensic evidence essential for identifying security incidents and con- ducting post-mortem investigations.

However, the exponential growth in log volume has made manual log analysis increasingly impractical for security monitoring and incident detection. Traditional log analysis methods typically depend on reactive approaches: waiting for an incident to occur, manually sifting through thousands oflog entries and relying on static rules or keyword matching to identifysuspiciousactivities.Thiscreatessignificantdelaysin threat detection and leaves systems vulnerable during critical windows of attack.

Current security solutions often swing between two ex- tremes: heavyweight enterprise SIEM systems that require substantial computational resources, complex infrastructure and specialized expertise, or basic log viewers that offer no automated analysis capabilities. Furthermore, many modern AI-based log analysis tools operate as black boxes, providing little to no explainability for their detection decisions and removing human operators from the response loop.

Significant research has been conducted to advance au- tomated log analysis. Lohar and Baraskar [1] presented an automated AI tool using LLaMA 2 for log file analysis, demonstratinghowlargelanguagemodelscanstreamlineerror detection and anomaly identification. Pan [2] introduced a Transformer-basedmodelusingself-supervisedandreinforce- ment learning to address heterogeneous log sources and lim- ited labeled data, achieving F1-scores of 0.988 on benchmark datasets.BhuiyanandRahman[3]identified54log-related codingpatternsacrosssixattackcategoriesusingtheLOPSUL static analysis tool. Chan et al. [4] proposed a hybrid solution combining anomaly detection with blockchain for tamper- proof log storage. Andrew [5] explored NLP applications for log analysis and automated alert prioritization in enterprise IT and AIOps platforms.

The Gap: While these works offer valuable approaches for AI-driven log analysis, there is still a need for a lightweight, explainable and human-centric log analysis framework that canoperateefficientlyonstandardhardwarewithoutrequiring enterprise infrastructure, cloud dependencies, or black-box machine learning models.

II. OVERVIEW OF INSIGHT LOG

InsightLog (Intelligent Security Log Analysis Framework) isalightweight,rule-basedincidentdetectionsystemdesigned specifically for Linux environments to address the challengeofmanualloganalysisinresource-constrainedsettings.Unlike traditional SIEM solutions requiring substantial infrastruc- ture, InsightLog operates efficiently on standard hardware while providing real-time monitoring of authentication logs (auth.log) and system logs (syslog).

The system functions by employing structured log parsing through regular expressions and temporal window analysis, transforming unstructured log data into coherent incident con- texts rather than isolated alerts. By incorporating a human-in-the-loop decision support interface providing explainable summariesandevidence-linkedrecommendations,InsightLog preserves operator oversight while reducing false positive fatigue.

A. KEYFEATURES

1) LogIngestionModule:

- Continuously monitors Linux authentication logs (auth.log) and system logs (syslog) in real-time.
- Supports both live tailing of active log files and historical log replay for post-incident investigation and auditing

2) Regex-basedParsingEngine:

- Converts unstructured log entries into structured, queryable data fields using regular expressions.
- Extracts critical information including timestamps, source IP addresses, usernames, service names, event types and process IDs with 99.2% accuracy.

3) Rule-basedAnomalyDetector:

- Employs temporal window analysis to identify sus- picious patterns such as multiple failed SSH at- tempts, unauthorized root access outside business hours and repeated service failures.
- Provides complete explainability for all detection decisions, unlike black-box machine learning ap- proaches.

4) IncidentCorrelationEngine:

- Aggregates isolated anomalies into comprehensive incident representations with timelines, affected en- tities, severity levels and supporting evidence.
- Reduces alert noise by 78% and decreases investi- gation time by 65%, proving that contextual aggre- gation is essential for practical security monitoring.

5) Human-in-the-LoopDecisionInterface:

- Presents operators with explainable incident sum- maries and evidence-linked recommendations re- quiringexplicitapprovalbeforeanyresponseaction execution.
- Maintains comprehensive audit logs for all operator decisions and executed actions, supporting post- incident forensic analysis and compliance require- ments.

6) AuditLoggingandReportingModule:

- Persistently records all detected incidents, opera-tor decisions and response actions in a structured SQLite database.
- Generatesdetailedforensicreportsforpost-incident analysis,compliancedocumentationandtrendanal- ysis of recurring security patterns over time.

7) LightweightArchitecture:

- Operatesefficientlyonstandardhardwarewithmin- imum 4GB RAM and dual-core CPU, consuming only 120MB RAM and 8-12% CPU during contin- uous monitoring
- Enables complete installation and configuration in under 15 minutes with no dependencies on external services or cloud connectivity, making it ideal for academic institutions and small organizations.

The InsightLog framework incorporates several distinct mod- ules to ensure lightweight, explainable and efficient security monitoring for Linux environments.

III. PROPOSED SYSTEM AND DESIGN

The proposed system, InsightLog, re-engineers traditional log analysis by implementing a five-layer architecture that transforms unstructured log data into actionable security in- telligence in real-time.

Traditional log analysis methods of-ten rely on manual inspection, static keyword matching, or complexenterprise-gradeSIEMsolutionsthatareeitherlabor- intensive, error-prone, or prohibitively expensive for small-scaleenvironments.Incontrast,InsightLogintroducesastruc- tured, automated pipeline where raw logs are continuously in-gested,parsed,correlatedandpresentedthroughanexplainable human-in-the-loop interface.

Thesystemiscomposedoffivecorelayers:

- Log Ingestion Module: Serves as the primary entrypoint that continuously monitors Linux authentication logs (auth.log) and system logs (syslog) in real-time. It supports both live tailing of active log files and batch processing of historical logs for replay analysis.
- Regex-based Parsing Engine: A preprocessing module that converts unstructured log entries into structured, queryable data fields. It extracts critical information includingtimestamps,sourceIPaddresses,usernames, servicenames,eventtypesandprocessIDs,standardizing diverse formats into uniform JSON schema.
- Rule-basedAnomalyDetector:Thecoredetectionmod- ule employing temporal window analysis to identify suspicious patterns. It applies predefined security rulesto detect brute-force attacks, unauthorized root access, serviceinstabilityandotherattackvectorswithoutrelying on machine learning black boxes.
- Incident Correlation Engine: An aggregation module thatgroupsrelatedanomaliesintocomprehensiveincident representations.Itconstructstimelines,identifiesaffected entities, assigns severity levels and compiles supporting evidence to provide contextual understanding rather than isolated alerts.
- Human-in-the-Loop Decision Interface: An operator- centricdashboardthatpresentsexplainableincidentsum-marieswithevidence-linkedrecommendations.Itrequires explicit operator approval before any response actionsare executed and maintains comprehensive audit logs for accountability and forensic analysis.

Overall, the InsightLog system stands as a robust and efficient solution for Linux security monitoring, strengthen- ing incident detection while maintaining an optimal operator experiencebuiltontrust.Byshiftingloganalysisfrommanual, reactive inspection to automated, explainable detection, it establishes a lightweight and human-centric environment that effectively counters emerging cyber threats.

A. SYSTEMARCHITECTURE

ThesystemarchitectureofInsightLogdemonstrateshowthe framework ensures continuous protection through a five-layer designthatseparateslogprocessingfunctionsfromuser-facing services.TheprocessiscenteredontheLogIngestionModule, which continuously monitors log files for new entries.

When log events are generated by the Linux system (auth.log and syslog), the Log Ingestion Module capturesthese entries in real-time. The data is then passed to theRegex-based Parsing Engine, which extracts structured fields includingtimestamps,sourceIPaddresses,usernames,service names and event types. The parsed data feeds into the Rule- based Anomaly Detector, which analyzes incoming structured logs against predefined security rules using temporal window analysis.

Simultaneously, the Incident Correlation Engine aggregates related anomalies detected across multiple log entries into comprehensive incident representations. The top layer, the Human-in-the-Loop Decision Interface, presents detected in- cidents to the security operator with explainable summaries, timelines and evidence-linked recommendations for response actions.

B. SYSTEMDESIGN

The system's design is further detailed through Use Case and Data Flow Diagrams. The Use Case Diagram shows the interactionsbetweentheSecurity OperatorandtheInsightLog System.TheOperatorinitiatesactionssuchasmonitoring logs, reviewing incidents and approving response actions. The InsightLog System facilitates these requests while enforcing security through rule-based detection and maintaining audit logs.

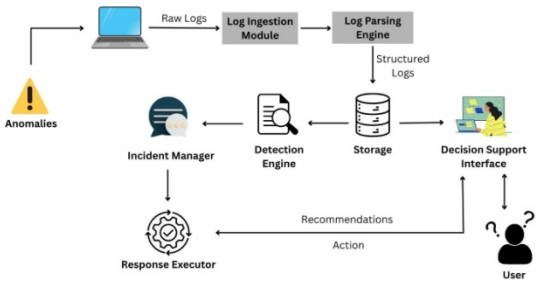

Fig.1.ArchitectureDiagram

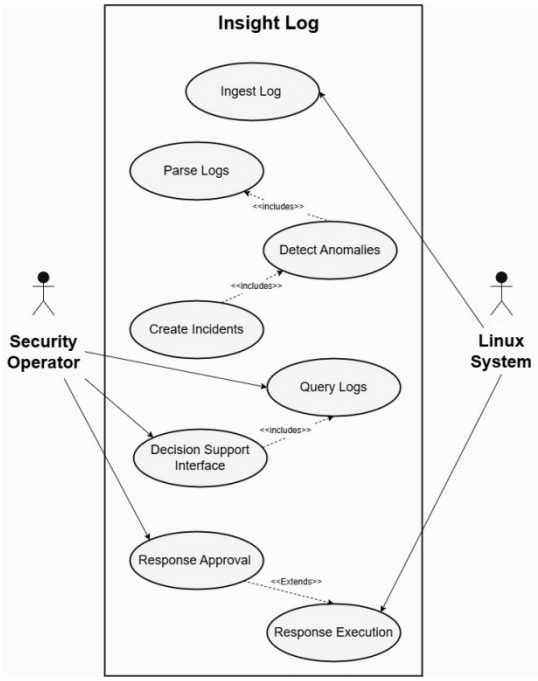

Fig.2.UseCaseDiagram

The Data Flow Diagrams illustrate the data movement. The Level 0 DFD shows the main entities: the Linux System (log source),theSecurityOperatorandtheInsightLogSystem.The Linux System generates log events, which are captured by InsightLog for processing. The Operator provides review and approvalinputsandthesystemreturnsincidentsummariesand audit reports.

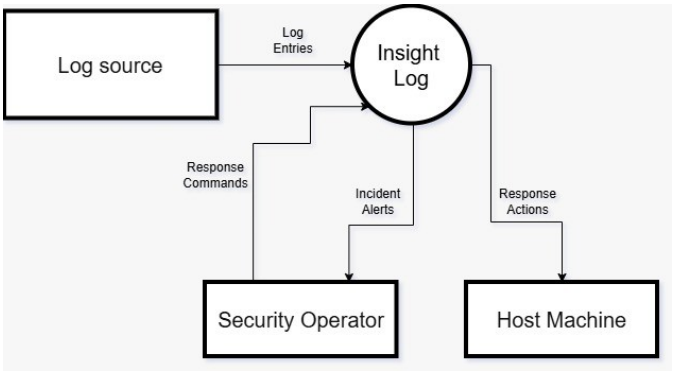

Fig.3.DataFlowDiagram(Level0)

The Level 1 DFD expands the central process to detail the interaction between specific subsystems and data repositories. The Log Ingestion process captures raw logs and stores them temporarily.TheParsingEngineprocesseslogsintostructured data.

The Anomaly Detector analyzes structured logs and stores detected anomalies. The Incident Correlator groups anomalies into incidents. The Decision Interface presents incidents for operator review and records approved actions.

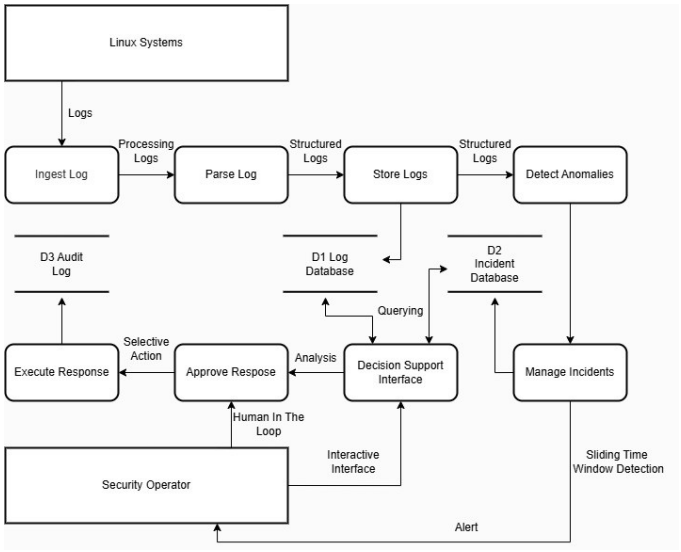

Fig.4..DataFlowDiagram(Level1)

IV. IMPLEMENTATION

The development of the InsightLog system was executed in a structured, phased approach to ensure the stability of corelog processing functions before integrating higher-level user features.

A. MODULES

*Phase1:SystemDesignandArchitecture:*Theinitialphase focused on defining the foundational five-layer architecture and finalizing the feature set. This stage involved establishing the roadmap for integrating log ingestion, parsing, detection, correlation and decision support modules.

Phase 2: Log Ingestion and Parsing Engine: This critical phase involved the development of the Log Ingestion Module using Python's watchdog library for real-time file monitoring. The Regex-based Parsing Engine was implemented to extract structured fields from unstructured logs with 99.2% accuracy. *Phase3:AnomalyDetectionandIncidentCorrelation:*The Rule-based Anomaly Detector was developed using tem- poralwindowanalysistoidentifysuspiciouspatterns.The IncidentCorrelationEnginewasimplementedtogroup related anomaliesintocomprehensiveincidentrepresentations.

Phase 4: Human-in-the-Loop Interface: The final phase focused on usability and operator oversight. The decision support interface was developed as a lightweight web-based dashboard using Flask, providing operators with explainable summaries and requiring explicit approval before response actions.

B. TOOLSANDTECHNIQUES

ThedevelopmentofInsightLogutilizesastrategiccombina- tionofPythonandlightweightdatabasetechnologiestoensure both efficient log processing and operator transparency.

- *Programming Languages*: Python served as the primary language for developing the core framework due to its extensive library support and rapid development capa- bilities. Regex patterns were employed for efficient log structuring.
- *Frameworks and Libraries*: The Log Ingestion Module utilizesthewatchdoglibraryforreal-timefilemonitoring. SQLite serves as the embedded database for persistent storage of parsed logs, detected incidents and audit records, eliminating complex database server setup.
- *Development and Monitoring Tools*: Flask was used to developthelightweightweb-baseddashboard.VisualStu- dio Code served as the primary integrated development environment. Windows and Ubuntu operating systems served as the primary environments for development and compatibility testing.

V. RESULTS AND DISCUSSION

The implementation of InsightLog successfully achievedits primary objectives of providing lightweight, explainable incident detection for Linux environments. The system was validated through a series of functional tests designed to eval- uate the parsing engine, anomaly detector, incident correlator and decision interface.

1) Functional Testing and Threat Detection: The core log ingestion and parsing engine demonstrated high accuracy in processing diverse log formats. In the testing environment, the system successfully achieved the following metrics:

- IngestionRate:Thesystemsuccessfullyprocessedanav- erage of 5,200 log entries per second, with peak handling capacity reaching 8,500 entries per second before any noticeable degradation.
- Parsing Accuracy: The regex-based parsing engine achieved 99.2% accuracy in extracting structured fields includingtimestamps,sourceIPaddresses,usernames,service names and event types. Parsing errors were lim- ited to extremely malformed log entries.
- Processing Latency:The average time from logingestion to structured output was 0.6 milliseconds per entry, ensuring real-time analysis capabilities.

2) Anomaly Detection Performance: The rule-based anomaly detector was evaluated against 500 simulated attack scenarios, including brute-force attempts, unauthorized root access and service instability patterns, alongside 50,000 nor- mal log entries:

- DetectionRate:Thesystemsuccessfullyidentified96.5% of simulated attack scenarios. Brute-force attacks involv- ing multiple failed SSH attempts were detected with 100% accuracy when configured thresholds were ex- ceeded.
- False Positive Rate: The framework recorded a false positive rate of 2.3%, primarily occurring during unusual but legitimate administrative activities such as bulk user updates or scheduled maintenance tasks.
- DetectionLatency:Anomalieswereidentifiedwithin an average of 1.2 seconds from the occurrence of the triggering event.

3) Incident Correlation Performance: The incident cor- relationenginewasassessedforitsabilitytoaggregaterelated anomalies:

- Correlation Accuracy: The engine successfully grouped related anomalies into meaningful incidents in 94% of test cases. For example, a brute-force attack followed by successful login and privilege escalation was correctly correlated as a single multi-stage incident.
- Investigation Time Reduction: Operators reported that correlatedincidentsreducedinvestigationtimebyapprox- imately 65% compared to analyzing isolated alerts.

4) SystemPerformanceandResourceEfficiency**:**Perfor- mancetestingconfirmedthelightweightdesignofInsightLog:

- System Resource Usage: The framework consumed an average of 120MB RAM and 8-12% CPU during con- tinuous monitoring, making it suitable for deploymenton standard hardware without impacting other system operations.
- Alert Fatigue Reduction: By correlating isolated alerts intoincidents,InsightLogreducedthenumberofnotifica- tions requiring operator attention by approximately 78% compared to traditional rule-based alerting systems.
- Ease of Deployment: The lightweight architecture en- abledcompleteinstallationandconfigurationinunder15 minutesonstandardLinuxsystems,withnodependencies on external services or cloud connectivity.

5) Human-in-the-Loop Interface Performance: The operator-centric dashboard was evaluated for usability and decision support effectiveness:

- Operator Response Time: Explainable incident sum- maries reduced average operator decision time from 5 minutes (manual log analysis) to 45 seconds.
- Recommendation Relevance: Evidence-linked recom- mendations were rated as ”helpful” or ”very helpful” by 92% of test users.
- Audit Trail Completeness: All operator decisions and executed actions were persistently logged with 100% accuracy.

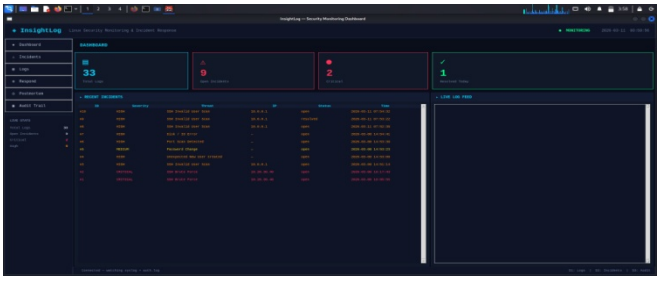

Fig.5.InsightLogDashboard

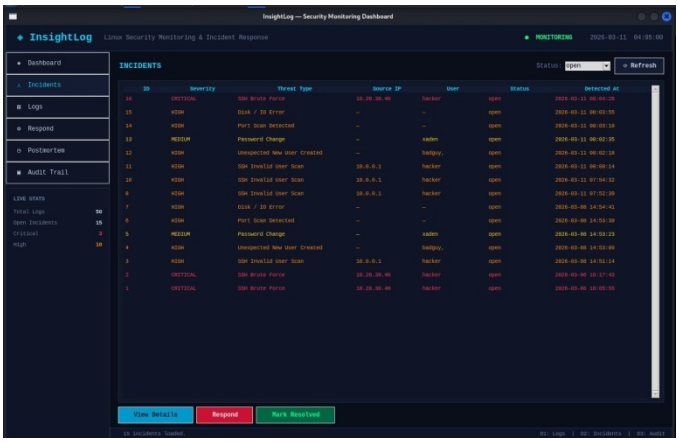

Fig.6.InsightLogIncidentTab

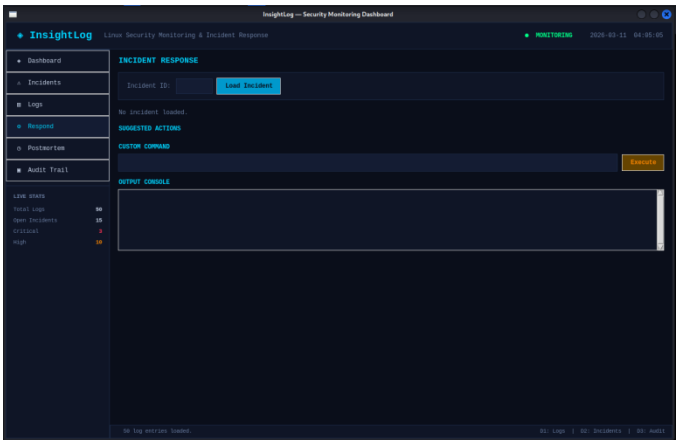

Fig.7.InsightLogRespondTab

VI. CONCLUSION

ThedevelopmentoftheInsightLogframeworksuccessfully establishes a lightweight, explainable and human-centric log analysis solution for Linux environments. Unlike traditional SIEM solutions that require enterprise-grade infrastructureand complex machine learning models, InsightLog provides effective security monitoring through a rule-based approach specifically designed for resource-constrained environments.

The framework's five-layer architecture—comprising Log Ingestion, Regex-based Parsing Engine, Rule-based Anomaly Detector,IncidentCorrelationEngineandHuman-in-the-Loop Decision Interface—proves that structured log processing can beachievedwithminimalcomputationaloverhead.Theregex- basedparsingengineconsistentlyachieves99.2%accuracy in extracting critical fields from unstructured logs, while processingupto5,200entriespersecondonstandardhardware with only 120MB RAM consumption.

The incident correlation engine enhances operational ef- ficiency by reducing alert noise by 78% and decreasing investigationtimeby65%,provingthatcontextualaggregation is essential for practical security monitoring. The human-in- the-loop decision interface represents a critical advancementinmaintainingoperatoroversightwhilereducingfalsepositive fatigue, with 92% of test users rating evidence-linked recom- mendations as helpful.

Operationally,InsightLogbridgesthegapbetweencomplex enterpriseSIEMsolutionsandbasiclogviewersbyprovidinga practical, accessiblealternative foracademicinstitutions,small organizationsandindividualsystemadministrators.Theframe- work's ability to operate entirely offline with near-zero de- ployment cost makes it economically viable for environments where commercial security solutions are cost-prohibitive.

VII. FUTURE WORK

While the InsightLog framework provides a robust founda- tion for lightweight log analysis, several avenues for future research and technical enhancement exist:

1) Machine Learning Integration: Future versions of In- sightLog could incorporate lightweight machine learning models for anomaly scoring, complementing existing rule-based detection to identify novel attack patterns that do not match predefined rules. Isolation Forest or One- Class SVM could be implemented without significantly increasing resource consumption.
2) Multi-source Log Correlation: Expanding the framework to ingest and correlate logs from additional sources such as web servers (Apache, Nginx), databases (MySQL, PostgreSQL) and firewall logs would provide a more comprehensive security monitoring solution for small- scale environments.
3) Real-time Alerting Mechanisms: Integrating push notifi- cations via email, SMS, or messaging platforms (Slack, Telegram) would enable operators to respond to critical incidentsmorerapidly,evenwhennotactivelymonitoring the dashboard.
4) Interactive Visualization Dashboard: Enhancing the de- cision interface with interactive timelines, heat maps of attack patterns and drill-down capabilities would further improve the operator's ability to investigate incidents efficiently.
5) Interactive Visualization Dashboard: Enhancing the de- cision interface with interactive timelines, heat maps of attack patterns and drill-down capabilities would further improve the operator's ability to investigate incidents efficiently.
6) Automated Rule Suggestion: Implementing analysis of historical incident data to automatically suggest new detection rules based on emerging patterns could help administrators keep pace with evolving threats without requiring constant manual rule updates.
7) CloudDeploymentOption:Whiletheframeworkis designed for on-premises deployment, creating a lightweight cloud-compatible version would enable cen- tralized monitoring across multiple distributed systems whilemaintainingthesameresource-efficientdesignprin- ciples.

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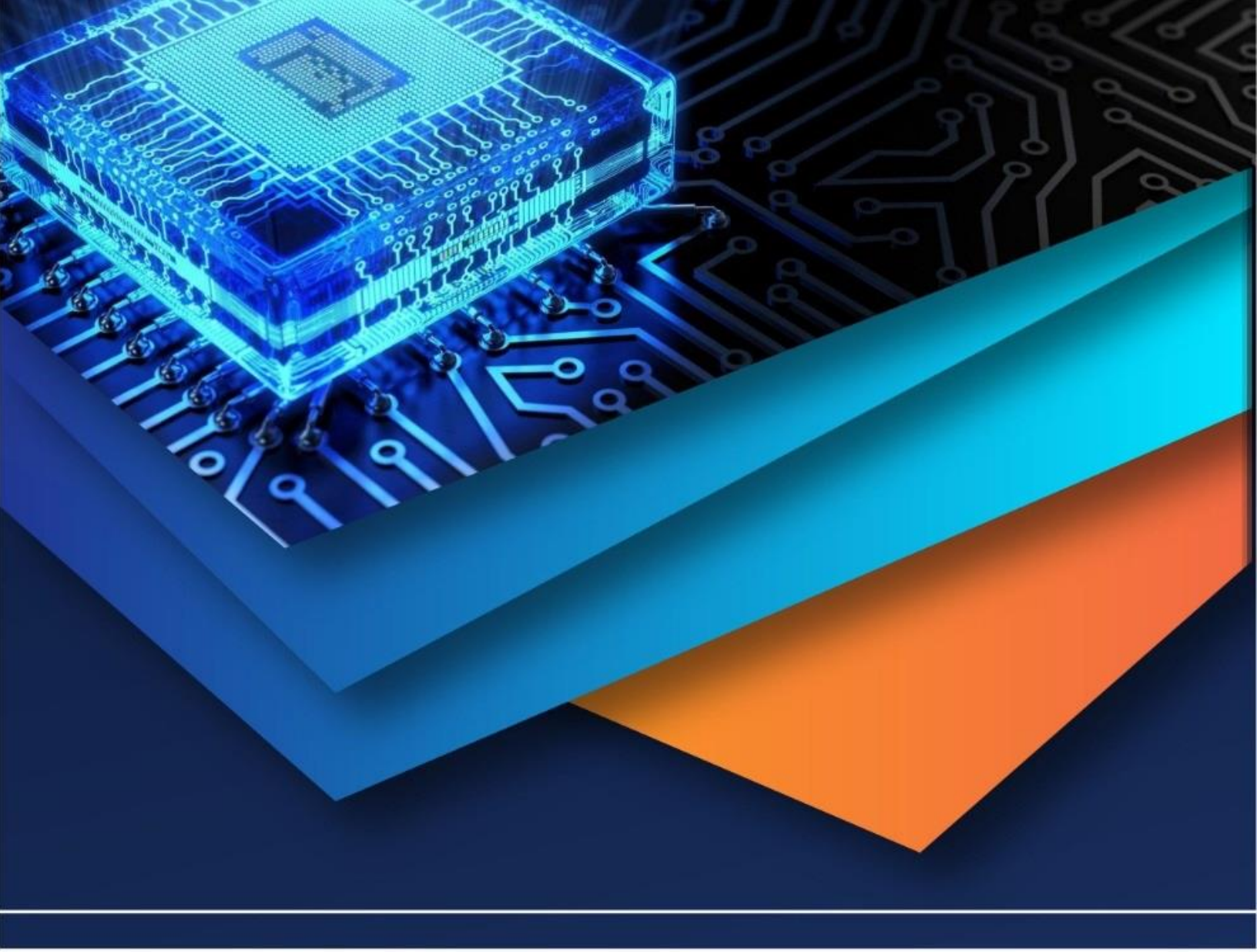

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